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Benefit-cost Analysis of the Waffle®: Initial Assessment

Dean A. Bangsund
Eric A. DeVuyst
F. Larry Leistritz

Department of Agribusiness and Applied Economics
Agricultural Experiment Station
North Dakota State University
Fargo, North Dakota 58105

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Executive Summary

The Red River of the North has a long history of flooding. A host of physical characteristics, along with man-made factors, contribute to widespread flooding in the Basin. Historically, attempts to mitigate flood damage in the Basin have been limited to using dikes/levees and waterways/diversions. Generally, within the greater Red River Basin, other flood mitigation strategies are insufficient by themselves to make meaningful reductions in flood damages. Despite ongoing efforts to combat flooding in the Basin, spring flooding continues to cause damage and concern among the region's inhabitants.

Another option to mitigating flood damages in the Red River Basin is the concept of using hundreds or thousands of 'micro-basin' storage areas comprised of roads and adjacent lands throughout the region. The micro-basin concept would utilize roads and other existing structures to act as temporary barriers to contain snow melt and flood runoff on adjacent lands. Flood water would be managed through culvert modifications to temporarily store water on those lands. The goal of using micro-basin storage would be to contain a sufficient volume of water over a reasonable period in the spring to lower the flood crest heights on streams and rivers throughout the basin. Water contained in the micro-basins would be gradually released after the threat of flooding had subsided. The use of roads and adjacent lands within the basin to temporarily hold water during periods of spring flooding has been referred to as the Waffle. The purpose of this report was to examine the economic feasibility of using the Waffle to reduce flood damages in the Basin.

A benefit-cost analysis was conducted for the Waffle. Costs of implementing, maintaining, and operating the Waffle were estimated for a 50-year period. Benefits in this study were limited to mitigated flood damages (i.e., the difference between flood damage with and without the Waffle) from four urban areas in the Basin. Although not included, the Waffle would be expected to mitigate flood damages (benefits) in rural areas, farmsteads, and other communities in the region and generate environmental benefits, such as reduced soil erosion, reduced sediment loading in waterways, and subsoil and groundwater recharge. The results of the study represent a conservative assessment of the economic feasibility of the Waffle since only a subset of potential benefits was included.

The Energy & Environmental Research Center at the University of North Dakota provided data on the physical size of the Waffle, which included acreage of land suitable for use in the Waffle delineated by county, typography, and land use, as well as the number of sections of land and associated costs of modifying culverts for the Waffle. A cost model was developed which used physical data on Waffle size combined with other economic data to estimate various expenses associated with the Waffle. Specific expenses included enrollment costs, landowner payments, infrastructure modifications and installations, and maintenance and administrative overhead.

Much of the data used for the benefits component of the analysis came from flood-stage damage functions (FSDF), developed by the U.S. Army Corps of Engineers, for selected communities in the Basin. The FSDFs relate river crest heights with probability of occurrence and expected damages to residential and commercial properties and public infrastructure at various crest elevations. Damage estimates within the functions were adjusted to reflect current economic conditions pertaining to the aggregate real (i.e., adjusted for effects of inflation) value of property at risk of flooding and included adjustments for recent changes in permanent flood protection (e.g., new or higher dikes). Further adjustment to the functions was performed to project expected damages based on future population change and annual change in the real aggregate value of residential and commercial property from 2006 through 2055.

The benefits of the Waffle were estimated as the difference between flood damages with and without the Waffle for several flood events at selected locations in the Basin. The flood events modeled included the 1997 flood, and several derivatives of the flows present during the 1997 flood. The Energy & Environmental Research Center provided estimated crest heights at key locations on the Red River for the modeled flood events with and without the Waffle.

Change in crest heights due to the Waffle influenced the expected level of flood damages for various flood events. Integration of the FSDF was performed with and without the Waffle to estimate expected (i.e., probability weighted) annual flood damages from 2006 through 2055. The difference in the expected damages (with and without the Waffle) represented mitigated flood damages (benefits). Benefits were computed and discounted annually over the 50-year period. Likewise, costs were estimated and discounted annually over the study period. Results from the analysis were expressed as the present value of net benefits (costs subtracted from benefits).

The analysis used several scenarios that reflected different expectations in Waffle size, cost, water storage capacity, and future population. Waffle size was divided into three acreage estimates (maximum, moderate, and minimum) each for a full-scale and half-scale Waffle. Further, two water storage assumptions (conservative and moderate) were provided for each scale. Costs were based on a baseline scenario, with several economic factors adjusted higher (pessimistic scenario) and lower (optimistic scenario) to provide a plausible range of expenses. Three sets of future FSDFs were generated for Fargo/Moorhead, Breckenridge, Wahpeton, Grand Forks/East Grand Forks, and Drayton based on baseline, optimistic, and pessimistic population forecasts. A host of scenarios was used largely due to the uncertainty pertaining to Waffle size and water storage capacity, knowledge gaps on the economic understanding of various operational aspects of the Waffle, and the inherent difficulties in projecting potential flood damages in study communities over a 50-year period. The combination of those situations produced 108 separate estimates of the net benefits of the Waffle.

Net benefits were positive in 106 of the 108 scenarios evaluated. The magnitude of net benefits over the 50-year period were substantial: 85 percent of the scenarios evaluated resulted in over $300 million in net benefits and nearly half of the combinations had net benefits in excess of $500 million. The results from two alternative analyses showed that the Waffle produced substantial net benefits when only used for relatively large floods (greater than 100-year events) and also revealed that the Waffle is not economically sensitive to the inclusion or absence of high-frequency flood damages from Fargo/Moorhead.

Overall, the economic feasibility of the Waffle, given the limited scope of benefits included in the study, was almost entirely determined by mitigated flood damages from Fargo/Moorhead. Without mitigated flood damages from Fargo/Moorhead, results from this study suggest the Waffle would only be economically under ideal conditions (11 of 108 possibilities) if implemented on a basin wide scale. Recent improvements and additions to structural flood protection in Wahpeton/Breckenridge and Grand Forks/East Grand Forks eliminate the potential to mitigate flood damages from all but the largest flood events. The relatively small pool of benefits produced by the Waffle in Wahpeton/Breckenridge and Grand Forks/East Grand Forks was insufficient to influence the economic feasibility of the Waffle under most conditions examined.

Observations from study results indicate that landowner payments (i.e., both retainer and water storage payments) had the most influence on Waffle costs. While payment acreage and payment rates greatly influenced expected costs, those cost factors did not affect economic feasibility. The economic feasibility of the Waffle also did not appear to be sensitive to the range of values used for future population in the study communities or water storage capacities. Again, while those factors had substantial effects on the level of gross benefits, conclusions on the economic feasibility of the Waffle were not influenced. The differences in net benefits between the full-scale and half-scale Waffle were greatest in the higher acreage scenarios, and diminishing net returns between the two Waffle scales suggest further analysis would be needed to determine an economically optimal scale for the Waffle. However, given current information, uncertainty on payment acreage and landowner enrollment makes estimating optimal Waffle size problematic.

Research over the past several years at the Energy & Environmental Research Center has demonstrated the technical feasibility of using a Waffle-based flood mitigation strategy in the Red River Basin. Even with several limitations in the scope of benefits and a lack of knowledge pertaining to some cost aspects of the Waffle, this analysis showed substantial potential for positive net benefits from using the Waffle to mitigate flood damages in the Basin. Questions remain regarding the financial feasibility of the Waffle, and many operational aspects and cost-related factors associated with the Waffle also remain unanswered. The positive results from this study suggest that dedicating additional resources to solving or answering many of the remaining issues with the Waffle would be justified. Perhaps additional resources could be used to implement a pilot version of the Waffle, albeit at a watershed or township level, to more fully understand the operational characteristics of the Waffle and provide the groundwork for more widespread implementation.

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INTRODUCTION

The Red River of the North has a long history of flooding. Anecdotal evidence suggests substantial floods occurred in the late 1700s prior to widespread settlement in the region. The earliest recorded major flood in the Red River Basin was in 1826, and remains the largest on record for most of the basin (International Joint Commission 1997). Since 1826, the basin has experienced a number of large floods. Some of the most notable floods were in 1852, 1861, 1897, 1950, 1966, 1969, 1975, 1978, 1979, 1989, 1996, 1997, and 2006 (International Joint Commission 1997, Bolles et al. 2004). The flood of 1997 was among one of the worst on record for many locations within the basin, and revealed that existing flood protection measures were inadequate to prevent widespread damage.

The physical characteristics of the Red River Basin make the region susceptible to widespread spring flooding. One of the overriding characteristics is that nearly all of the basin is remarkably flat. From Wahpeton, ND to Lake Winnepig, Manitoba, Canada, the elevation changes about 233 feet over a distance of about 545 river miles (International Joint Commission 1997). The slope of the basin averages about 0.5 foot per mile, but varies from 0.2 feet per mile in the northern valley to about 1.3 feet per mile in the southern valley. The gentle gradient results in slow river flows that produce limited drainage capacity.

Additional problems within the region stem from a shallow river channel, combined with flat surrounding topography, which allows water to easily overflow river banks and quickly inundate surrounding lands. High clay content in the soils of the region provide limited water absorption and contribute to flooding (International Joint Commission 2000). Further, unlike many major river systems in the U.S., spring melt and runoff first occur in the headwaters. The Red River drains northward, so water flow can be slowed or stopped by frozen regions in the northern portions of the basin. This effect is often compounded by snow melt and runoff that continues to proceed northward with the flow of excess water from southern regions in the basin. These conditions can produce enormous potential for flooding (U.S. Army Corps of Engineers 1998, 2000a).

Other factors contributing to flood damages in the basin include drainage of natural wetlands, agricultural drainage on crop land, and the proximity of settlements in or near flood plains. Also contributing to flooding is the constriction of river channels from dikes and levees that exist near and around the major communities in the basin (U.S. Army Corps of Engineers 1998). In essence, the Red River basin is prone to flooding due to a host of natural features, and the social and economic effects of periodic flooding are accentuated due to manmade contributing factors.

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*Research scientist, associate professor, and professor, respectively, Department of Agribusiness and Applied Economics, North Dakota State University, Fargo.

Due to the frequent flooding and physical characteristics of the basin, numerous structural and nonstructural approaches have been considered to help mitigate flood damages. The primary structural flood mitigating strategies for spring floods have included dikes/levees, both permanent and temporary, and flood-water diversions or channels. Over the course of the past century, social, environmental, and economic criteria have been acceptable for creating dikes, levees, and diversions (International Joint Commission 1997). Despite the use of levees and diversions within the basin, spring flooding continues to cause damage and concern among the region's inhabitants.

Other measures, such as small- and large-scale dams and wetland restoration also have been considered. Currently, the perception is that an insufficient number of small- and large-scale dams would meet economic and environmental acceptance, and as such, the use of reservoirs would not provide substantial flood protection in the region (International Joint Commission 2000). The use of reservoirs would attenuate floods only if they were part of a broader strategy and combined with other measures (International Joint Commission 2000). Wetland restoration has been considered as a potential flood mitigation strategy, but it also has been deemed insufficient by itself to influence widespread flooding in the basin (International Joint Commission 2000, Shultz and Leitch 2003). Generally, within the greater Red River Basin, dams, wetland restoration, and other measures are not sufficient by themselves to make meaningful reductions in flood damages, and are not economical for widespread implementation to reduce flood damages.

Another option to mitigating flood damages in the Red River Basin is the concept of using hundreds or thousands of 'micro-basin' storage areas comprised of roads and adjacent lands throughout the region. The micro-basin concept would utilize roads and other existing structures to act as temporary barriers to contain snow melt and flood runoff on adjacent lands. Flood water would be managed through culvert modifications to temporarily store water on those lands. The goal of using micro-basin storage would be to contain a sufficient volume of water over a reasonable period in the spring to lower the flood crest heights on streams and rivers throughout the basin. Water contained in the micro-basins would be gradually released after the threat of flooding had subsided. The use of roads and adjacent lands within the basin to temporarily hold water during periods of spring flooding also has been the referred to as 'waffle storage' (International Joint Commission 2000).

In 2002, the Energy & Environmental Research Center at the University of North Dakota began investigating the feasibility of implementing a Waffle-based flood mitigation strategy for the Red River Basin (Bolles et al. 2004). The overall goal of the Waffle would be to provide additional flood protection to complement existing structural and non-structural flood mitigation strategies in the basin. Since the start of the project in 2002, most of the research effort has focused on hydrologic and hydraulic issues associated with spring-time floods. Initial results suggest a Waffle-based approach to flood control in the Red River Basin is technically feasible and could provide a substantial increase to existing flood protection measures in the region (Bolles et al. 2004).

While a Waffle-based flood mitigation strategy appears to be technically feasible in the Red River Basin (Bolles et al. 2004), the issue of economic feasibility has yet to be addressed. Insights on the economic feasibility of the Waffle will enable researchers, policy makers, civic planners, and other interested individuals to make important decisions on how to proceed with further research and/or implementation of the Waffle. If the Waffle is shown to not be cost-effective, further evaluation of the Waffle might not be appropriate; however, if the Waffle is shown to be cost-effective, justification would exist to devote additional resources towards evaluating remaining issues (e.g., legal, strategic, and operational questions, and address any remaining hydrologic and hydraulic modeling concerns). Further, insights on the economic feasibility of the Waffle might influence the development of other flood mitigating efforts in the event that the Waffle is unlikely to be implemented as a flood mitigation strategy. The purpose of this report is to provide a first assessment of the cost-effectiveness of the Waffle and provide insights into the economic feasibility of using the Waffle to mitigate flood damages in the Red River Basin.

OBJECTIVES

The purpose of this report is to evaluate the economic feasibility of the Waffle using a benefit-cost analysis. Specific objectives include:

1) estimate the costs of maintaining and operating the Waffle,

2) estimate the mitigated flood damages (benefits) from the Waffle, and

3) estimate net benefits of the Waffle over a reasonable range of physical and economic values.

METHODOLOGY

The overall method used to evaluate the economic feasibility of the Waffle was a net present value analysis. Present value analyses attempt to track the costs and benefits of a project or activity over a specific period. Typically, projects or activities, such as the Waffle, are evaluated over extended periods (i.e., 25 to 50 years). Given the time frames involved, a variety of estimation techniques are usually required to project costs and benefits over the life of the project/activity. In addition, costs and benefits are often discounted to account for the influences of time on economic values. The following sections describe both data and techniques used to project future costs and benefits.

Data

Data for this study came from a number of sources. Descriptions and use of data are contained in the following sections, while the presentation of most data is contained in appendices.

Acreage

Two primary issues pertain to acreage of land associated with the Waffle. Land throughout the Red River Basin was evaluated for the potential to temporarily store water based on criteria developed by the Energy & Environmental Research Center (EERC) at the University of North Dakota (Bolles et al. 2004). Land associated with the Waffle can be divided into *flooded acreage* and *payment acreage*. *Flooded acreage* represents the amount, location, and type of land used for temporary water storage, and represents only the surface acreage of land used to intentionally retain water through a series of culvert control devices. However, the economic analysis needed to distinguish between the amount of land actually flooded and the amount of acres that would require some form of compensation. *Payment acreage* represents both estimates of the flooded acreage and estimates of additional acreage affected by temporary water storage. Those additional acres would be inaccessible for farming or other uses due to lost access (e.g., surrounding water prevents or blocks access to non-flooded land).

Due to varying elevations within any given section[1] of land throughout the Red River Basin, the acreage affected by temporary water storage is going to be greater than the acreage of land that temporarily holds flood water (Figure 1). The intentional flooding of land in most situations can affect access and/or use of adjacent or nearby land within any given section. The extent of additional land affected by intentional flooding within any particular section will vary based on a number of factors, but one of the key elements is the amount of relief or change in elevation within and around that section. Land suitable for use in the

[1] A section of land is typically considered to be one mile by one mile and is approximately 640 acres.

Waffle (i.e., flooded acreage) was divided into three relief categories[2], and the basin-wide potential for additional acreage affected by the Waffle varies for each of the relief categories (Figure 1). In situations where little elevation change occurs within a section (i.e., relief category 0-2), the amount of additional land (i.e., non-flooded land) affected by temporary flooding can be relatively low. For moderate changes in elevation within a section (i.e., relief category 2-4), a greater potential exists for additional land to be affected by temporary flooding. In situations where greater overall changes in elevation occur (relief category 4-11), the amount of land affected by temporary flooding can be quite variable. Flooding within the section can be localized to one end of the section, concentrated on the periphery of the land tract, or represent a combination of situations where substantial acreage is affected by relatively minor amounts of flooded acreage (Figure 1).

Bolles et al. (2004) documented the process of how land was deemed suitable for use in the Waffle. Land suitable for temporary water storage in the Red River Basin is available in 43 counties in North Dakota, Minnesota, and South Dakota. The surface use or physical characteristics of the land were described by thirteen different land categories (Table 1). Land within each county and classification was further separated by three relief categories (i.e., a measure of the relative change in elevation within a given land tract). Thus, land suitable for the Waffle was delineated by land classification, county, and relief category. After determining the amount of land suitable for use in the Waffle, a series of analyses were conducted, based on elevation and topographical data, to estimate the amount of payment acreage associated with the Waffle (Kurz et al. 2007).

Some adjustments to the payment acreage data were performed for the economic analysis. Initially, cropland and pasture were reported by the EERC as a single land use category. To more accurately estimate the potential payments required for the two land types, separate estimates of the acreage for cropland and pasture were generated. County-level data on the total acreage of cropland and pasture were obtained from National Agricultural Statistics Service (2004). A county-wide ratio of cropland to pasture was used with Waffle data to create separate estimates of the amount of payment acreage for cropland and pasture. The analysis assumed that the payment acreage of cropland and pasture in the Waffle, which was initially combined in one land use category, would be representative of the county-wide ratio of cropland and pasture acreage obtained from the National Agricultural Statistics Service (2004).

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[2]The three relief categories were designated as 0-2, 2-4, and 4-11. The relief category 0-2 represents tracts of land with relatively small amounts of elevation change within those tracts. The relief category 2-4 represents tracts of land with greater relative amounts of elevation change within those tracts. The relief category 4-11 represents tracts of land with relatively large changes in elevation within those tracts.

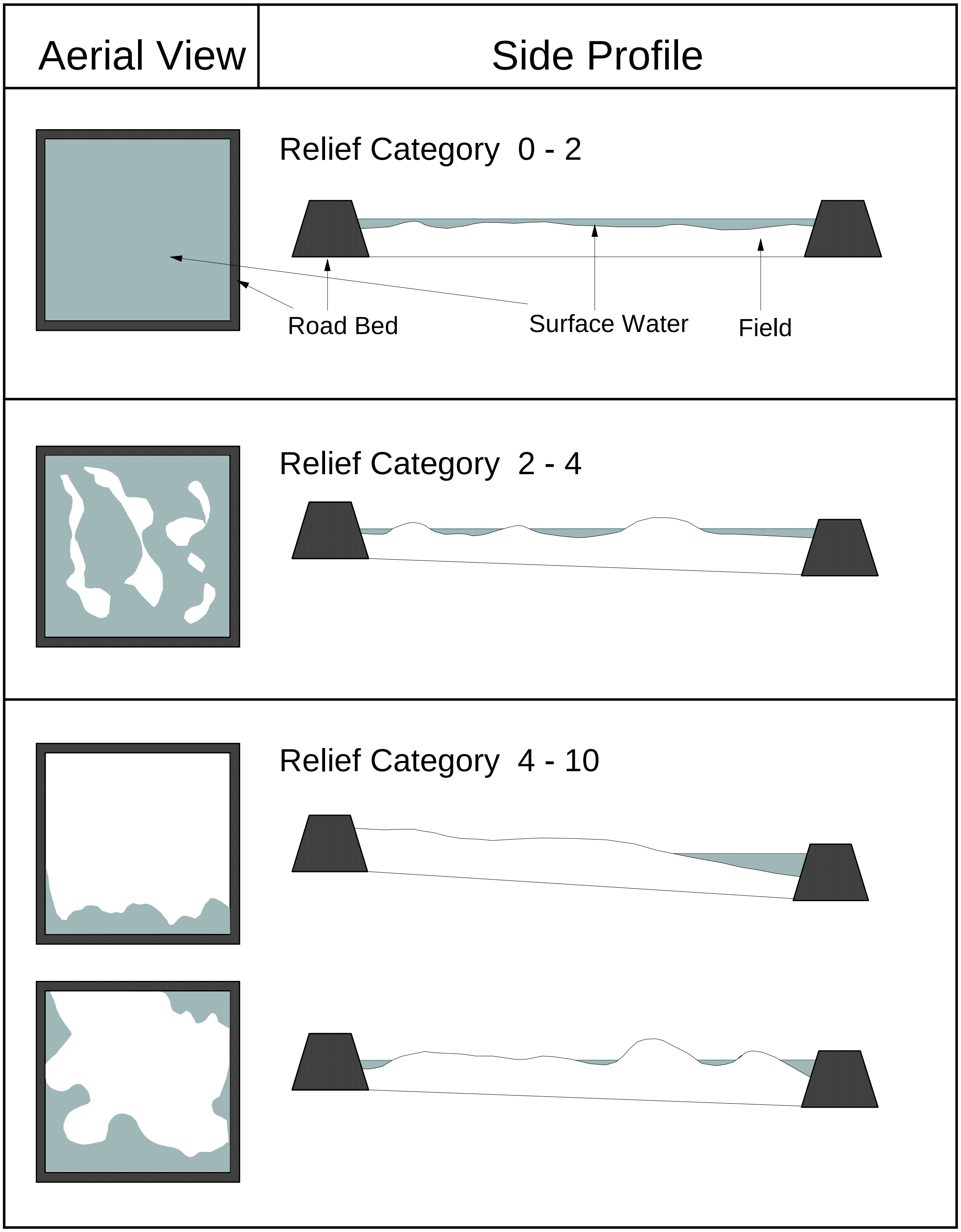

Figure 1. Conceptual Relationship between Land Relief, Flooded Acreage, and Payment Acreage for Land Enrolled in the Waffle.

Table 1. Classification of Land in the Waffle

Land Use Categories for Economic Analysis	Land Use Categories for Modeling Water Storage	Share of Land in the Waffle
Cropland	Cropland and Pasture	86%
Pasture	Cropland and Pasture	
	Herbaceous Rangeland	
	Mixed Rangeland	4%
Other Land	Deciduous Forest	
	Evergreen Forest	
	Lakes	
	Forested Wetland	
	Nonforested Wetland	
	Strip Mines, Quarries, Gravel Pits	
	Transitional Areas- - Barren Ground	
	Transportation, Communication, Utilities	
	Industrial	10%

Source: Energy & Environmental Research Center (2007).

For purposes of estimating landowner compensation for participation in the Waffle, the economic analysis also assumed that pasture and rangeland could be combined into one land use category. Data on payment acreage for land in the Waffle included two additional rangeland categories (i.e., Herbaceous Rangeland and Mixed Rangeland) (Table 1). Estimates of pasture acreage and estimates of acreage in herbaceous and mixed rangeland were combined into one land use category in each county. Despite the different land use designations, from an economic perspective, rental rates for pasture and rangeland in the Red River Basin were assumed to be similar.

Time and resource constraints prevented the development of separate payment rates for all land use categories. For the economic analysis, remaining land use categories were combined into an 'other' land category (Table 1). Examples of the land use categories that were combined into the 'other' category include wetlands, forests, lakes, and developed areas.

Two scale options for the Waffle were considered. The full-scale and half-scale options were based on differing rates of utilization of land suitable for use in the Waffle, and do not refer to the geographic scope of the Waffle. The full-scale option assumes all land suitable for use in the Waffle is enrolled, while the half-scale option assumes half of the land suitable is enrolled. The Waffle was considered to be implemented basin wide (i.e., U.S. portion only), and the reduction in acreage in the half-scale scenario was distributed evenly across all suitable land. Three potential estimates of payment acreage were developed for each scale. These three acreage estimates were developed to account for the uncertainty associated with estimating actual acreage affected by water storage because of different estimation techniques and various sources of land elevation data (Kurz et al. 2007). As a result of having two scale options with three acreage estimates per scale, a total of six possible combinations of Waffle acreage were generated. For the full-scale option, total Waffle payment acreage basin wide ranged from 1.4 million acres for the maximum scenario to 405,000 acres for the minimum scenario. Total Waffle payment acreage basin wide for the half-scale option ranged from 709,000 acres for the maximum scenario to 204,000 acres for the minimum scenario. The greatest acreage was enrolled in Minnesota across all combinations (Table 2). Cropland composed the greatest percentage of land enrolled in the Waffle across all six combinations (Table 2). County level acreage estimates by land type, classification, and relief contour were placed in Appendix A.

<u>Number of Sections of Land</u>

Information on the number of sections of land in the Waffle was required to estimate the cost of culvert modifications. Unfortunately, the number of sections of land cannot be directly determined from payment acreage. In many cases, the acreage of land within any section used to temporarily store water is considerably less than the 640 acres in a section. The EERC provided the number of sections of land by county and relief category for each land use classification (Appendix A).

<u>Culvert Modifications</u>

The fundamental concept associated with the Waffle is the ability to temporarily store water in micro-basins created by the network of roads and adjacent fields. Temporary water storage can only be accomplished if the Waffle can control the amount of water and the length of time water is stored. The Waffle can accomplish those goals by installing control devices on culverts in the sections of land enrolled in the Waffle. These devices are designed to hold back water at a pre-determined height, but allow additional water to naturally flow over the pipes and through the culverts. When the threat of flooding has passed, stored water would be gradually released so as to not contribute to additional flooding.

The collection and analysis of data on the number of culverts, size of culverts, and distribution of culverts throughout the entire Red River Basin was beyond the scope of this study. However, the EERC was able to use data previously collected for their hydrologic and hydraulic modeling to generate estimates of the number and size of control devices needed, based on relief category, in three watersheds in the Red River Basin. The EERC also was able to estimate the useful life of the control devices based on anticipated operating conditions (e.g., water pH, frequency of use). Based on the above factors, the EERC produced estimates of the per-section infrastructure costs of modifying existing culverts and the anticipated installation expenses for the control devices (Appendix B). Based on data in 2005, culvert control devices ranged from about $3,600 per section for relief category 4 - 10 to $11,600 per section for relief category 0 - 2. Installation costs in 2005 were estimated to range from $800 per section for relief category 4 - 10 to $1,200 per section for relief category 0 - 2.

Table 2. Estimates of Payment Acreage by Waffle Size

	Full-scale		Half-scale	
Category	Minimum	Maximum	Minimum	Maximum
State				
North Dakota	191,840	628,320	96,256	315,040
Minnesota	210,016	776,800	105,888	388,960
South Dakota	3,456	9,440	1,728	4,800
Total	405,312	1,414,560	203,872	708,800
Land Type and Relief Contour				
Cropland				
0 - 2	140,431	421,293	72,525	217,576
2 - 4	109,914	549,572	53,722	268,611
4 - 10	100,183	250,457	49,980	124,949
Total	350,528	1,221,323	176,227	611,136
Pasture				
0 - 2	4,529	13,587	2,355	7,064
2 - 4	4,329	21,628	2,150	10,749
4 - 10	8,361	20,903	4,484	11,211
Total	17,216	56,117	8,989	29,024
Other Land				
0 - 2	19,840	59,520	9,440	28,320
2 - 4	13,312	66,560	6,912	34,560
4 - 10	4,416	11,040	2,304	5,760
Total	37,568	137,120	18,656	68,640

Note: A moderate acreage scenario representing an approximate average between the minimum and maximum acreage was omitted from the table.

The cost data provided by the EERC were used with data on the number of sections to produce estimates of the basin-wide costs of purchasing and installing the culvert control devices. A lack of data and resources prevented the study from using separate estimates for each watershed in the Red River Basin or separate estimates for smaller geographic units (e.g., township, county). Instead, the per-section infrastructure and installation costs for the Red Lake Watershed were used to produce estimates for the entire basin (Appendix B). The characteristics of the number, size, and distribution of culverts in the Red Lake Watershed were considered sufficient to project costs for the entire Red River Basin. Since costs were based on 2005 data, minor adjustments to the infrastructure and installation expenses were included in cost projections.

Landowner Compensation

A premise early in the evaluation of the technical and economic feasibility of the Waffle was that landowners who enrolled land in the Waffle would receive some level of financial compensation. Specifics on the level of compensation needed or required have not been fully explored; however, the premise that financial compensation will be required for landowners to participate in the Waffle is generally accepted (Bolles et al. 2004).

This study was not designed to address a number of questions pertaining to landowner compensation rates, such as the level of compensation required to secure landowner cooperation, the upper level of compensation capable of being paid by the Waffle, or the contract structure or payment structure most favorable to landowners. These and other financial compensation issues are well beyond the scope of this study. It is likely that insights on amount of financial compensation needed to entice most landowners and producers to enroll land in the Waffle will not be fully understood until many of the details on planting delays and other potential physical effects on crop production stemming from temporary water storage can be determined. Similarly, issues on contract or payment structure will remain unresolved until it is known how participation in the Waffle may affect other income sources (e.g., crop insurance payments, farm program provisions). Instead, the approach used in this study was to evaluate the cost-effectiveness of the Waffle over a plausible range of financial compensation levels.

In order to evaluate a range of payment levels consistent with the economic value of land enrolled in the Waffle, the analysis tied financial compensation rates to the level of cash rents for non-irrigated cropland and pasture. From an agricultural perspective, cash rents are a market-based level of compensation, negotiated between a landowner and an agricultural producer in the form of a cash payment, that secures the right of a individual(s) to produce or raise a crop on leased land. This approach provides sufficient flexibility to evaluate the overall effects of different payment rates on the cost-effectiveness of the Waffle and still tie compensation rates to general land productivity without requiring specific information on landowner preferences or requirements.

County-level cash rent data for cropland and pasture/rangeland in North Dakota and South Dakota were obtained from the National Agricultural Statistics Service (2005a, 2005b) while cash rent data for Minnesota were obtained from Hachfeld et al. (2005) (Appendix C). Estimates of future levels of cash rent were based on the index of cash rent paid by farmers in the U.S. (U.S. Department of Agriculture 1997, 2005). The cash rent index was adjusted for inflation using the Gross Domestic Product-Implicit Price Deflator (U.S. Department of Commerce 2006). The long-term trend in real (i.e., inflation adjusted) cash rents was used to project future levels of cash rent in the Red River Basin.

The level of cash rents vary throughout each county based on a variety of factors. Some of the most prevalent factors include land productivity, crops raised, and individual landowner preferences and rental arrangements. For example, cash rents for land used to raise sugarbeets are usually higher than for land used to raise small grains. Also, cash rents for land outside of the Red River Valley are generally lower than cash rents for land in the Valley. While these and other differences can influence the level of cash rents, projected values for county average cash rents were used for all land within a county enrolled in the Waffle. Data were not available to differentiate Waffle acreage within a county for purposes of adjusting payment levels associated with potential variations in the level of cash rent. All payments for land in each county were tied to a single level (i.e., average value) for cash rent in that county. Using an average cash rent value for all Waffle acreage in a county results in compensation rates being higher in some situations and lower in other situations than if payment levels were more closely tied to local conditions.

While future cash rent values were projected based on a long-term trend in real cash rents, several factors can influence the level of expected cash rents in the future. Examples of those factors may include a change in the mix of crops grown in the Red River Valley and market effects of shifts in domestic demand and supply for agricultural commodities. Examples of both factors are currently occurring as a result of recent market influences associated with ethanol and bio-fuels. The increased demand for corn has resulted in higher corn prices, increased acreage allocated to corn production, and increases in cash rents. By contrast, if high value row-crops, such as sugarbeets and potatoes, disappear from the Valley and are not replaced with other high value row-crops, cash rents could actually decrease (in real terms).

Flood-stage Damage Functions

The economic analysis needed to estimate the mitigated flood damages (i.e., benefits) that are likely to result from implementing the Waffle. In order to estimate mitigated flood damages, it was critical to determine the likely amount of flood damages over a reasonable range of flood crest heights for specific points along key tributaries and rivers in the basin.

The key economic component for developing estimates of the potential mitigated flood damages (benefits from the Waffle) in this study was the flood-stage damage functions developed by the U.S. Army Corps of Engineers (USACE). The flood-stage damage functions estimate flood damages that are likely to occur in a community at various crest heights for major rivers/tributaries in the region. Conceptually, within the benefit-cost framework, the benefits of the Waffle represent the difference in flood damages that can be expected to occur with and without the Waffle. Flood-stage damage functions provide the basic information needed to estimate the mitigated flood damages associated with the Waffle.

Flood-stage damage functions (FSDFs) were obtained for Fargo-Moorhead, Grand Forks-East Grand Forks, Wahpeton, Breckenridge, Grafton, Drayton, and Crookston (Table 3) (U.S. Army Corps of Engineers 1997, 1998, 2000a, 2000b, 2003, 2004, 2005). The FSDFs were based on data from different years. The years for which the FSDFs were developed ranged from 1995 for Crookston to 2004 for Fargo-Moorhead. While all functions contained estimated damages for residential and commercial property, the FSDF for some communities also contained additional damages and costs for relocation, public infrastructure, vehicle damages, and emergency response expenses (Table 3).

Table 3. Flood-stage Damage Functions, Selected Cities, North Dakota and Minnesota

Location	Damages Included in Functions	Base Data for Functions
Fargo/Moorhead/ Oakport Township, MN	Residential property, commercial property, public infrastructure, relocation costs, vehicle damages, emergency response costs	2004
Grand Forks/East Grand Forks	Residential property, commercial property, public infrastructure	1997
Wahpeton	Residential property, commercial property	1999
Breckenridge	Residential property, commercial property	1999
Grafton	Residential property, commercial property, public infrastructure, relocation costs, vehicle damages, emergency response costs	2002
Drayton	Residential property, commercial property, public infrastructure, relocation costs, vehicle damages, emergency response costs	2003
Crookston	Residential property, commercial property	1995

The FSDF provide the general relationship between flood severity and level of flood damages. For all communities, except Fargo-Moorhead, the FSDF needed to be adjusted to reflect current conditions. The level of damages estimated in the functions are subject to changes in the level of flood protection in the community and changes in the aggregate value of property at risk from flooding. Discussions with personnel from the USACE indicated that the FSDFs were based on existing permanent flood protection measures in each community at the time the functions were estimated (U.S. Army Corps of Engineers 2006). Alternatively, the level of flood protection within most of the communities has changed due to the addition of permanent dikes/levees, relocation of residential and/or commercial properties, the addition of diversions or floodways, and/or changes in the protection provided by increasing the height of existing levees/dikes. In addition, the damages projected in the FSDFs were based on permanent flood protections that met with approval from the USACE within each community, and do not include adjustments to damages provided by temporary flood protection measures (e.g., earthen levees constructed during severe floods, adding fill to increase the height of existing permanent levees). Finally, the damages in the functions do not reflect the new, or in some cases, expected future flood protection levels once ongoing flood protection projects are finished. For example, the FSDF for Grand Forks-East Grand Forks was estimated based on data from 1998, and the relationship between flood severity and expected flood damages does not account for the changes in local flood protection measures recently implemented in the two cities (i.e., increased scope and height of levees/dikes and residential property relocations). Similarly, recent improvements in the protection levels provided by higher levees/dikes in Wahpeton and Breckenridge and the completion of the diversion near Breckenridge were not included in the FSDF for those cities.

Since the FSDFs were not reflective of the expected future level of flood protection measures in some cities, damage estimates for some flood crest elevations within the FSDFs were eliminated (i.e., damages were put to zero). In the case of Grand Forks/East Grand Forks, Wahpeton, and Breckenridge, current flood protection projects are expected to eliminate damages according to the USACE for defined areas of the cities below a certain crest height. The elimination of damages in Grand Forks/East Grand Forks, Wahpeton, and Breckenridge are treated differently than expected damages in Fargo/Moorhead. In the case of Grand Forks/East Grand Forks, Wahpeton, and Breckenridge, the elimination of flood damages comes from USACE approved flood protection measures so all estimated damages for flood crest heights below the capacity of the flood protections can be expected to be eliminated. However, the USACE does not recognize the ability of temporary dikes and levees in Fargo and Moorhead to provide protection when creating the FSDF in those cities. Essentially, local flood fighting efforts are not credited with eliminating flood damages in Fargo/Moorhead. As a result, the FSDF indicates substantial damages due to floods of modest size while real world conditions indicate that the cities of Fargo/Moorhead, to date, have been very successful in preventing most damages using a variety of temporary flood fighting provisions in conjunction with permanent levees. Unfortunately, it is clearly beyond the scope of this study to estimate the difference between the amount of damages that are predicted within the FSDF and the amount of actual (i.e., out of pocket) losses incurred within the two communities for any-sized flood over the next 50 years.

The discrepancy between the estimates of damages in the USACE FSDFs and the actual value of flood damages in Fargo/Moorhead would require some revision of the definition of damages and/or some recognition of the ability of temporary dikes/levees to abate flood damages. Within the issue of the definition of expected flood damages is the cost of providing temporary dikes/levees and the non-monetary value of volunteer labor and donated materials used in sandbagging and other local flood fighting measures. A more comprehensive approach would be to more clearly define whether damages need to be actual or if they should be hypothetical in the absence of temporary dikes/levees and include some estimates of the costs, which should include non-monetary expenses, of temporary flood fighting measures. The USACE definition of damages was used to estimate the benefits of the Waffle, even though the damage estimates within the FSDF may not necessarily relate to real world conditions for all flood events.

Population Projections

Future values for the FSDFs were based on three possible population projections for each city. The population projections were based on data and reports developed for the Red River Valley Water Supply Project and on information from the Minnesota State Demographic Center (Minnesota State Demographic Center 2002, Bureau of Reclamation 2005, Northwest Economic Associates 2003). The three population projections included a main projection, a optimistic projection and a pessimistic projection. The implications for future population were different in most cities for each scenario. For example, the population for Fargo was expected to increase in each scenario, whereas, population for all but the largest communities decreased in the pessimistic scenario (Appendix C). The optimistic projection had an 18 percent increase in population over the base scenario. The pessimistic scenario had a 14 percent decrease in population over the base scenario. Total population in 2050 in the study communities for the main, optimistic, and pessimistic scenarios was 370,453, 437,240, and 318,341, respectively (Appendix C). Since the evaluation period for the Waffle was extended out to 2055, populations for the study communities in all projections were based on simple extrapolations to 2055 of population growth between 2045 and 2050 in each city.

Residential and Commercial Property Values

The nominal value of aggregate residential and commercial property values in each study community was collected to provide data to adjust the FSDFs to current conditions (i.e., 2005) and provide input for projecting future values for the FSDFs. While the number of years of data available varied by community, information on aggregate residential and commercial values were obtained back to 1990 for most cities (Appendix C). In nearly all cases, information on nominal aggregate residential and commercial values were obtained from city and county governments. All residential and commercial property values were net of land (i.e., value of land was not included). The values used in this study only include residential structures covered by local property tax regulations, and may not contain items such as storage sheds, dog kennels, or other miscellaneous facilities/items.

Indices

Several indices were used to adjust nominal values to real (i.e., corrected for effects of inflation) values, as well as provide information for projecting future FSDF values between 2006 through 2055.

Office of Federal Housing Enterprise Oversight

The Office of Federal Housing Enterprise Oversight (OFHEO) is an independent entity within the U.S. Department of Housing and Urban Development that has oversight responsibilities for the Federal National Mortgage Association (Fannie Mae) and Federal Home Loan Mortgage Corporation (Freddie Mac). The OFHEO also maintains a housing price index that tracks the movement of single-family house prices throughout the United States and in specific geographic areas (Office of Federal Housing Enterprise Oversight 2006). Separate OFHEO indices were obtained for Fargo-Moorhead, Grand Forks-East Grand Forks, North Dakota, and Minnesota (Appendix C). The OFHEO housing price index is reported quarterly in nominal dollars. The OFHEO index was adjusted by the Consumer Price Index for Housing to reflect a real housing price index (i.e., inflation adjusted).

Consumer Price Index

The Consumer Price Index (CPI) is a measure of the change in prices over time for various bundles of goods and services purchased by consumers in the United States. The CPI is often used to measure inflation in the United States economy. The Consumer Price Index for Housing was used to adjust the OFHEO housing price index to reflect real dollars (Appendix C).

National Council of Real Estate Investment Fiduciaries

The National Council of Real Estate Investment Fiduciaries (NCREIF) tracks the capital and income returns from a variety of commercial property acquired in the private market for investment purposes. Since a commercial real estate index was not available from public sources, data from the NCREIF property index on quarterly capital appreciation were combined with the Gross Domestic Product-Implicit Price Deflator to create a real commercial property index.

U.S. Bureau of Economic Analysis

The U.S. Bureau of Economic Analysis, U.S. Department of Commerce, tracks the value of all goods and services produced by labor and property in the U.S. This value is reported as the gross domestic product, which is used to measure the size and growth of an economy. The U.S. Bureau of Economic Analysis also produces a number of indices designed to track the changes in prices within an economy. One of those indices is the Gross Domestic Product-Implicit Price Deflator (GDP-IPD) which is not limited to price changes felt by consumers. The GDP-IPD was used to adjust some indices from nominal dollars to real dollars.

U.S. Department of Agriculture

The U.S. Department of Agriculture (USDA) provides a nominal index for cash rents paid on farmland in the U.S. (U.S. Department of Agriculture 1997, 2005). The nominal index was adjusted using the GDP-IPD to produce a real cash rent index. The change or trend in the real cash rent index was then used to project the rate of change in future cash rents, which was part of the model used to estimate future costs of the Waffle.

Methods

The economic framework for analyzing the Waffle is a net present value analysis. In its simplest form the sum of the present value of costs is subtracted from the sum of the present value of benefits to assess the economic advisability of the Waffle. A 50-year time horizon was used, which is consistent with the USACE time horizon for similar evaluations and coincides with the estimated useful life of culverts and other structural modifications needed to implement the Waffle. A real discount rate, *d*, of 5 percent is used. The net present value of the Waffle is computed as:

(1) $$NPV = \sum_{t=2006}^{2055} (E[B_t] - C_t) \times (1 + d)^{-(t-2005)}$$

where $E[B_t]$ are expected benefits and C_t are costs in year t.

<u>Benefits</u>

Benefits accruing from the Waffle include mitigated flood damages to residential, commercial, and public property, prevented disruptions to economic activity, and various environmental benefits, such as improved water quality, reduced soil erosion, and subsoil moisture and groundwater recharge. Unfortunately, quantitative measures of these benefits were only estimated for flood damages to buildings and infrastructure in the largest municipal areas within the U.S. portion of the Red River Basin. Estimates of the environmental benefits of the Waffle would require substantially more resources than were available to conduct this study. Subsequently, only mitigated flood damages are considered as economic benefits. This limitation in the breath of benefits means the economic feasibility of the Waffle is narrowly based only on its flood mitigation effects. Within that context, the scope of this study is further limited to only include mitigated flood damages for a limited number of communities in the Basin. These two limitations in scope suggest that the results provided in this report be viewed as highly conservative estimates of economic viability of the Waffle.[3]

A flood-stage damage function relates flood crest height, measured in elevation above mean sea level (msl) or some reference flood height, to expected property damages. Crest heights at a given point on a river are tied to annual flood frequencies. The annual flood frequency represents the probability or likelihood of a crest height reaching a given elevation. For example, a 100-year flood event has the probability of occurrence of 0.01 (1 chance in 100 years). The FSDFs provide estimates of damages for numerous crest heights at the given location, and those crest heights are often expressed in 1-foot increments above and below a reference flood elevation. Data for the FSDF for Fargo/Moorhead/Oakport Township are presented as an example (Table 4). Appendix D contains data on flood frequencies and flood elevations used in the FSDFs for other cities.

Despite listing flood damages for 1-foot increments in crest elevations, not all crest elevations were provided with a flood frequency. Using reported elevations and associated flood frequencies as reference values, linear interpolation and extrapolation were employed to estimate the missing frequencies (Table 4). The result is that each elevation within the FSDF has an annual probability of occurrence.

For each municipal area, USACE reports only a few elevations with frequencies. For example, the FSDF reported in Table 4 shows elevations for the 2-, 5-, 10-, 20-, 50-, 100-, 200-, and 500-year events. Frequencies are not reported for each elevation. The impacts of the Waffle, however, are not likely to fall exactly on these frequencies. For example, a 100-year flood event pre-Waffle is not likely to become exactly a 50-year (or 20-year) event post-Waffle. Linear interpolation and extrapolation techniques were used to approximate frequencies of various elevations (Table 4). The resulting FSDF can then be used to evaluate flood damages for nearly all flood events. Similar adjustments to the FSDFs were performed for the other cities (Appendix D).

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[3]Essentially, all of the costs of operating the Waffle are included in this study, but only a subset of the actual benefits are estimated and included in the final analysis. Costs are not likely to change with the addition of environmental benefits to the analysis.

Table 4. Flood-stage Damage Function, Fargo, Moorhead, and Oakport Township, 2005

U.S. Army Corps of Engineers Data			Flood-Stage Damage Function		
Recurrence Interval	Flood Frequency	Crest Height (msl)	Crest Height (msl)	Flood Damages (000s $)	Interpolated/ Extrapolated Flood Frequency
2-year	0.5	881.34			
5-year	0.2	888.92			
10-year	0.1	891.66			
			894	0	0.0602
20-year	0.05	894.6	895	4,401	0.04689
			896	7,540	0.03912
			897	13,686	0.03135
			898	39,387	0.02358
50-year	0.02	898.46	899	107,795	0.01789
			900	277,569	0.01398
100-year	0.01	901.02	901	543,441	0.01008
			902	1,173,942	0.0075
200-year	0.005	902.98	903	1,765,180	0.00497
			904	2,396,937	0.00349
500-year	0.002	905	905	3,018,172	0.002
			906	3,662,200	0.00051

Source: U.S. Army Corps of Engineers (2005).

To compute expected damages, the FSDF is integrated from the lower end of damages distribution to the maximum specified flood crest, H. Mathematically, a FSDF is a probability density function. As a FSDF is given as set of discrete points and flood frequencies, it is necessary to fit a piece-wise linear function through the points to approximate the underlying probability density function. In Figure 2, the points of the FSDF are represented with an "+" and linear segments connect each of the points. An integral in used to compute expected damages as follows:

(2)
$$E[D] = \int_0^H D \cdot f(D)dD$$

where *E[D]* is expected flood damage and *f(D)* is the piece-wise linear flood stage probability density function. Marginal damages beyond *H* are presumed zero as all property has been destroyed at a crest height of *H* and beyond.

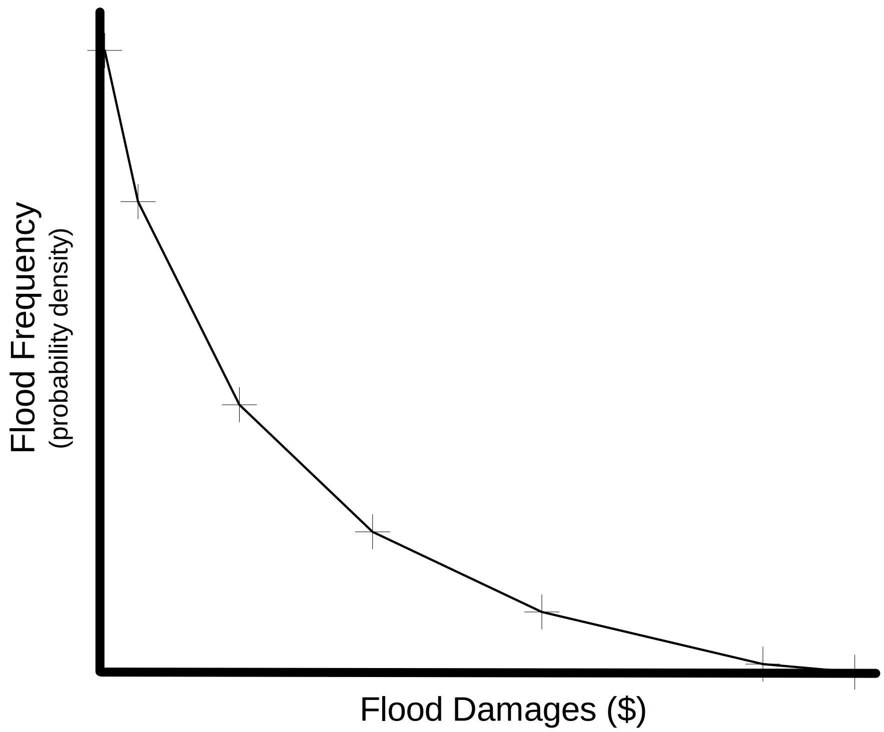

Figure 2. Conceptual Diagram of Flood Frequency and Flood Damages within a Piece-wise Linear Function.

The analysis used in this study needed to estimate benefits of the Waffle over a 50-year period. One approach would be to estimate the mitigated flood damages (i.e., damages with and without the Waffle) for a single year, and then project that year's benefits over a 50-year period. Therefore, mitigated flood damages would come from a single FSDF for each city, with the FSDF for that city being tied to economic conditions present at the time the function was developed (e.g., 2004 for Fargo/Moorhead). The USACE has primarily used the above approach in forecasting project benefits in their assessments of the economic feasibility of structural flood protection measures in communities in the Red River Basin (U.S. Army Corps of Engineers 1997, 1998, 2000a, 2000b).

A key problem with the USACE approach is that over a 50-year period the aggregate value of local property at risk of flooding is likely to change. If local conditions change, then expected flood damages represented in the FSDF also are likely to change. However, the number of physical, social, and economic factors affecting property at risk from flooding is likely to be numerous, and forecasting those values, and their effect on estimated flood damages, is beyond the scope of this study. This study developed an approach that allowed FSDFs to change over time with growth (or decline) in population and with changes in real (inflation adjusted) property values, assuming all other factors held constant. The end result is an annual series of FSDFs for each city from 2006 through 2055. An integration was performed for each annual function for each city, thereby allowing potential benefits from the Waffle to change over time as cities change population and as property values change.

The USACE developed FSDFs for Grand Forks/East Grand Forks, Fargo/Moorhead, Breckenridge, Wahpeton, Drayton, Grafton, and Crookston over various years, ranging from 1995 to 2005 (see Table 3). So while the functions, regardless of date produced, provide the basic relationships between flood event size (i.e., river crest height) and expected flood damages, the FSDFs for most cities needed to be updated to account for recent changes in aggregate property values and the influences of new or improved structural flood mitigation projects. First, the flood-stage damage functions were updated to reflect 2004 conditions[4]. After values were changed to reflect 2004 conditions, annual functions from 2006 through 2055 were forecasted to reflect changes in population and property values. Finally, the influences of new or improved structural flood mitigation projects on the FSDFs were incorporated. The techniques used to make those adjustments and changes are discussed in the following sections.

Updating Residential Flood-stage Damage Functions

The aggregate value of residential, commercial, and public infrastructure properties at risk of flooding has changed since the FSDFs were developed. To adjust for these changes, data on the aggregate value of residential and commercial properties, net of land, from 1990 through 2004 were collected from city and county agencies (see Appendix C).

Two sources of change in the aggregate value of residential properties were considered. First, the aggregate value of existing residential structures at the time of the Corps' estimation of the FSDF (here after called report date) could have changed–probably appreciated in value. Second, the addition of residential structures built since the report date also would increase aggregate property values. The two components influencing the aggregate value of properties are represented as:

(3) ΔAggregate property value$_t$ = Δexisting property value$_t$ + value from new construction$_t$.

For residential structures existing at the report date, a real index of housing values (hereafter called real housing index) was constructed using the Office of Federal Housing Enterprise Oversight (OFHEO) nominal housing index and the Consumer Price Index (CPI) for Housing. Separate housing value indices were available for Fargo-Moorhead and Grand Forks-East Grand Forks. State-level indices for MN and ND were used for the remaining

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[4] At the time the study was initiated, data were only available through 2004. Funding and time constraints prevented the inclusion of more recent data.

cities in each respective state. The real housing index was applied to residential damages at each flood-event elevation (i.e., crest height) in the FSDFs, thereby providing an update to the FSDF to account for changes in the real value of existing structures as of 2004.

Updating the FSDFs also required adjusting for additional damages arising from residential structures built after the report date for each municipal area. For the cities of Moorhead, Grand Forks, and Wahpeton, nominal aggregate housing values were available for 1990 through 2004. For the remaining cities, missing data were estimated using linear interpolation/extrapolation or by correlation of values from a nearby city with a 15-year series of published aggregate housing values. Using the OHFEO Index of Housing Prices and the CPI for housing, aggregate housing values from the report date were adjusted to 2004 dollars. The real aggregate housing value from the report date (reflected in 2004 dollars) was compared to the aggregate housing value in 2004. The difference in the two values was assumed to be due to additional residential structures.

All residential structures (i.e., primarily homes) added since the report date (1997 or later for all but one city) were assumed to be constructed at or above the elevation that corresponds to the 100-year flood event for that city. This assumption means that the FSDFs do not include additional damages for new residential structures at elevations below the 100-year flood event. At and above the 100-year flood elevation, additional damages were incrementally added to each elevation in the FSDF based on the relationship of existing damage values (i.e., in 2004 dollars) to the real value of aggregate residential values from the report year. This approach assumes that not all new residential structures would be affected at the 100-year and higher elevations, instead an increasing percentage of the aggregate value of new residential property was added as crest heights increased above the 100-year elevation in the FSDFs. Essentially, the FSDFs were adjusted to reflect greater damage to new residential properties the more crest heights exceeded the 100-year flood elevation.

Updating Commercial Flood-stage Damage Functions

As with the residential FSDFs, two sources of change are considered in the damage functions. First, aggregate value (i.e., net of land) for existing commercial properties since the report date for each municipal area has changed–often depreciated. Second, new commercial structures have been built and renovations/improvements have been made to existing structures since the report date.

A real commercial property value index was applied to commercial damages at each flood-event elevation (i.e., crest height) in the FSDFs, thereby providing an update to the FSDF to account for changes in the real value of existing structures as of 2004. This adjustment accounts for change in potential damages due to change in the real value of pre-existing commercial properties.

Aggregate commercial property value from the report year was adjusted to reflect 2004 dollars and compared to the actual aggregate property value in 2004. The difference was attributed to structures added and renovations/improvements of existing structures since the report date. However, unlike residential property, commercial development since 1997 could not necessarily be assumed to take place at or above the 100-year flood plain. To varying extent, “new” commercial property value includes replacement, renovation, and/or improvement of older, antiquated structures. Since data were not readily available to sort out the amount of value due to renovation and improvement versus structures built at new sites, the difference between report values and 2004 values were allocated across all FSDF elevations. The allocations were based on the ratio of damages at that elevation to the report date aggregate property value.

Forecasting Residential Flood Stage Damage Functions

Flood-stage damage functions were estimated annually for each city for 2006 through 2055 by using future aggregate commercial and residential property values as a proxy to adjust future damage levels within the flood-stage damage functions. The approach assumes that generally as the aggregate value of property increases in a community, the potential damages from a flood also increase, providing no additional flood protection measures are implemented. The approach also assumes that real property values, both commercial and residential, are correlated with population and are subject to time trends. The forecasted property values for each year (2006 through 2055) are then given as:

(4) Aggregate real property value_t = (Intercept + per capita aggregate property value trend × year) × population_t.

To project future levels of damages within the FSDFs based on changes in aggregate property values, the time trend in per capita aggregate property values was estimated using regression. Historical nominal property values were expressed in real (2004 dollars) terms using the real housing index. Real aggregate residential property values were divided by population to obtain a 15-year series on real per capita aggregate residential property values. Regression analysis was then used to determine the time trend in the per capita values (Table 5). The same procedures were used with commercial property and yielded time trends in real per capita aggregate commercial property values in each study community (Table 6). Statistically significant time trends in per capita aggregate residential property values were found for all six study cities. Positive trends were found for all cities except Drayton. Forecasting the negative per capita trend in Drayton with future population resulted in zero property values in year 2048 and thereafter. This result was suspect and real per capita residential property values were held constant at the 10-year historical average for Drayton[5].

[5]Regardless of approach, the influence of changes in Drayton’s property values on the final results is negligible.

Table 5. Results of Regressions of Per Capita Residential Real Property Values, 1990 through 2004

City	n	Intercept	Year Coefficient	Standard Error	R^2
Fargo	15	-1315438.741	667.636	31.381	0.97
Moorhead	15	-1705428.304	865.466	68.056	0.93
Grand Forks	15	-1343944.804	682.857	52.304	0.93
East Grand Forks	15	-1886808.363	955.466	56.029	0.96
Wahpeton	15	-289908.628	151.321	24.359	0.75
Breckenridge	15	-741677.4	382.989	104.596	0.51
Crookston*	12	358818.249	-170.333	105.605	0.21
Drayton	10	539187.782	-262.71	93.865	0.5
Grafton*	15	-252811.38	133.528	34.51	0.54

* Data were collected for Crookston and Grafton but the impact of the Waffle on flood stage for those cities was not available.

Table 6. Results of Regressions of Per Capita Commercial Real Property Values, 1990 through 2004

City	n	Intercept	Year Coefficient	Standard Error	R^2
Fargo	15	-1196918.687	605.795	54.952	0.9
Moorhead	15	-414347.435	209.546	24.541	0.85
Grand Forks	15	-1160266.833	586.945	46.46	0.93
East Grand Forks	15	-404246.482	204.838	20.176	0.89
Wahpeton	15	-512098.736	259.969	28.044	0.87
Breckenridge	15	-353733.808	178.445	5.893	0.99
Crookston*	12	-345225.907	174.516	11.492	0.96
Drayton	10	9436.626	-2.624	16.489	0
Grafton*	15	-258304.401	132.379	29.336	0.61

* Data were collected for Crookston and Grafton but the impact of the Waffle on flood stage for those cities was not available.

For per capita commercial property value, only Drayton's trend was insignificant. Again, Drayton's real per capita commercial property value was held constant at the ten-year historical average value.

Population projections for each city also were collected for the same period (2006 through 2050) (see Appendix C). Population projections for 2051 through 2055 represented extrapolations of the change in population from 2045 to 2050. The trend in per capita values (i.e., regression results) were multiplied by long-term population forecasts to estimate future aggregate residential and commercial property values for each year of the 2006 through 2055 period.

To forecast the FSDFs, damages at each elevation were annually adjusted to reflect (real) changes in existing property values. This was a two step process. First, a trend in real property values was determined using the OHFEO index to account for the increase in real property value. The annual percentage change in real property values, as estimated by the trend, was used to adjust damages at each elevation. For example, if an elevation of 900 feet (msl) had damages of $120 million in 2008 and the trend shows a 1.2 percent increase in real property values, the damages at 900 feet in 2009 were forecasted at $121.4 million ($120 million × 1.012).

The next step in the process was to incorporate the effects of changes in population into the damage estimates. Equation (4) was used to forecast aggregate residential property values for each city annually from 2006 through 2055. Given that aggregate residential property value and the change in existing residential property value had been forecasted, the change in housing value due to new homes was estimated by subtracting the change in the value of existing structures from the change in aggregate housing value. Or by rewriting equation (3), the change in housing value due to new homes can be expressed as:

(5) $\text{New construction}_t = \Delta\text{Aggregate property value}_t - \Delta\text{existing property value}_t$.

Existing property values were projected annually from 2006 through 2055. Time-trends were estimated for the annual real housing indices (Table 7). In equation (6), the estimated annual real housing index is given as:

(6) $\text{Real housing index}_t = \text{intercept} + \text{trend} \times t$.

The real housing indices were forecasted annually to 2055. The percentage change in the forecasted values was multiplied by real housing values from year t-1 to find housing values in year t, or

(7) $\text{Real housing value}_t = \text{Real housing value}_{t-1} \times$ percentage change in forecasted real housing index.

When the annual changes in equation (7) are computed, the results can be used in equation (5) to find the forecasted value of newly constructed homes.

Table 7. Time Trend Analysis for Real Housing Index, 1990 through 2004

City or State	n	Intercept	Year Coefficient	Standard Error	R^2
Fargo/Moorhead	15	-3912.075	2.027	0.272	0.81
Grand Forks/East Grand Forks	15	-2914.471	1.525	0.292	0.678
North Dakota	15	-5172.556	4.735	0.283	0.874
Minnesota	15	-18859.922	9.586	0.986	0.879

Given the assumption that new residential construction occurs at or above an elevation equal to the 100-year flood frequency, additional flood damages from new structures were allocated to the FSDFs starting at the 100-year flood frequency. It was assumed that the relative portion of incremental damages at each flood stage remained constant as total potential damages increased. Two steps were required to assign the incremental damages to each flood stage. First, damages were compared at each elevation above the 100-year frequency to damages at one foot below the 100-year flood frequency. The difference between these values was divided by total residential property value to arrive at a percentage. Second, that percentage was multiplied by the value of new residential properties constructed in each year (2006 through 2055). The resulting value was added to damages at that elevation from the previous year. For example, consider the FSDF for Fargo/Moorhead in Table 4. From the table, the flood stage one foot below the 100-year event is 900 feet msl which corresponds to $277.6 million in damages. The damages at 901 feet msl are $543.4 million. If it is assumed that total property value is $5 billion in year 2008, the incremental damages are 5.32 percent (($543.4 million - $277.6 million)/$5 billion) of aggregate property value. If $20 million of new housing value (i.e., due to population change) is added in 2008, then it is assumed that damages at 901 feet msl will increase by $1,063,488 (0.0532 × $20 million). This process is then repeated for each elevation above the 100-year frequency. As elevation above the 100-year frequency increases, so does the percentage and the allocation of incremental damages at that elevation. The entire process is repeated annually from 2006 through 2055.

Forecasting Commercial Flood-stage Damage Functions

To forecast future commercial FSDFs, increases in damages from existing structures and new damages due to additional structures had to be incorporated. However, since new construction was assumed to occur at all elevations in the study communities, it was only necessary to project total commercial property values annually. Separate adjustments to damages at or above the 100-year frequency were not necessary. As with residential property, adjustments for the commercial FSDFs involved 1) computing the time trend in real per capita aggregate commercial property values; 2) projecting that trend annually from 2006 through 2055; and 3) multiplying the projected trend by population forecasts to estimate aggregate commercial property values from 2006 through 2055. The relative damages associated with each elevation in the FSDFs were held constant across the 50-year time horizon. For example, if damages at the 100-year frequency were 10 percent of aggregate commercial property value in 2006, then 10 percent of total estimated aggregate commercial value in 2006 was assigned to the damages at the 100-year frequency. The same procedure was performed for each year forecasted (i.e., 2006 through 2055).

Damages accruing to public infrastructure were contained within the commercial flood-stage damage functions for some cities and were provided as separate flood-stage damage functions for other cities (see Table 3). Future values for the amount of flood damages to public infrastructure were generally assumed to parallel the level of flood damages associated with residential and commercial properties. Thus, as a community changes population over time, the potential change in flood damages to public infrastructure was assumed to be proportionate to the potential changes in flood damages associated with residential and commercial property.

No attempt was made to tie future damages to changes in the level of personal and/or business property in the study communities. Whatever proportion of expected damages that were represented by loss of personal property (e.g., furniture, appliances, other belongings) and business property (e.g., computers, office equipment, inventory) within the functions was retained as the future expected damages were forecasted. In other words, damages were not adjusted up or down to correspond with an increase/decrease in the relative value (ratio of the value of personal belongings and business property compared to the value of residential and commercial structures) of property at risk.

Improvements in Structural Flood Protection

Finally, improvements in structural flood protection developed since 1997 are incorporated into the FSDFs. Various structural improvements have been implemented or are being implemented in Grand Forks/East Grand Forks and Wahpeton/Breckenridge. Flood damages below the level of protection for those projects were set to zero, which is consistent with the definition of damages set forth by the USACE. No adjustments for new protections were necessary for the FSDFs in Fargo/Moorhead and Drayton.

Expected Future Damages

After updating the FSDFs for each area, the expected damages before and after implementing the Waffle are computed using integration. Implementation of the Waffle decreases the frequency of various flood heights. The EERC Waffle research project estimated the change in flood crest heights associated with Waffle implementation. These crest reductions were estimated for various flood crest heights for both the full- and half-scale Waffle scenarios under two water storage capacities. Waffle data from the EERC also represented points on the FSDF, and remaining crest reductions for other points on the curve were estimated using interpolation. Changes in frequency came from integration of flood probabilities in the model, which was a result of a new set of flood crest heights tied to the original USACE data on flood frequencies.

Expected damages both with and without the Waffle are computed using equation (2) for each year (2006 through 2055). The expected annual benefits from the Waffle are computed as annual difference in expected damages without Waffle and with the Waffle. This difference is computed for each of the 50 years, discounted to 2006 dollars and summed, generating the total discounted benefits.

Costs

A deterministic model was developed to estimate the costs of operating the Waffle over a 50-year period. Key parameters and inputs for the model included landowner payment structures; landowner payment rates (percentage of expected future cash rents); structural, installation, and maintenance costs for culvert control devices; payment acreage by land type, relief category, county, and Waffle scale; administration expenses, enrollment costs, inflationary factors, and a discount rate. The model was designed to provide estimates of the present value of Waffle costs over a 50-year period for a range of physical and economic values. Since the model is deterministic, adjustments in the values of key cost factors were used to determine the sensitivity of costs to changes in input factors. A brief description of cost inputs and parameters is described in the following sections.

Culvert Modification, Installation, and Annual Maintenance Costs

Culvert devices designed for the Waffle were estimated by the EERC to remain operational for approximately 50 years. Since the expected life of the control devices was estimated to equal the time frame for evaluating the Waffle, culvert modifications and installation expenses were considered a one-time expense, incurred in the first year of the 50-year evaluation period. It is acknowledged that some additional removal and installation expenses are likely to occur at the end of any contract period as some land tracts exit the Waffle (i.e., not re-enroll) or as other land tracts enter the Waffle (i.e., enroll for the first time). These potential expenses were not modeled.

Basically, the amount of land by relief category was the primary factor influencing the culvert modification and installation expenses within the model. The EERC provided cost estimates for culvert modifications for land sections delineated by three relief categories for three watersheds in the Red River Basin (see Appendix B). Based on the work conducted by the EERC, the cost of culvert modifications and installation expenses varied by relief category per section, and was not considered to change by land classification. A single set of anticipated modification and installation expenses were used in the model and were based on data from the Red Lake Watershed (see Appendix B). Thus, the overall cost for culvert modification and installation expenses for the Waffle were based on the number of sections of land by relief category. Data on the number of sections of land by relief category for each acreage option for each scale scenario were provided by the EERC.

While culvert modifications and installation expenses were considered one-time expenses, due to a host of potential circumstances, those devices were considered to require periodic maintenance, inspection, and repair. Expenses for periodic maintenance, inspection, and repair were collectively called maintenance costs, and were simply expressed annually as a percentage of culvert modification and installation costs since data were not available to suggest a more appropriate level for those expenses. Each year's maintenance cost was based on applying the inflationary factor to the previous year's maintenance cost, thereby allowing those costs to increase over time.

Waffle Scale, Acreage, and Landowner Payments

Two Waffle scales were considered. The EERC provided three acreage estimates for each Waffle scale (see Appendix A). The combinations of scale and acreage resulted in six different estimates of the physical 'footprint' of the Waffle. Each acreage option within the full- and half-scale sizes determines the number of payment acres by land classification, relief category, county, and state (see Appendix A).

Three different payment structures to landowners were incorporated into the model: 1) payments are made only during years when fields are flooded; 2) payments are made every year regardless of whether water is stored; and 3) payments represent a combination of annual and flood-event compensation. An additional approach used in the cost model was to assume that the Waffle would require landowners to agree to some contract period whereby the land would remain available to be used in the Waffle. The model was designed to provide for a retainer payment at the beginning of each contract period. For example, if contract periods were to last 10 years, then a landowner(s) of a single tract of land could receive 5 retainer payments, one every 10 years, assuming the land tract remained in the Waffle over the 50-year period. Retainer payments were allowed to vary based on a percentage of cash rent. Contract length and the level of retainer payments were both input variables in the model.

Another factor which influences the estimation of landowner compensation was a minimum flood frequency or flood-event size that resulted in the Waffle storing water. Early on in the analysis it was realized that it would make little economic sense to use the Waffle to mitigate flood damages for relatively minor spring-time flood events. However, this approach implies that the appropriate government agencies would have sufficient predictive capacity to know when the Waffle would be required to mitigate flooding in the Red River

Basin. Flood frequency was used to adjust the level of landowner payments to account for the annual probability of water storage. For example, if the Waffle is only used on a 50-year or larger flood and the landowner was to receive $75 per acre that year for water storage, the model estimated a payment that year for $1.50 per acre (1/50 x $75). This same procedure was repeated annually except that payments would change as cash rents were allowed to increase over time. The flood frequency used in the cost model was tied to the smallest flood size used by the EERC to evaluate flood crest height reductions.

Landowner payments were generated for all payment acreage in the Waffle. When the Waffle stores water, it was assumed that all tracts would be used for that flood event. Although it would be possible for the Waffle to selectively choose tracts of land to store water on depending upon local conditions for any particular flood event, the cost model assumes all land receives a payment in all flood events. This assumption is consistent with the perception that Waffle has the most potential to mitigate the effects of larger floods.

Enrollment and Administrative Costs

The model allows for costs associated with enrolling land in the Waffle and administration of the Waffle. Enrollment expenses were included to approximate a cost for conducting meetings, performing outreach efforts to educate landowners, producers, and the general public, and provide some expense for drawing up legal contracts, negotiations, filing easements, and any other expense associated with enrolling land in the Waffle and making the Waffle operational. Unfortunately, information was not available on what those expenses would likely be, so initial enrollment expenses were modeled as a flat dollar rate per section. The bulk of enrollment costs were modeled as one-time expenses at the beginning of the 50-year period. Additional enrollment expenses could be expected at the beginning of each contract period. However, enrollment costs after the first contract period were considered minimal compared to the costs covered by enrollment expenses at the beginning of Waffle operation, and were estimated as a percentage of the expenses incurred at Waffle startup. The reoccurring enrollment expense coincided with the length of contract.

Estimates of the cost to administer the Waffle were not available, nor was secondary data available to provide a proxy for those expenses. It would be anticipated that administration expense, after all land enrollment is complete and the Waffle is fully functional, would likely be relatively moderate for most years, but that costs could be substantial in years when the Waffle actually stores water. Administrative expenses would obviously be greater during the years when the Waffle is used due to the resources needed to distribute landowner payments, assess status of devices, monitor water storage levels, record water flows and volumes, review and/or modify operational procedures, mitigate any unforeseen local problems with water storage, provide controlled release of stored water, and so on. For simplicity, an average annual amount of administrative expense was modeled. However, since it could be argued that some administrative functions could increase as the work load and complexity increases with Waffle scale, an additional amount of administrative expense was modeled as a function of Waffle scale. The additional expense was a flat monetary rate tied to Waffle acreage.

Study Limitations

The goal of this study was to provide a first assessment of the cost-effectiveness of the Waffle. As additional data becomes available and as the level of understanding of the Waffle improves, a number of refinements in the benefits and costs of the Waffle would be warranted. These improvements could stem from including material previously omitted, applying alternative estimation techniques, and/or refining existing baseline data to more accurately reflect an evolving understanding of how the Waffle would be implemented and operated. The following discussion highlights some of the data and methodological limitations of this study.

Estimation of Benefits

This study used a conservative estimate of the potential benefits of the Waffle. Benefits of the Waffle were limited to mitigated flood damages in seven communities in the Red River Basin. Additional benefits that could be examined in future assessments include the following.

1) Mitigated flood damages to rural homes, farmsteads, and agricultural buildings, as well as mitigated damages to the numerous small communities located along tributaries and the Red River.

2) The beneficial economic effects of reduced probability of levee failure associated with lower crest heights. Also, the savings or benefits associated with extending the useful life of existing flood protection measures that may result from the Waffle.

3) Potential long-term agronomic or economic benefits to agricultural land resulting from temporary water storage.

4) Potential economic benefits to groundwater recharge, improved water quality, reduced soil erosion, or other environmental benefits.

5) Mitigated flood damages that might occur within the Canadian portion of the Red River Basin as a result of the Waffle being used in the U.S. portion of the basin.

6) Mitigated flood damages associated with rural roads, bridges, and other public infrastructure not contained in existing functions. Also, economic benefits accruing from the prevention of road closures on rural, state, or federal transportation systems.

7) Reduction in costs associated with implementing preventive measures tied to the removal, relocation, or handling of toxic, hazardous, or sensitive materials prior to impending floods.

8) Possible reduction in Federal Flood Insurance costs and or the potential to remove or redefine flood plain designations.

Refinements in the estimation of the flood-stage damage functions would be valuable for future assessments of the Waffle. A re-estimation or re-calculation of the flood-stage damage functions for nearly all of the communities included in the study would improve the potential estimation of mitigated flood damages. While the flood-stage damage functions used in this study were current with respect to existing flood protection measures in all of the cities, the flood-stage damage functions could be improved if they were updated to include recent changes in the location and value of residential, commercial, and public infrastructure. While attempts were made in this study to update flood-stage damage functions for changes in the value of residential, commercial, and public infrastructure at risk for flooding using secondary data, the flood-stage damage functions would be more accurately updated if new primary data were used with the USACE estimation techniques.

Estimation of Costs

The following limitations/refinements apply to cost estimates.

1) Costs of culvert modifications throughout the basin were based on the costs associated with a single watershed. An improvement would be to include separate estimates of the likely costs of culvert modifications for each watershed in the Red River Basin or more closely tie the costs of culvert modifications to local conditions, regardless of watershed considerations.

2) Cash rents on agricultural cropland were used as a proxy for estimating financial compensation on non-agricultural lands enrolled in the Waffle. While the amount of non-agricultural land in the Waffle is minor compared to agricultural land, future economic assessments of the Waffle may benefit from using other approaches to estimating the level of financial compensation needed for non-agricultural lands.

3) Maintenance costs for the culvert modifications should be based on engineering assessments of the rate of failure over the life of the devices. Data on the cost of labor and

materials to periodically monitor, maintain, and occasionally repair the control devices are currently unavailable.

4) Administrative expenses could be refined as the operational and overhead requirements of the Waffle are better understood. Would an operational Waffle-based flood mitigation strategy require a regional headquarters? Would there be satellite offices located throughout the basin? What would be the basin-wide staffing requirements to monitor and operate the Waffle? What additional resources would be required to insure that the Waffle operates efficiently during spring floods?

5) The cost of getting the Waffle implemented is largely unknown, and those expenses could be more accurately estimated with additional information. At this point, the resources needed to educate the public, develop and design landowner contracts, resolve possible legal obstacles, address any legislative issues, resolve any international conflicts, and handle any other unforeseen aspects of developing and implementing the Waffle are not well understood. Would a pilot Waffle be first implemented in a single watershed, with the lessons learned being applied throughout the basin? What might be a realistic time line to implement the Waffle basin wide?

6) Current information on the level, frequency, and nature of landowner compensation needed to make the Waffle operational is insufficient, and details on those issues are likely to remain elusive until more information is known about 1) the physical effects of temporary water storage and 2) how participation in the Waffle may affect other income sources (e.g., crop insurance payments, farm program provisions). From a planning perspective, some fundamental issues remain unanswered. What level of compensation is necessary to entice landowners to enroll? Does the level of compensation need to be correlated with the length of time water is stored? What effect will contract design have on the willingness of landowners to cooperate in the Waffle? Also, the issue of compensation rates and volume of water stored on any given land tract raises questions on economic efficiency of enrolling land in the Waffle. A more thorough understanding of the interaction between landowner compensation and willingness to enroll, economic efficiency of water storage, landowner contract design, and other related issues is likely to require additional research.

7) Landowner compensation was based on payment acreage, which was held constant regardless of the size of flood event. If the amount of payment acreage changes with the size of flood event, then estimates of landowner compensation should also be tied to the size of flood event. Conceptually, all acreage enrolled in the Waffle may not be needed or may not be used to temporarily store runoff with smaller-sized flood events, especially if flood severity for any particular event is unequal throughout the Basin. If the amount of acreage flooded by the Waffle varies, then it is possible that payment acreage could also vary. If payment acreage actually varies by size of flood event, then it is likely that landowner compensation is overstated with smaller-sized flood events. Since smaller-sized flood events

are likely to occur more frequently, and smaller-sized flood events could potentially have less payment acreage, the ability to refine landowner compensation based on flood size could greatly improve cost estimates. The capacity to tie payment acreage more closely to the size of the flood event would provide a refinement in the cost estimates associated with the Waffle.

8) Data were not available to differentiate Waffle acreage within a county for purposes of adjusting payment levels associated with potential variations in cash rent. All payments for land in each county were tied to a single level (i.e., average value) for cash rent in that county. Using an average value for all Waffle acreage in a county results in compensation rates being higher in some situations and lower in other situations than if payment levels were more closely tied to local conditions. A potential refinement in estimating landowner compensation would be to use more localized cash rents for land in the Waffle, rather than using county average cash rents.

RESULTS

This report provides a first assessment of the cost-effectiveness of the Waffle and provides insights into the economic feasibility of using the Waffle to mitigate flood damages in the Red River Basin. The results presented in the following sections should be considered under the context that a considerable amount of uncertainty and knowledge gaps remain on both the cost and benefit aspects of the Waffle. A refinement in those data gaps and a reduction in many of this study's limitations would increase the confidence in the economic analysis.

Benefits were estimated for the appropriate combinations of Waffle scale, storage volumes, and population projections. The analysis produced 12 estimates of the level of Waffle benefits. However, a discrete number of cost estimates would require a subjective number of values to be used for many cost factors. As a result, a reasonable range of values for some cost factors was used to limit the number of cost estimates for the Waffle. Total costs of operating the Waffle are presented, along with a separate section for gross benefits. Finally, total costs and gross benefits are combined.

Costs

The costs of operating the Waffle over a 50-year period are provided in present value terms (i.e., future costs discounted to the present time). For sake of limiting the potential number of estimates of the cost of operating the Waffle, a baseline scenario was developed using reasonably acceptable values for cost inputs, given current knowledge about the Waffle. While the baseline scenario produced a cost estimate for each combination of Waffle scale and payment acreage, cost inputs were adjusted to reflect a more economically favorable scenario and a more economically unfavorable scenario (Table 8).

The input values that remained unchanged across all cost scenarios were a 5 percent discount rate, a 10-year contract period, an 11-year or larger flood event for using the Waffle, and landowners received payments only when water was stored (not including retainer payments).

For the baseline cost scenario, values for key economic variables included $1,500 per section for enrollment expenses, retainer payments equal to 125 percent of cash rent, water storage payment rates equal to 175 percent of cash rent, maintenance costs equal to 1 percent of the cost of culvert control devices, administrative expenses starting at $250,000 per year with an additional $2 for every 100 acres enrolled, and annual inflation rate of 2.75 percent (Table 8).

The key variables that were adjusted between optimistic and pessimistic cost scenarios were enrollment expense, retainer payment, water storage payment, maintenance, administrative expense, and inflation rate (Table 8).

Table 8. Input Values for Key Variables and Parameters for Baseline, Optimistic, and Pessimistic Scenarios on Waffle Operation Costs, 50-year Period

Input Variable[a]	Value used for Input Variables: Optimistic Scenario	Baseline Scenario	Pessimistic Scenario
Enrollment cost per section (startup)	$1,000	$1,500	$2,000
Enrollment cost per section (at end of each contract period)	15% of costs at start-up	25% of costs at start-up	40% of costs at start-up
Landowner retainer payment per acre per contract (percent of cash rent)	100%	125%	150%
Length of enrollment contract	10 years	10 years	10 years
Cash rent on 'other' land (percent of cash rent on cropland)	50%	75%	100%
Landowner payment per acre when water is stored (percent of cash rent)[b]	125%	175%	250%
Flood-event frequency when Waffle is used	11-year event	11-year event	11-year event
Average administrative expenses per year	$200,000	$250,000	$350,000
Additional administrative expense based on Waffle scale	$0.10 per acre	$0.20 per acre	$0.30 per acre
Annual culvert maintenance cost as a percentage of the value of culvert devices	0.5%	1%	2%
Inflationary adjustment for administrative and maintenance costs	2.5% per year	2.75% per year	3% per year
Discount rate	5%	5%	5%
Cost per section for culvert control devices by relief category			
0 - 2	$11,600	$12,700	$14,500
2 - 4	$9,400	$10,300	$11,700
4 - 10	$3,600	$4,000	$4,500
Installation cost per section for culvert control devices by relief category			
0 - 2	$1,200	$1,320	$1,500
2 - 4	$1,000	$1,100	$1,250
4 - 10	$800	$880	$1,000

[a] Detailed description of cost variables can be found on pages 27 through 29.

[b] Payments made only when water is stored.

Cash and discounted (i.e., present value) costs were generated to gauge the relative influence of default input values on the overall cost structure for the Waffle (Table 9). A considerable difference exists between the cash and discounted values for expenses, depending upon what point during the 50-year period the expense was predicted to occur.

For example, maintenance costs, which are modeled to occur each year, represent nearly $48 million in cash costs, but only represent $14.5 million in present value costs. Overall, cash costs of operating the Waffle would be about 2.5 to 3 times higher than present value costs (Table 9).

Table 9. Total Cash and Discounted Costs Associated with Input Values, Baseline Scenario, Full-scale Waffle with Maximum Acreage, 2006 through 2055

Input Variable	Input Value	Cash Costs[a]	Present Value[b]
Enrollment cost per section (startup)	$1,500	$7,184,000	$6,841,000
Enrollment cost per section (at end of contract period)	25% of costs at start-up	$7,182,000	$2,333,000
Landowner retainer payment per acre per contract (percent of cash rent)[c]	125%	$533,967,000	$222,812,000
Landowner water storage payment per acre (percent of cash rent)[d]	175%	$704,883,000	$238,331,000
Minimum administrative expenses per year	$250,000	$26,203,000	$7,349,000
Additional administrative expenses based on Waffle scale	$0.20 per acre	$29,652,000	$8,317,000
Annual culvert maintenance cost as a percentage of the value of culvert devices	1%	$47,982,000	$13,458,000
Culvert devices and installation per section by relief contour		$45,779,000	$43,599,000
0 - 2	$14,020		
2 - 4	$11,400		
4 - . 10	$4,880		
	Totals[e]	$1,402,832,000	$543,041,000

[a] Cash expenses were not discounted and represent sum of expenses over 50-year period.

[b] Expenses discounted annually at a rate of 5 percent.

[c] Based on 10-year contract period.

[d] Waffle used at 11-year flood event or larger.

[e] Waffle size equal to 1,414,560 payment acres.

Baseline Cost Scenario

The baseline cost scenario represented an attempt to provide a cost projection that was not overly pessimistic or optimistic. In some cases, values for various inputs represented best estimates or best guesses and were considered reasonable, given data and knowledge limitations. The present value of costs for the full-scale Waffle for the baseline scenario ranged from $543 million with maximum acreage to $208 million with minimum acreage (Table 10). The present value of costs for the half-scale Waffle for the baseline scenario ranged from $275 million with maximum acreage to $108 million with minimum acreage. Across both the full- and half-scale Waffle sizes, the largest expense was for payments to landowners, followed by equipment and installation expenses associated with the culvert control devices (Appendix E contains Waffle expenses by category for each cost scenario).

Table 10. Present Value of Projected Costs of the Waffle, 2006 through 2055

Scale and Acreage Estimate	Cost Scenarios		
	Baseline	Optimistic	Pessimistic
	----------------------------- 000s $ -----------------------------		
Full-scale			
Minimum	207,931	155,739	287,326
Moderate	362,191	269,537	494,872
Maximum	543,040	402,721	738,602
Half-scale			
Minimum	107,964	80,915	149,494
Moderate	184,797	137,578	252,897
Maximum	275,505	204,386	375,132

Optimistic Cost Scenario

A number of values for input variables and parameters were adjusted to reflect an optimistic set of expectations regarding the operational costs of the Waffle to provide some lower bounds of the costs associated with the Waffle. Essentially, in the optimistic cost scenario it was less costly to get the Waffle operational and less costly to compensate landowners (i.e., relatively lower retainer and water storage payments). Other cost reductions came from slightly lower administrative overhead and more favorable long-term inflation rates.

The present value of Waffle costs under the optimistic cost scenario with the full-scale size ranged from $403 million with maximum acreage to $156 million with minimum acreage (Table 10). With the half-scale size, costs of operating the Waffle ranged from $204 million for maximum acreage to $81 million with minimum acreage.

Waffle costs for the full-scale option with maximum acreage were projected to decrease by 26 percent from the baseline scenario to the optimistic scenario ($543 million down to $403 million) (Table 10). In the half-scale option, Waffle costs for the maximum acreage in the baseline scenario also decreased by 26 percent in the optimistic scenario ($276 million compared to $204 million) (Table 10).

Pessimistic Cost Scenario

Several inputs and parameters were adjusted to reflect an pessimistic set of expectations regarding the operational costs of the Waffle to provide some upper bounds of the costs of the Waffle. The cost inputs that were adjusted in the pessimistic scenario included the level of retainer payments, water storage payments, maintenance costs, inflationary factors, and enrollment and administration costs (see Table 8).

Waffle costs for the full-scale option with maximum acreage were projected to change from $543 million in the baseline scenario to $739 million in the pessimistic scenario (Table 10). The change represented a 36 percent increase in costs compared to the baseline scenario. In the half-scale option, Waffle costs for the maximum acreage in the baseline scenario were estimated at $276 million, compared to $375 million in the pessimistic scenario (Table 10).

Gross Benefits

Unlike the cost model, the benefits model did not contain the same degree of flexibility to adjust all input variables or parameters. The factors that did change in the estimation of benefits included future population projections and estimated changes in river crest heights associated with Waffle scale and anticipated storage volumes. Three population projections were used to adjust the damage values in the FSDFs for future population changes in the study communities. For each population projection, four possible sets of crest height reductions were used. Estimated reductions in crest heights were generated by the EERC for the full-scale and half-scale implementation of the Waffle with moderate and conservative water storage scenarios for each scale. The combination of population projections, Waffle scale, and water storage scenarios produced 12 estimates of Waffle benefits.

Crest Height Reduction

The EERC estimated the hydrologic and hydraulic effects of water storage from the Waffle on the intensity of spring floods throughout the Red River Basin. One of the results of this fundamental analysis of the Waffle's performance was the estimated difference between crest heights on the Red River without the Waffle and crest heights with the Waffle. The change in crest heights for the Red River at key locations provided a measure of the performance of the Waffle in reducing the intensity of a flood event. The change in flood intensity, measured by a change in crest height, could then be used with the FSDFs to estimate mitigated flood damages (benefits).

The EERC evaluated the performance of the Waffle using full-scale and half-scale scenarios with a moderate and conservative estimate of water storage capacity for each scale. A number of considerations and assumptions went into the analysis of both the moderate and conservative water storage capacities for the Waffle. The factors considered and the values used for those analyses are highlighted in Appendix F. Since the primary data for the analysis of the Waffle's potential performance on reducing crest heights along the Red River came from the 1997 flood, several flood event sizes were developed that were based on derivatives (i.e., percentages) of the water flows present in 1997. The Waffle was evaluated for the following flood events: 50 percent of 1997, 100 percent of 1997, 125 percent of 1997, 150 percent of 1997, and 200 percent of 1997. Since the 1997 flood was not considered the same event size at all locations in the Red River Basin, the frequency for the flood events modeled by the EERC also varied by location (Table 11). The key locations along the Red River included Wahpeton/Breckenridge, Fargo/Moorhead, Grand Forks/East Grand Forks, and Drayton. Estimates of crest height reductions were not generated for other locations along the Red River and for other tributaries in the Basin.

Table 11. Approximate Frequency of Flood Event Sizes Evaluated for Waffle Flood Reduction

Flood Event Evaluated	Estimated Flood Frequency (years)[a]			
	Fargo / Moorhead	Grand Forks / East Grand Forks	Wahpeton / Breckenridge	Drayton
50% of 1997	21	11	25	25
1997	122	130	241	278
125% of 1997	251	338	893	>10,000
150% of 1997	500	1250	1160	>10,000
200% of 1997	>10,000	>10,000	>10,000	na

[a] Frequency based on USACE data. Derivatives of 1997 flood are not linear.
NA=not available.

The Waffle was estimated to reduce crest heights by a few tenths of a foot to several feet, depending upon flood event size, Waffle scale, water storage assumptions, and location along the Red River (Table 12) (Appendix F). Of particular interest would be the effect of the Waffle on 1997 flood crest heights, since the 1997 flood can serve as a real world reference for most individuals. In Wahpeton/Breckenridge, the Waffle was estimated to reduce the Red River crest height by 0.15 feet (conservative storage under half-scale Waffle) to 1.92 feet (moderate storage under full-scale Waffle) for conditions present during the 1997 flood. By contrast in Fargo/Moorhead, the Waffle in 1997 would have reduced the crest height on the Red River by 3.91 feet (conservative storage under half-scale Waffle) to 6.17 feet (moderate storage under full-scale Waffle). In the case of Fargo/Moorhead, the anticipated crest height reductions appear to be substantial. Similar magnitude of change could have occurred in Grand Forks/East Grand Forks in 1997, where the Waffle could have reduced the crest height of the Red River by 0.67 feet (conservative storage under half-scale Waffle) to 4.97 feet (moderate storage under full-scale Waffle). A 5-foot lower crest height in Grand Forks/East Grand Forks in 1997 would likely have been sufficient to spare the metro area from the catastrophic damage of that flood.

Table 12. Estimated Crest Heights of Red River With and Without the Waffle at Key Locations, by Waffle Scale, Flood Event Size, and Water Storage Scenarios

Flood Event Size	River Crest Heights (feet)				
		Conservative Water Storage		Moderate Water Storage	
	No Waffle	Half-scale	Full-scale	Half-scale	Full-scale
	------------------------------ Wahpeton/Breckenridge ------------------------------				
50% of 1997	17.54	17.23	16.81	16.14	15.2
1997	23.43	23.28	23.01	22.42	21.51
125% of 1997	25.8	25.67	25.4	24.86	23.97
150% of 1997	27.89	27.8	27.56	27.14	26.23
200% of 1997	31.56	31.56	31.33	30.93	30.14
	--------------------------------- Fargo/Moorhead ---------------------------------				
50% of 1997	33.01	29.19	28.49	27.26	25.32
1997	39.94	36.03	35.57	34.81	33.77
125% of 1997	41.87	38.5	38.11	37.39	36.2
150% of 1997	43.25	40.59	40.19	39.56	38.49
200% of 1997	45.35	42.94	42.76	42.35	41.67
	-------------------------- Grand Forks/East Grand Forks --------------------------				
50% of 1997	45.22	44.01	42.68	40.36	36.03
1997	54.2	53.53	52.7	51.23	49.23
125% of 1997	57.61	57.15	56.33	54.97	52.99
150% of 1997	59.77	59.59	59.22	58.19	56.33
200% of 1997	62.55	62.46	62.07	61.4	60.44
	------------------------------------- Drayton -------------------------------------				
50% of 1997	42.63	42.02	41.43	40.58	38.91
1997	47.31	47.01	46.61	45.93	44.95
125% of 1997	48.96	47.74	48.38	47.77	46.85
150% of 1997	50.37	50.2	49.86	49.31	48.47
200% of 1997	na	na	na	na	na

Source: Kurz et al. (2007).

Baseline Growth Scenario

The baseline scenario was evaluated based on a population projection for the study communities. Future population was a key input affecting the level of potential damages that could occur in the study communities. Obviously, all things equal, an increase/decrease in population would translate to more/less property at risk from flood related damage. The more potential damage, the greater the potential for mitigated flood damages (benefits) associated with the Waffle.

The present value of the benefits of the Waffle ranged from $605 million with conservative water storage capacities with the half-scale Waffle under the baseline population scenario to $915 million with moderate water storage capacities with the full-scale Waffle (Table 13). Obviously the greater reductions in crest heights found with the moderate water storage capacities in each Waffle scale translated to greater mitigated flood damages in the study cities. Approximately $250 million in benefits separated the moderate and conservative water storage assumptions for the full-scale Waffle whereas about $200 million separated benefits for the half-scale Waffle in the baseline population scenario (Table 13).

Table 13. Present Value of Gross Benefits of the Waffle, 2006 through 2055

Scale and Water Storage Estimates	Population Scenarios		
	Baseline	Optimistic	Pessimistic
	----------------------------	000s $	----------------------------
Full-scale			
Moderate	914,790	1,020,861	885,019
Conservative	668,226	752,846	652,444
Half-scale			
Moderate	811,629	907,900	786,914
Conservative	605,554	684,309	592,929

Optimistic Growth Scenario

The optimistic population scenario was based on projections for growth in population in Fargo, Grand Forks, Breckenridge, East Grand Forks, and Moorhead. For Drayton and Wahpeton, the main and optimistic projections were unchanged since population growth data consistent with the conditions used in the main population forecast could not be found. The greatest numerical change in population between the two forecasts was found in Fargo and Moorhead (see Appendix C). The optimistic scenario resulted in an 18 percent increase in population in the four study communities over the population projections found in the baseline scenario. The use of the optimistic scenario was to demonstrate that population increases can affect the future expected benefits of the Waffle. Granted, the location of the population growth can also influence the results, since current property values, past trends in property values, and existing flood protection measures all differ for the study communities.

The present value of the gross benefits of the Waffle ranged from $670 million with conservative water storage capacities with the half-scale Waffle to $1 billion with moderate water storage capacities with the full-scale Waffle (Table 13). An 18 percent increase in population between the main and optimistic scenarios produced 11 to 13 percent increases in mitigated flood damages. Over $250 million in benefits separated the moderate and conservative water storage capacities in the optimistic population scenario for the full-scale Waffle.

Pessimistic Growth Scenario

The pessimistic growth scenario forecasted population declines for Drayton, Wahpeton, and Moorhead. In Fargo, Grand Forks, and East Grand Forks, population growth was reduced compared to the baseline scenario. In Breckenridge, population was unchanged from the baseline projection (see Appendix C). Overall, population in the study communities in the pessimistic scenario was collectively 14 percent lower than in the baseline scenario. The use of the pessimistic scenario was to demonstrate that less robust population growth can affect the future expected benefits of the Waffle relative to more robust population growth.

The present value of the gross benefits of the Waffle ranged from $593 million with conservative water storage capacities with the half-scale Waffle to $885 million with moderate water storage capacities with the full-scale Waffle (Table 13). An 14 percent decline in population between the main and pessimistic scenarios produced only a 2 to 3 percent decrease in mitigated flood damages. The difference between the three scenarios is partially due to the relative influences of population growth and changes in real property values. Increasing populations within a community were modeled to have a greater influence on the total value of property at risk from flooding than constant or declining populations. Population only accounted for part of the change in overall property values, the other factor was the trend in real (inflation adjusted) property values. The net result was that lower growth in population or, in some communities, population decline, resulted in relatively less change in flood damages than changes of similar magnitude with population growth.

Net Benefits

Results from the appropriate cost and benefit scenarios were combined to evaluate the economic viability of the Waffle. Results of combining costs and benefits are presented in net terms (i.e., costs subtracted from benefits).

Baseline Growth Scenario

Under the baseline population scenario, net benefits of the Waffle were positive across all cost, scale, and water storage situations except one. Within the baseline population scenario, as expected, net benefits across all combinations were highest with the optimistic cost scenario and lowest with the pessimistic cost scenario. In the baseline cost scenario, net benefits with the full-scale Waffle were estimated to range from over $700 million with moderate water storage combined with minimum acreage to about $125 million with conservative water storage combined with maximum acreage (Table 14). When costs were reduced in the optimistic cost scenario, net benefits were estimated to range from about $760 million with moderate water storage combined with minimum acreage to nearly $266 million with conservative water storage combined with maximum acreage. An increase in costs found with the pessimistic cost scenario produced net benefits which ranged from $627 million with moderate water storage combined with minimum acreage to nearly -$70 million with conservative water storage combined with maximum acreage (Table 14).

With the full-scale Waffle, net benefits from moderate water storage scenarios ranged from 50 percent up to 200 percent greater than net benefits associated with conservative water storage capacities (Table 14). Net benefits for the full-scale Waffle for both moderate and conservative water storage capacities increased by 50 to over 250 percent between the minimum acreage and maximum acreage cost scenarios. Substantial changes in the magnitude of net benefits were observed between combinations of water storage capacities and acreage scenarios, both within and between Waffle scales.

In the baseline cost scenario, net benefits with the half-scale Waffle were estimated to range from over $700 million with moderate water storage combined with minimum acreage to about $330 million with conservative water storage combined with maximum acreage (Table 14). Most patterns of the relative level of net benefits for the half-scale Waffle within the cost scenarios were similar to those observed with the full-scale Waffle. However, the half-scale Waffle with moderate water storage had higher net benefits than the full-scale Waffle with moderate water storage in seven of the nine cost scenarios. The half-scale Waffle had slightly higher net benefits than the full-scale Waffle in the moderate and maximum acreage combinations across the baseline, optimistic, and pessimistic cost scenarios for moderate water storage (Table 14). The same pattern of increased net benefits across all cost scenarios occurred between the half-scale and full-scale Waffle with conservative water storage assumptions.

The difference in net benefits between conservative and moderate water storage with the half-scale Waffle appeared to be generally less than the differences associated with the full-scale Waffle. Also, the degree of increase in net benefits for the half-scale Waffle for both moderate and conservative water storage capacities between the minimum acreage and maximum acreage cost scenarios were less than those found with the full-scale Waffle.

Table 14. Net Benefits of the Waffle, Baseline Population Scenario, 2006 through 2055

Cost and Acreage Scenarios	Full-scale Waffle		Half-scale Waffle	
	Moderate Water Storage	Conservative Water Storage	Moderate Water Storage	Conservative Water Storage
	---------- 000s $ ----------			
Baseline Cost Scenario				
Minimum Acreage	706,859	460,295	703,665	497,590
Moderate Acreage	552,599	306,035	626,832	420,757
Maximum Acreage	371,750	125,186	536,124	330,049
Optimistic Cost Scenario				
Minimum Acreage	759,051	512,487	730,714	524,639
Moderate Acreage	645,253	398,689	674,051	467,976
Maximum Acreage	512,069	265,505	607,243	401,168
Pessimistic Cost Scenario				
Minimum Acreage	627,464	380,900	662,135	456,060
Moderate Acreage	419,918	173,354	558,732	352,657
Maximum Acreage	176,188	(70,376)	436,497	230,422

Optimistic and Pessimistic Growth Scenarios

The optimistic population scenario served to provide an estimate for increased benefits (i.e., relative to baseline population) from the Waffle due to a greater increase in the region's future population. The pessimistic population scenario served to provide an estimate of reduced benefits (i.e., relative to baseline population) from the Waffle associated with a lower rate of increase in the region's future population. The lower rate of growth in future population reduced the relative amount of aggregate value of property at risk of flooding.

As was expected, net benefits were greatest across all cost, scale, and water storage combinations with the optimistic population scenario (Table 15). Since all but one combination of factors produced positive net benefits in the baseline scenario, it would be expected that an increase in gross benefits associated with the optimistic population scenario would produce an increase in net benefits. Similarly, net benefits were lowest for each cost, scale, and water storage combination with the pessimistic population scenario (Table 15). Several combinations were estimated to generate net benefits in excess of $800 million under the optimistic population scenario, while the highest net benefits in the pessimistic population scenario were about $700 to $730 million (Table 16).

Table 15. Net Benefits of the Waffle, Optimistic Population Scenario, 2006 through 2055

Cost and Acreage Scenarios	Full-scale Waffle: Moderate Water Storage	Full-scale Waffle: Conservative Water Storage	Half-scale Waffle: Moderate Water Storage	Half-scale Waffle: Conservative Water Storage
	---- 000s $ ----			
Baseline Cost Scenario				
Minimum Acreage	812,930	544,915	799,936	576,345
Moderate Acreage	658,670	390,655	723,103	499,512
Maximum Acreage	477,821	209,806	632,395	408,804
Optimistic Cost Scenario				
Minimum Acreage	865,122	597,107	826,985	603,394
Moderate Acreage	751,324	483,309	770,322	546,731
Maximum Acreage	618,140	350,125	703,514	479,923
Pessimistic Cost Scenario				
Minimum Acreage	733,535	465,520	758,406	534,815
Moderate Acreage	525,989	257,974	655,003	431,412
Maximum Acreage	282,259	14,244	532,768	309,117

As was found in the baseline population scenario, net benefits with moderate and maximum acreage scenarios were generally greater with the half-scale Waffle than with the full-scale Waffle, regardless of water storage assumptions. For example, comparing the conservative water storage scenarios with the full-scale and half-scale Waffle shows that the half-scale Waffle has higher net benefits in all cost scenarios. Across the baseline, optimistic, and pessimistic cost scenarios, substantial difference in net returns could be seen in both the full-scale and half-scale Waffle options when comparing net returns between minimum and maximum acreage assumptions for both the optimistic and pessimistic population scenarios (Tables 15 and 16).

Table 16. Net Benefits of the Waffle, Pessimistic Population Scenario, 2006 through 2055

Cost and Acreage Scenarios	Full-scale Waffle		Half-scale Waffle	
	Moderate Water Storage	Conservative Water Storage	Moderate Water Storage	Conservative Water Storage
	---------- 000s $ ----------			
Baseline Cost Scenario				
Minimum Acreage	677,088	444,513	678,950	484,965
Moderate Acreage	522,828	290,253	602,117	408,132
Maximum Acreage	341,979	109,404	511,409	317,424
Optimistic Cost Scenario				
Minimum Acreage	729,280	496,705	705,999	512,014
Moderate Acreage	615,482	382,907	649,336	455,351
Maximum Acreage	482,298	249,723	582,528	388,543
Pessimistic Cost Scenario				
Minimum Acreage	597,693	365,118	637,420	443,435
Moderate Acreage	390,147	157,572	534,017	340,032
Maximum Acreage	146,417	(86,158)	411,782	217,797

Alternative Evaluation

The economic feasibility of the Waffle is subject to a host of factors–some of which are addressed in this report while others were beyond the scope of this analysis. The goal of this study was to provide a first assessment of the economic viability of the Waffle knowing that this first assessment would not and could not answer all of the economic questions. The paucity of real, tangible data on the start-up, operational, and administrative characteristics of the Waffle make it problematic to generate additional sensitivity analyses of Waffle costs. A greater understanding of the costs of the Waffle will only occur when the knowledge gaps are filled. A similar limitation exists on how much sensitivity analysis should be performed on the benefits of the Waffle with respect to adjusting future population, property values, and other economic variables. Another consideration is that whole categories of benefits have been excluded, and the benefits that are used in this study are subject to a definition of flood damages set forth by the USACE that do not match real-world effects (i.e., particularly in Fargo/Moorhead) in many flood-event sizes.

Given that additional analyses involving changes to hypothetical costs and additional population forecasts would not likely improve the understanding of the economic feasibility of the Waffle, two changes to the baseline conditions were considered: 1) the Waffle was modeled to only be used with low-frequency flood events and 2) the FSDF for

Fargo/Moorhead was adjusted to reflect accepted flood protection through a 100-year event, thereby, putting flood susceptibility of Fargo/Moorhead and Drayton at a level that more closely matches protections found in Grand Forks/East Grand Forks and Wahpeton/Breckenridge.

In both of the following analyses, costs of the Waffle were based on baseline assumptions, with the trigger level for using the Waffle set at the 101-year level. All other input variables and parameters associated with costs of operating the Waffle remained unchanged. The costs will not change with either analysis; however, the level of benefits will change. The reason for the change in gross benefits is that the elimination of damages in Fargo/Moorhead at or below the 100-year event has methodological implications based on the integration of flood frequencies and the anticipated difference between with and without flood damages. When the Waffle is only used for low flood frequencies, damages below the 100-year event frequency would cancel out (i.e., same level of damages with and without the Waffle) when the FSDF is not modified. When the FSDF is modified by putting damages to zero below at or below the 100-year event, the difference between damages with and without the Waffle changes considerably, as the crest heights for floods over the 100-year event size are lowered to less than the 100-year event size; the damages at those elevations are zero, and hence the Waffle is calculated to mitigate the entire level of damage at that elevation. This treatment of damages does not occur when only the frequency of Waffle use is modified (e.g., conditions in the other alternative).

Large Flood Events Only Scenario

Operationally, landowner payments for water storage represent a major component of Waffle costs, especially when using an 11-year flood frequency for water storage (Note: the 11-year flood frequency corresponds to data for the flood event size associated with 50 percent of the 1997 flood–the smallest flood event modeled by the EERC-see Table 11). Operating the Waffle at those flood frequencies definitely increases costs and produces few flood-related benefits. In Grand Forks/East Grand Forks and Wahpeton/Breckenridge, improvements in structural flood protections act to eliminate any mitigated flood damages associated with flood events less than the 1997 flood (i.e., flood damages are zero at elevations below 1997 flood crest heights). Most of the communities in the Red River Valley have reasonable protections for high-frequency (low impact) floods, regardless of the flood damages defined by the USACE in their FSDFs. For example, the flood in the spring of 2006 was particularly large, but actual damages throughout the basin were relatively minor. In the case of Fargo/Moorhead, the FSDF for the cities suggested that the area should have incurred $112 million in flood damages, which clearly did not occur. Fargo/Moorhead incurred some expense building temporary dikes and sandbag levies, but received very little actual flood damage. Why incur substantial expenses to provide redundant flood protection? The alternative analysis assumed the Waffle was only used for flood events larger than the 100-year frequency.

The costs of operating the Waffle only for flood events larger than the 100-year frequency decreased compared to the baseline analysis due to a reduction in total landowner payments (see Appendix E). When landowner payments are made only when water is stored, it would be anticipated, all things equal, that costs would decrease when the Waffle was used less frequently. Costs of operating the full-scale and half-scale Waffle decreased by 28 to 39 percent, when compared to baseline analyses, based on the minimum and maximum acreage scenarios, respectively. For the maximum acreage scenario with full-scale Waffle, costs in the alternative analysis were estimated at $331 million compared to $543 million in the baseline analysis (Table 17).

Net benefits in this alternative scenario were generally lower in magnitude to the baseline analysis across all combinations of acreage, scale, and water storage assumptions (Table 17). Both gross benefits and costs decreased compared to the baseline analysis, which was expected since the Waffle was scheduled to be used less frequently than in the baseline analysis. The difference between net returns in the two analyses suggests that the economics of the Waffle are influenced to some extent by the treatment of how often the Waffle is used. However, nearly all of the benefits within the model that accrue from high-frequency (low impact) floods come from the FSDF for Fargo/Moorhead. When the changes in gross benefits and costs are evaluated, the economics of the Waffle remained substantially positive despite limiting the use of the Waffle to only mitigating low-frequency (high impact) flood events. It would appear that the Waffle would be economical if it was only used to mitigate low-frequency, high impact floods.

Table 17. Gross Benefits, Costs, and Net Benefits of the Waffle from Large Flood Events Only, Baseline Population, 2006 through 2055

	Full-scale Waffle		Half-scale Waffle	
Results	Moderate Water Storage	Conservative Water Storage	Moderate Water Storage	Conservative Water Storage
Alternative Analysis	-- 000s $	--------------------------------------		
Gross Benefits	659,371	426,250	558,858	370,541
Costs				
Minimum Acreage	147,154	147,154	77,441	77,441
Moderate Acreage	231,637	231,637	119,520	119,520
Maximum Acreage	330,666	330,666	169,190	169,190
Net Benefits				
Minimum Acreage	512,217	279,096	481,417	293,100
Moderate Acreage	427,734	194,613	439,338	251,021
Maximum Acreage	328,705	95,584	389,668	201,351
Baseline Analysis	------ results from baseline analysis provided for comparison------			
Gross Benefits	914,790	668,226	811,629	605,554
Costs				
Minimum Acreage	207,931	207,931	107,964	107,964
Moderate Acreage	362,191	362,191	184,797	184,797
Maximum Acreage	543,040	543,040	275,505	275,505
Net Benefits				
Minimum Acreage	706,859	460,295	703,665	497,590
Moderate Acreage	552,599	306,035	626,832	420,757
Maximum Acreage	371,750	125,186	536,124	330,049

Notes: Only flood-events larger than 100-year frequency were modeled.

Modified Fargo/Moorhead Scenario

This alternative analysis focused. primarily on the treatment of potential mitigated flood damages in Fargo/Moorhead and Drayton, but also included changes in the frequency of use for the Waffle. This alternative analysis eliminates the flood damages for 100-year or smaller floods in Fargo/Moorhead. The elimination of damages at those elevations reflects more closely real world events and anticipates some of the changes that would occur to the FSDF if the metro area implemented additional permanent flood protections. Also, it more closely reflects the expected level of damages in the other metro areas in the Valley. For consistency, Drayton was also assumed to be flood-proof to the 100-year level.

The FSDF for Fargo/Moorhead indicates that substantial damages begin occurring in the two cities with modest elevations in the Red River. For example in 2006, according to the FSDF for Fargo/Moohead, at an elevation of 895 feet msl which equates to about a 22-year event, damages would be about $3.6 million. While some damages occur at relatively low river heights due to inundation of park areas, golf courses, and other relatively unprotected areas, local flood fighting efforts in combination with permanent protections act to eliminate most damages to residential and commercial structures for high-frequency flood events. As stated before, the FSDF represents damages that would likely occur in the absence of local flood fighting provisions (i.e., temporary dikes, sandbagging). It is difficult to reconcile the level of damages suggested by the FSDF for higher frequency floods in the two cities with the level of damages that actually occur. Another example can be drawn from the spring 2006 flood. The Red River in Fargo/Moorhead reached a crest of 899 msl, which according to the FSDF should have produced about $112 million in damages.

Despite that the Fargo/Moorhead area does not have a large-scale structural flood protection project similar to those in the finishing stages in Grand Forks/East Grand Forks and Wahpeton/Breckenridge, Fargo/Moorhead has repeatedly, to date, used a combination of temporary and permanent flood fighting measures to prevent widespread flood damage. It would be safe to assume that those efforts will continue to be successful in the future with flood-events of similar size (e.g., 1997, 2006).

Fargo/Moorhead continues to pursue additional flood protection provisions for parts of the two cities. It is possible that structural protections will be implemented in the near future changing the FSDF for the two cities. Permanent, structural flood protection is already underway in Oak Port Township as properties are being acquired to begin construction of a dike in that area. Also, plans to implement permanent flood protection continue to be debated for regions of south Fargo (Nowatzki 2007a). Spring flooding in June of 2007 renewed debates on a permanent downtown dike for Fargo (Nowatzki 2007b).

Much of the damages in the FSDF for Fargo/Moorhead are a function of definition in that they result from no local flood fighting provisions and begin occurring with high-frequency floods. However, damages predicted in the FSDFs for very large flood events are less sensitive to those assumptions and represent a stronger correlation between flood size and real damages since the river crest heights for those events exceed, in most cases, the capacities of existing permanent structural flood protections. Also, at these extreme flood crest heights, the reliability of temporary provisions for flood mitigation becomes tenuous. It is of greater value to focus solely on the mitigated flood damages from large floods, since Fargo/Moorhead, for various reasons, appears to consistently eliminate damages from lesser floods.

The final reason for adjusting the FSDF for Fargo/Moorhead is to reduce the mitigated flood damages from Fargo/Moorhead and evaluate how those reductions influence the economic feasibility of the Waffle. The pool of benefits from Fargo/Moorhead, given the current FSDF, completely dominates the economic feasibility of the Waffle. The percentage of all benefits arising from mitigated damages in Fargo/Moorhead under the moderate water storage scenarios represent 79 percent to 84 percent of all benefits (Appendix G). The percentage of damages coming from Fargo/Moorhead increase under the conservative water storage scenarios and range from 93 to 97 percent of total benefits (Appendix G). When the Waffle is predicted to have less influence reducing the effects of large floods, the potential to mitigate damage in the other cities decreases. Since the FSDF for Fargo/Moorhead implies the cities are vulnerable to small and medium flood events, the relative share of mitigated damages from Fargo/Moorhead increase. Given the absence of other benefits in the analysis (e.g., environmental, rural infrastructure, small communities), the economic feasibility of the Waffle to this point has been solely determined by how much damages are derived from Fargo/Moorhead.

Net benefits in this alternative scenario were similar in magnitude to the baseline analysis (Table 18). Both gross benefits and costs decreased compared to the baseline analysis, which was expected since the FSDF for Fargo/Moorhead was adjusted and the Waffle was scheduled to be used less frequently than in the baseline analysis. In this alternative, gross benefits decreased slightly more than costs in the minimum acreage scenarios, which resulted in lower net benefits compared to the baseline analysis (Table 18). However, in most of the moderate and maximum acreage scenarios, costs decreased slightly more than gross benefits resulting in higher net benefits compared to the baseline analysis. Overall, net benefits ranged from $674 million to $255 million, depending upon acreage, scale, and water storage assumptions (Table 18). While numerically some combinations of acreage, scale, and water storage capacities produced greater net returns under the assumptions used in this alternative when compared to the baseline analysis, the difference between net returns in the two analyses suggests that the economics of the Waffle are not overly sensitive to the inclusion or absence of high-frequency flood damages within the FSDF for Fargo/Moorhead.

Table 18. Gross Benefits, Costs, and Net Benefits of the Waffle, Modified Damages in Fargo/Moorhead and Drayton, Baseline Population, 2006 through 2055

	Full-scale Waffle		Half-scale Waffle	
Results	Moderate Water Storage	Conservative Water Storage	Moderate Water Storage	Conservative Water Storage
Alternative Analysis	-- 000s $	---------------------------------------		
Gross Benefits	821,223	585,910	731,318	533,564
Costs				
Minimum Acreage	147,154	147,154	77,441	77,441
Moderate Acreage	231,637	231,637	119,520	119,520
Maximum Acreage	330,666	330,666	169,190	169,190
Net Benefits				
Minimum Acreage	674,069	438,756	653,877	456,123
Moderate Acreage	589,586	354,273	611,798	414,044
Maximum Acreage	490,557	255,244	562,128	364,374
Baseline Analysis	------- results from baseline analysis provided for comparison-------			
Gross Benefits	914,790	668,226	811,629	605,554
Costs				
Minimum Acreage	207,931	207,931	107,964	107,964
Moderate Acreage	362,191	362,191	184,797	184,797
Maximum Acreage	543,040	543,040	275,505	275,505
Net Benefits				
Minimum Acreage	706,859	460,295	703,665	497,590
Moderate Acreage	552,599	306,035	626,832	420,757
Maximum Acreage	371,750	125,186	536,124	330,049

Notes: Only flood-events larger than 100-year frequency were modeled. Damages in the FSDF for Fargo/Moorhead and Drayton were set to zero for elevations at or below the 100-year flood event.

SUMMARY AND CONCLUSIONS

The Waffle appears to be cost-effective at mitigating economic damages associated with large flood events, given the current knowledge about its operational characteristics and physical effects on crest heights in the Basin. Due primarily to a lack of certainty or confidence on various economic aspects of the Waffle, a plausible range of costs was evaluated and combined with a range of mitigated flood benefits from four urban areas in the Basin. However, despite substantially large net benefits, variations in acreage and water storage assumptions produced rather large swings in the magnitude of those net benefits. The analysis was extremely conservative by only including a potential sub-set of the likely benefits of the Waffle. The inclusion of basin-wide environmental benefits and flood damage mitigation in small communities and rural areas would only increase the economic attractiveness of the Waffle.

Despite that the Waffle appears to be economical over a wide range of possibilities, a number of uncertainties warrant further investigation. The costs of implementing the Waffle are unknown. Landowner willingness to participate throughout the Basin is unknown. How would temporarily storing water affect farm program payments and insurable crop yields? Would landowners enroll sufficient land in the Waffle at the payment levels used in the analysis? Answers to these and other cost-related factors, in addition to other operational issues, are not yet available. As a result, a range of costs were used, but most of those expenses still represent best guesses at this point.

What is the economically optimal scale of the Waffle? Two-scale options, a full-scale and a half-scale Waffle, were used. The basis for the scale options was due to uncertainty on landowner participation. Within each scale, three acreage possibilities were considered. Again, three acreage options were required to cover the uncertainty pertaining to payment acreage associated with flooded acreage. The point is that data on two critical physical measures of the Waffle – payment acreage (minimum, moderate, and maximum acreage scenarios) and landowner enrollment (full- and half-scale scenarios) – remain estimates that have not been calibrated from township- or watershed-level ground observations. The implication is that the economics appeared to show diminishing net returns between the half- and full-scale Waffle. These results suggest further analysis should be conducted to determine the optimal scale of the Waffle; however, uncertainty on payment acreage and landowner enrollment makes estimating optimal Waffle size problematic.

The results of this study also generate questions on targeting land enrollment to protect selected areas and raise concerns over the geographic scope of Waffle implementation. For example, the economics of the Waffle were almost entirely determined by what happens in Fargo/Moorhead. In nearly all scenarios, the Waffle would be economical if only benefits from Fargo/Moohead were included. Without Fargo/Moorhead, the Waffle would not be economical except under a limited number of conditions, given the breadth of benefits in this study. For the remainder of the basin, could Waffle enrollment be targeted on a smaller scale to more closely match costs and benefits? A substantial amount of acreage in counties in the northern third of the Basin were included in the analysis. Should enrollment (and hence cost estimates) in those counties be more closely matched to localized benefits? What level of economic criteria should be used to justify enrollment in the Waffle? Clearly, acreage next to the Canadian border is likely to produce few benefits in the U.S. portion of the Basin. It is possible that targeting enrollment in the southern Red River Valley would provide most of the Waffle benefits at a fraction of the cost of even the half-scale scenario.

This first assessment of the Waffle limited benefits to mitigated flood damages from four urban areas. A number of other mitigated flood damages could also be evaluated. The Waffle's effect on mitigating flood damage to rural infrastructure, farmsteads, smaller communities, and commerce is largely unknown. Would the Waffle's effects on lower crest heights also reduce damages to those rural properties? What mitigation of damages from overland flooding could the Waffle generate? How much mitigated flood damage would be generated in the Canadian side of the Red River Basin?

No attempt was made to model environmental benefits associated with the Waffle. It is a foregone conclusion that including environmental benefits at this point would add to the economic attractiveness of the Waffle. However, would the location or generation of environmental benefits be sufficient to change the scale or influence the targeting of land enrollment in the Waffle? Would some environmental benefits accrue to land enrolled in the Waffle? If so, those benefits need to be documented and quantified to be of value to landowners when making decisions on enrollment. If the Waffle reduces the flow of sediment, fertilizers, and other pollutants into Lake Winnipeg, what implications would that have on financial support for the Waffle from Canadian authorities? A host of operational and economic issues remain unanswered on the environmental aspects of the Waffle.

Flood risk imposes real costs on property owners. Some of these costs are cash, such as added insurance premiums; other costs are non-cash, such as depressed property values. If flood risks decrease, both cash and non-cash costs are reduced. However, this study did not consider the benefits associated with these mitigated costs. It is also reasonable to expect that reduced flood risk, in some locations, will spur economic development. In areas that have received flood protection measures, anecdotal evidence suggests that residential and commercial development has followed as a result of that flood protection. Economic theory supports this argument. If the costs of developing and owning real property decrease, the value of development increases. So, more development results from increased flood protection. Again, this study's assessment does not account for these potential economic benefits.

The issue of who pays for flood protection generated by the Waffle merits consideration. Currently, the costs for structural flood protection are paid for with a mix of federal, state, and local funding with the U.S. Army Corps of Engineers having responsibility for designing, constructing, and monitoring flood mitigation structures. Which federal program(s) would contribute financially to a non-structural flood protection project such as the Waffle? Would new federal legislation be required to obtain federal funds? How would federal use of National Economic Development (NED) planning criteria change the level of net economic benefits? It would seem that a potential obstacle to implementing the Waffle basin wide could be financial feasibility. Regardless of the level of net benefits, the costs of operating the Waffle basin wide would require, at a minimum, several hundred million dollars over the next half century. While the benefits would be represented by mitigated flood damages and non-market environmental benefits, operating the Waffle would require real funds and/or dedicated financial support. Evaluation of economic feasibility is one issue; however, it is another separate issue to obtain the funds to operate the Waffle on a basin wide scale.

Despite an extremely conservative approach to estimating the net benefits of the Waffle, the Waffle appears to be capable of generating around \$200 million to \$600 million in net benefits over a 50-year period. While these initial results are substantial, policymakers are still likely to be concerned about the number of issues, questions, and obstacles that remain unanswered. The positive results from this study suggest that dedicating additional resources to solving many of the remaining issues with the Waffle would be justified. Perhaps additional resources could be used to implement a pilot version of the Waffle, albeit at a watershed or township level, to more fully understand the operational characteristics of the Waffle. Information from a pilot study would provide most of the necessary information to refine economic analyses, and provide the groundwork for more widespread implementation.

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APPENDIX A

Estimated Payment Acreage and Sections of Land, by Land Type, Relief Category, County, State, and Waffle Scale

Appendix Table A1. Estimated Payment Acreage for Full-scale and Half-scale Waffle, by Land Type, Relief Contour, County, and State

		Relief	Half-scale Waffle			Full-scale Waffle		
State/County	Land Type	Contour	Minimum	Moderate	Maximum	Minimum	Moderate	Maximum
North Dakota								
Barnes	Cropland	0 - 2	0	0	0	0	0	0
		2 - 4	117	352	587	294	881	1,468
		4 - 10	3,112	6,224	7,780	6,224	12,449	15,561
	Pasture	0 - 2	0	0	0	0	0	0
		2 - 4	11	32	53	26	79	132
		4 - 10	280	560	700	560	1,119	1,399
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	64	128	160	64	128	160
Benson	Cropland	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	373	746	933	693	1,386	1,732
	Pasture	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	75	150	187	139	278	348
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	0	0	0	0	0	0
Cass	Cropland	0 - 2	5,484	8,774	16,451	11,281	18,049	33,842
		2 - 4	3,760	11,281	18,801	8,586	25,758	42,929
		4 - 10	6,518	13,036	16,294	13,161	26,322	32,902
	Pasture	0 - 2	116	186	349	239	383	718
		2 - 4	80	239	399	182	546	911
		4 - 10	138	276	346	279	558	698
	Other Land	0 - 2	160	256	480	320	512	960
		2 - 4	64	192	320	64	192	320
		4 - 10	0	0	0	0	0	0
Cavalier	Cropland	0 - 2	0	0	0	157	252	472
		2 - 4	1,195	3,586	5,976	2,013	6,039	10,065
		4 - 10	4,970	9,939	12,424	9,751	19,501	24,377
	Pasture	0 - 2	0	0	0	3	4	8
		2 - 4	85	254	424	163	489	815
		4 - 10	86	173	216	169	339	423
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	64	192	320	64	192	320
		4 - 10	128	256	320	320	640	800
Eddy	Cropland	0 - 2	0	0	0	0	0	0
		2 - 4	200	600	1,000	350	1,050	1,751
		4 - 10	0	0	0	0	0	0
	Pasture	0 - 2	0	0	0	0	0	0
		2 - 4	56	168	280	98	294	489
		4 - 10	0	0	0	0	0	0

Appendix Table A1. Continued

State/County	Land Type	Relief Contour	Half-scale Waffle Minimum	Half-scale Waffle Moderate	Half-scale Waffle Maximum	Full-scale Waffle Minimum	Full-scale Waffle Moderate	Full-scale Waffle Maximum
North Dakota								
Eddy-cont.	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	0	0	0	0	0	0
Foster	Cropland	0 - 2	0	0	0	0	0	0
		2 - 4	55	166	277	111	332	554
		4 - 10	0	0	0	0	0	0
	Pasture	0 - 2	0	0	0	0	0	0
		2 - 4	9	26	43	81	244	406
		4 - 10	0	0	0	0	0	0
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	0	0	0	0	0	0
Grand Forks	Cropland	0 - 2	4,823	7,717	14,470	8,402	13,443	25,205
		2 - 4	2,801	8,402	14,003	5,601	16,804	28,006
		4 - 10	2,738	5,477	6,846	5,663	11,327	14,159
	Pasture	0 - 2	137	219	410	238	381	715
		2 - 4	143	430	717	223	668	1,114
		4 - 10	270	539	674	417	833	1,041
	Other Land	0 - 2	160	256	480	160	256	480
		2 - 4	0	0	0	64	192	320
		4 - 10	0	0	0	128	256	320
Griggs	Cropland	0 - 2	0	0	0	0	0	0
		2 - 4	392	1,177	1,962	897	2,691	4,485
		4 - 10	0	0	0	0	0	0
	Pasture	0 - 2	0	0	0	0	0	0
		2 - 4	56	167	278	127	381	635
		4 - 10	0	0	0	0	0	0
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	0	0	0	0	0	0
McHenry	Cropland	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	173	346	433	346	693	866
	Pasture	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	275	550	687	358	715	894
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	64	128	160	128	256	320
Nelson	Cropland	0 - 2	0	0	0	0	0	0
		2 - 4	58	173	289	173	519	866
		4 - 10	808	1,616	2,020	1,789	3,578	4,472
	Pasture	0 - 2	0	0	0	0	0	0

Appendix Table A1. Continued

State/County	Land Type	Relief Contour	Half-scale Waffle Minimum	Half-scale Waffle Moderate	Half-scale Waffle Maximum	Full-scale Waffle Minimum	Full-scale Waffle Moderate	Full-scale Waffle Maximum
North Dakota								
Nelson-cont.	Pasture	2 - 4	6	19	31	19	57	94
		4 - 10	88	176	220	195	390	488
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	64	128	160	128	256	320
Pembina	Cropland	0 - 2	3,765	6,025	11,296	7,688	12,300	23,063
		2 - 4	3,891	11,673	19,455	7,719	23,157	38,596
		4 - 10	1,883	3,765	4,707	3,640	7,280	9,100
	Pasture	0 - 2	235	375	704	312	500	937
		2 - 4	141	423	705	345	1,035	1,724
		4 - 10	37	75	93	72	144	180
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	0	0	0	0	0	0
Pierce	Cropland	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	582	1,164	1,455	1,217	2,434	3,043
	Pasture	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	122	244	305	383	766	957
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	0	0	0	0	0	0
Ransom	Cropland	0 - 2	0	0	0	122	195	367
		2 - 4	0	0	0	0	0	0
		4 - 10	1,515	3,030	3,787	3,079	6,158	7,697
	Pasture	0 - 2	0	0	0	38	61	113
		2 - 4	0	0	0	0	0	0
		4 - 10	981	1,962	2,453	1,657	3,314	4,143
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	0	0	0	0	0	0
Richland	Cropland	0 - 2	6,390	10,224	19,170	13,997	22,395	41,991
		2 - 4	3,104	9,311	15,518	6,025	18,074	30,124
		4 - 10	3,043	6,086	7,607	6,572	13,145	16,431
	Pasture	0 - 2	330	528	990	723	1,157	2,169
		2 - 4	224	673	1,122	375	1,126	1,876
		4 - 10	349	698	873	852	1,703	2,129
	Other Land	0 - 2	0	0	0	480	768	1,440
		2 - 4	64	192	320	256	768	1,280
		4 - 10	256	512	640	320	640	800
Rolette	Cropland	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0

Appendix Table A1. Continued

State/County	Land Type	Relief Contour	Half-scale Waffle Minimum	Half-scale Waffle Moderate	Half-scale Waffle Maximum	Full-scale Waffle Minimum	Full-scale Waffle Moderate	Full-scale Waffle Maximum
North Dakota								
Rolette-cont.	Cropland	4 - 10	54	108	135	108	216	270
	Pasture	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	10	20	25	20	40	50
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	0	0	0	0	0	0
Sargent	Cropland	0 - 2	0	0	0	145	232	435
		2 - 4	522	1,567	2,612	1,451	4,353	7,254
		4 - 10	3,598	7,196	8,996	7,022	14,045	17,556
	Pasture	0 - 2	0	0	0	15	24	45
		2 - 4	54	161	268	149	447	746
		4 - 10	370	740	924	722	1,443	1,804
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	128	384	640	128	384	640
		4 - 10	128	256	320	192	384	480
Sheridan	Cropland	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	432	864	1,080	816	1,633	2,041
	Pasture	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	208	416	520	336	671	839
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	64	128	160	64	128	160
Steele	Cropland	0 - 2	0	0	0	153	244	458
		2 - 4	489	1,466	2,444	855	2,566	4,277
		4 - 10	1,466	2,933	3,666	2,872	5,744	7,180
	Pasture	0 - 2	0	0	0	7	12	22
		2 - 4	23	70	116	41	122	203
		4 - 10	70	139	174	136	272	340
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	128	256	320	128	256	320
Towner	Cropland	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	61	184	307
		4 - 10	491	982	1,228	921	1,842	2,302
	Pasture	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	3	8	13
		4 - 10	85	170	212	103	206	258
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	0	0	0	64	128	160

Appendix Table A1. Continued

State/County	Land Type	Relief Contour	Half-scale Waffle Minimum	Half-scale Waffle Moderate	Half-scale Waffle Maximum	Full-scale Waffle Minimum	Full-scale Waffle Moderate	Full-scale Waffle Maximum
North Dakota								
Traill	Cropland	0 - 2	5,864	9,382	17,591	10,776	17,242	32,329
		2 - 4	3,486	10,459	17,432	6,402	19,207	32,012
		4 - 10	2,789	5,578	6,973	5,452	10,903	13,629
	Pasture	0 - 2	56	90	169	104	166	311
		2 - 4	34	101	168	62	185	308
		4 - 10	27	54	67	52	105	131
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	128	384	640	128	384	640
		4 - 10	64	128	160	64	128	160
Walsh	Cropland	0 - 2	3,015	4,823	9,044	5,879	9,406	17,636
		2 - 4	2,050	6,150	10,250	3,738	11,214	18,691
		4 - 10	1,507	3,015	3,768	3,135	6,270	7,838
	Pasture	0 - 2	185	297	556	361	578	1,084
		2 - 4	126	378	630	230	690	1,149
		4 - 10	93	185	232	193	386	482
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	64	192	320
		4 - 10	128	256	320	192	384	480
Wells	Cropland	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	968	1,936	2,420	1,765	3,530	4,412
	Pasture	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	248	496	620	411	822	1,028
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	0	0	0	0	0	0
Minnesota								
Becker	Cropland	0 - 2	0	0	0	0	0	0
		2 - 4	240	720	1,200	300	900	1,500
		4 - 10	780	1,560	1,950	1,680	3,360	4,201
	Pasture	0 - 2	0	0	0	0	0	0
		2 - 4	16	48	80	20	60	100
		4 - 10	52	104	130	112	224	279
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	64	128	160	64	128	160
Beltrami	Cropland	0 - 2	0	0	0	129	207	388
		2 - 4	104	311	518	207	622	1,036
		4 - 10	0	0	0	0	0	0
	Pasture	0 - 2	0	0	0	31	49	92
		2 - 4	24	73	122	49	146	244
		4 - 10	0	0	0	0	0	0

Appendix Table A1. Continued

State/County	Land Type	Relief Contour	Half-scale Waffle Minimum	Half-scale Waffle Moderate	Half-scale Waffle Maximum	Full-scale Waffle Minimum	Full-scale Waffle Moderate	Full-scale Waffle Maximum
North Dakota								
Beltrami	Other Land	0 - 2	640	1,024	1,920	1,440	2,304	4,320
		2 - 4	832	2,496	4,160	1,536	4,608	7,680
		4 - 10	0	0	0	0	0	0
Big Stone	Cropland	0 - 2	0	0	0	0	0	0
		2 - 4	62	185	309	62	185	309
		4 - 10	0	0	0	0	0	0
	Pasture	0 - 2	0	0	0	0	0	0
		2 - 4	2	7	11	2	7	11
		4 - 10	0	0	0	0	0	0
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	0	0	0	0	0	0
Clay	Cropland	0 - 2	4,924	7,878	14,772	10,002	16,003	30,006
		2 - 4	2,647	7,940	13,233	5,478	16,434	27,390
		4 - 10	677	1,354	1,693	1,600	3,201	4,001
	Pasture	0 - 2	196	314	588	398	637	1,194
		2 - 4	105	316	527	218	654	1,090
		4 - 10	27	54	67	64	127	159
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	64	192	320	128	384	640
		4 - 10	0	0	0	0	0	0
Clearwater	Cropland	0 - 2	257	411	770	513	821	1,540
		2 - 4	257	770	1,283	565	1,694	2,823
		4 - 10	0	0	0	0	0	0
	Pasture	0 - 2	63	101	190	127	203	380
		2 - 4	63	190	317	139	418	697
		4 - 10	0	0	0	0	0	0
	Other Land	0 - 2	1,760	2,816	5,280	3,040	4,864	9,120
		2 - 4	1,024	3,072	5,120	2,240	6,720	11,200
		4 - 10	0	0	0	128	256	320
Grant	Cropland	0 - 2	314	502	941	1,097	1,756	3,292
		2 - 4	1,693	5,080	8,466	2,508	7,525	12,542
		4 - 10	376	753	941	815	1,631	2,038
	Pasture	0 - 2	6	10	19	23	36	68
		2 - 4	35	104	174	52	155	258
		4 - 10	8	15	19	17	33	42
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	64	192	320	64	192	320
		4 - 10	0	0	0	64	128	160
Kittson	Cropland	0 - 2	3,359	5,375	10,078	6,414	10,262	19,241
		2 - 4	2,199	6,597	10,995	5,253	15,759	26,265
		4 - 10	1,405	2,810	3,512	2,871	5,742	7,177
	Pasture	0 - 2	161	257	482	306	490	919

Appendix Table A1. Continued

State/County	Land Type	Relief Contour	Half-scale Waffle Minimum	Half-scale Waffle Moderate	Half-scale Waffle Maximum	Full-scale Waffle Minimum	Full-scale Waffle Moderate	Full-scale Waffle Maximum
North Dakota								
Kittson-cont	Pasture	2 - 4	105	315	525	251	753	1,255
		4 - 10	67	134	168	137	274	343
	Other Land	0 - 2	2,880	4,608	8,640	6,400	10,240	19,200
		2 - 4	1,728	5,184	8,640	3,200	9,600	16,000
		4 - 10	320	640	800	576	1,152	1,440
Lake of the Woods	Cropland	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	0	0	0	0	0	0
	Pasture	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	0	0	0	0	0	0
	Other Land	0 - 2	0	0	0	160	256	480
		2 - 4	64	192	320	64	192	320
		4 - 10	0	0	0	0	0	0
Mahnomen	Cropland	0 - 2	0	0	0	0	0	0
		2 - 4	305	915	1,524	549	1,646	2,744
		4 - 10	1,280	2,561	3,201	2,256	4,512	5,640
	Pasture	0 - 2	0	0	0	0	0	0
		2 - 4	15	45	76	27	82	136
		4 - 10	64	127	159	112	224	280
	Other Land	0 - 2	160	256	480	160	256	480
		2 - 4	128	384	640	256	768	1,280
		4 - 10	192	384	480	448	896	1,120
Marshall	Cropland	0 - 2	5,607	8,971	16,820	9,967	15,948	29,902
		2 - 4	4,797	14,390	23,984	9,843	29,528	49,214
		4 - 10	1,059	2,118	2,648	1,931	3,862	4,828
	Pasture	0 - 2	153	245	460	273	436	818
		2 - 4	131	394	656	269	808	1,346
		4 - 10	29	58	72	53	106	132
	Other Land	0 - 2	1,280	2,048	3,840	3,040	4,864	9,120
		2 - 4	1,152	3,456	5,760	2,304	6,912	11,520
		4 - 10	256	512	640	576	1,152	1,440
Norman	Cropland	0 - 2	3,942	6,307	11,825	8,514	13,623	25,543
		2 - 4	1,955	5,865	9,776	4,162	12,487	20,812
		4 - 10	2,270	4,541	5,676	4,667	9,334	11,668
	Pasture	0 - 2	58	93	175	126	201	377
		2 - 4	29	87	144	62	185	308
		4 - 10	34	67	84	69	138	172
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	192	384	480	192	384	480
Otter Tail	Cropland	0 - 2	0	0	0	0	0	0

Appendix Table A1. Continued

State/County	Land Type	Relief Contour	Half-scale Waffle Minimum	Half-scale Waffle Moderate	Half-scale Waffle Maximum	Full-scale Waffle Minimum	Full-scale Waffle Moderate	Full-scale Waffle Maximum
North Dakota								
Otter Tail	Cropland	2 - 4	0	0	0	59	178	296
		4 - 10	119	237	296	237	474	593
	Pasture	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	5	14	24
		4 - 10	9	19	24	19	38	47
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	0	0	0	0	0	0
Pennington	Cropland	0 - 2	2,754	4,406	8,262	5,508	8,813	16,523
		2 - 4	2,632	7,895	13,158	5,263	15,789	26,315
		4 - 10	122	245	306	184	367	459
	Pasture	0 - 2	126	202	378	252	403	757
		2 - 4	120	361	602	241	723	1,205
		4 - 10	6	11	14	8	17	21
	Other Land	0 - 2	320	512	960	800	1,280	2,400
		2 - 4	192	576	960	384	1,152	1,920
		4 - 10	0	0	0	0	0	0
Polk	Cropland	0 - 2	9,367	14,988	28,102	16,861	26,978	50,583
		2 - 4	4,808	14,425	24,042	9,742	29,226	48,709
		4 - 10	2,061	4,122	5,152	3,997	7,993	9,992
	Pasture	0 - 2	233	372	698	419	670	1,257
		2 - 4	120	359	598	242	726	1,211
		4 - 10	51	102	128	99	199	248
	Other Land	0 - 2	320	512	960	480	768	1,440
		2 - 4	320	960	1,600	512	1,536	2,560
		4 - 10	192	384	480	192	384	480
Red Lake	Cropland	0 - 2	1,081	1,730	3,244	1,854	2,966	5,561
		2 - 4	1,112	3,337	5,561	2,286	6,859	11,431
		4 - 10	0	0	0	0	0	0
	Pasture	0 - 2	39	62	116	66	106	199
		2 - 4	40	119	199	82	245	409
		4 - 10	0	0	0	0	0	0
	Other Land	0 - 2	160	256	480	960	1,536	2,880
		2 - 4	128	384	640	320	960	1,600
		4 - 10	0	0	0	0	0	0
Roseau	Cropland	0 - 2	1,722	2,755	5,166	3,757	6,011	11,271
		2 - 4	1,252	3,757	6,262	2,818	8,453	14,089
		4 - 10	0	0	0	0	0	0
	Pasture	0 - 2	38	61	114	83	133	249
		2 - 4	28	83	138	62	187	311
		4 - 10	0	0	0	0	0	0
	Other Land	0 - 2	1,440	2,304	4,320	2,240	3,584	6,720
		2 - 4	768	2,304	3,840	1,472	4,416	7360

Appendix Table A1. Continued

State/County	Land Type	Relief Contour	Half-scale Waffle Minimum	Half-scale Waffle Moderate	Half-scale Waffle Maximum	Full-scale Waffle Minimum	Full-scale Waffle Moderate	Full-scale Waffle Maximum
North Dakota								
Roseau-cont.	Other Land	4 - 10	0	0	0	64	128	160
Stevens	Cropland	0 - 2	310	496	930	620	992	1,859
		2 - 4	310	930	1,550	1,240	3,719	6,198
		4 - 10	0	0	0	0	0	0
	Pasture	0 - 2	10	16	30	20	32	61
		2 - 4	10	30	50	40	121	202
		4 - 10	0	0	0	0	0	0
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	0	0	0	0	0	0
Traverse	Cropland	0 - 2	4,995	7,991	14,984	8,272	13,236	24,817
		2 - 4	3,122	9,365	15,608	6,181	18,542	30,904
		4 - 10	562	1,124	1,405	1,186	2,372	2,966
	Pasture	0 - 2	125	201	376	208	332	623
		2 - 4	142	427	712	219	658	1,096
		4 - 10	14	28	35	30	60	74
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	0	0	0	64	128	160
Wilkin	Cropland	0 - 2	4,554	7,286	13,662	8,323	13,316	24,968
		2 - 4	3,957	11,871	19,786	8,919	26,758	44,597
		4 - 10	1,005	2,010	2,512	2,198	4,397	5,496
	Pasture	0 - 2	86	138	258	157	252	472
		2 - 4	75	225	374	169	506	843
		4 - 10	19	38	48	42	83	104
	Other Land	0 - 2	160	256	480	160	256	480
		2 - 4	0	0	0	0	0	0
		4 - 10	0	0	0	0	0	0
South Dakota								
Marshall	Cropland	0 - 2	0	0	0	0	0	0
		2 - 4	45	136	227	45	136	227
		4 - 10	91	181	227	136	272	340
	Pasture	0 - 2	0	0	0	0	0	0
		2 - 4	19	56	93	19	56	93
		4 - 10	37	75	93	56	112	140
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	0	0	0
		4 - 10	0	0	0	0	0	0
Roberts	Cropland	0 - 2	0	0	0	0	0	0
		2 - 4	105	314	523	157	471	785
		4 - 10	1,151	2,302	2,877	2,197	4,394	5,493
	Pasture	0 - 2	0	0	0	0	0	0
		2 - 4	23	70	117	35	105	175

Appendix Table A1. Continued

		Relief	Half-scale Waffle			Full-scale Waffle		
State/County	Land Type	Contour	Minimum	Moderate	Maximum	Minimum	Moderate	Maximum
North Dakota								
Roberts-cont	Pasture	4 - 10	257	514	643	491	982	1,227
	Other Land	0 - 2	0	0	0	0	0	0
		2 - 4	0	0	0	64	192	320
		4 - 10	0	0	0	256	512	640

Source: Kurz et al. (2007).

Appendix Table A2. Estimated Number of Sections of Land for Full-scale and Half-scale Waffle, by Land Type, Relief Contour, County, and State

State/County	Land Type	Relief Contour	Waffle Size	
			Half-scale	Full-scale
North Dakota				
Barnes	Cropland	0 - 2	0	0
		2 - 4	2	4
		4 - 10	47	94
	Pasture	0 - 2	0	0
		2 - 4	0	1
		4 - 10	6	12
	Other Land	0 - 2	0	0
		2 - 4	0	0
		4 - 10	1	1
Benson	Cropland	0 - 2	0	0
		2 - 4	0	0
		4 - 10	5	10
	Pasture	0 - 2	0	0
		2 - 4	0	0
		4 - 10	2	3
	Other Land	0 - 2	0	0
		2 - 4	0	0
		4 - 10	1	1
Cass	Cropland	0 - 2	34	70
		2 - 4	59	134
		4 - 10	102	205
	Pasture	0 - 2	1	2
		2 - 4	1	3
		4 - 10	2	5
	Other Land	0 - 2	1	2
		2 - 4	1	1
		4 - 10	0	0
Cavalier	Cropland	0 - 2	0	1
		2 - 4	19	31
		4 - 10	77	152
	Pasture	0 - 2	0	0
		2 - 4	1	3
		4 - 10	2	3
	Other Land	0 - 2	0	0
		2 - 4	1	1
		4 - 10	2	5
Eddy	Cropland	0 - 2	0	0

Appendix Table A2. Continued

State/County	Land Type	Relief Contour	Waffle Size Half-scale	Full-scale
Eddy-cont.	Cropland	2 - 4	2	4
		4 - 10	0	0
	Pasture	0 - 2	0	0
		2 - 4	2	3
		4 - 10	0	0
	Other Land	0 - 2	0	0
		2 - 4	0	0
		4 - 10	0	0
Foster	Cropland	0 - 2	0	0
		2 - 4	1	2
		4 - 10	0	0
	Pasture	0 - 2	0	0
		2 - 4	0	1
		4 - 10	0	0
	Other Land	0 - 2	0	0
		2 - 4	0	0
		4 - 10	0	0
Grand Forks	Cropland	0 - 2	30	52
		2 - 4	43	87
		4 - 10	42	88
	Pasture	0 - 2	1	2
		2 - 4	3	4
		4 - 10	5	7
	Other Land	0 - 2	1	1
		2 - 4	0	1
		4 - 10	0	2
Griggs	Cropland	0 - 2	0	0
		2 - 4	5	12
		4 - 10	0	0
	Pasture	0 - 2	0	0
		2 - 4	2	4
		4 - 10	0	0
	Other Land	0 - 2	0	0
		2 - 4	0	0
		4 - 10	0	0
McHenry	Cropland	0 - 2	0	0
		2 - 4	0	0
		4 - 10	1	3
	Pasture	0 - 2	0	0
		2 - 4	0	0

Appendix Table A2. Continued

State/County	Land Type	Relief Contour	Waffle Size Half-scale	Full-scale
McHenry-cont.	Pasture	4 - 10	6	8
	Other Land	0 - 2	0	0
		2 - 4	0	0
		4 - 10	1	2
Nelson	Cropland	0 - 2	0	0
		2 - 4	1	2
		4 - 10	11	25
	Pasture	0 - 2	0	0
		2 - 4	0	1
		4 - 10	3	6
	Other Land	0 - 2	0	0
		2 - 4	0	0
		4 - 10	1	2
Pembina	Cropland	0 - 2	23	48
		2 - 4	61	120
		4 - 10	29	57
	Pasture	0 - 2	2	2
		2 - 4	2	6
		4 - 10	1	1
	Other Land	0 - 2	0	0
		2 - 4	0	0
		4 - 10	0	0
Pierce	Cropland	0 - 2	0	0
		2 - 4	0	0
		4 - 10	8	16
	Pasture	0 - 2	0	0
		2 - 4	0	0
		4 - 10	3	9
	Other Land	0 - 2	0	0
		2 - 4	0	0
		4 - 10	0	0
Ransom	Cropland	0 - 2	0	1
		2 - 4	0	0
		4 - 10	17	35
	Pasture	0 - 2	0	0
		2 - 4	0	0
		4 - 10	22	39
	Other Land	0 - 2	0	0
		2 - 4	0	0
		4 - 10	0	0

Appendix Table A2. Continued

State/County	Land Type	Relief Contour	Waffle Size Half-scale	Full-scale
Richland	Cropland	0 - 2	40	87
		2 - 4	48	94
		4 - 10	47	102
	Pasture	0 - 2	2	5
		2 - 4	4	6
		4 - 10	6	14
	Other Land	0 - 2	0	3
		2 - 4	1	4
		4 - 10	4	5
Rolette	Cropland	0 - 2	0	0
		2 - 4	0	0
		4 - 10	1	1
	Pasture	0 - 2	0	0
		2 - 4	0	0
		4 - 10	0	1
	Other Land	0 - 2	0	0
		2 - 4	0	0
		4 - 10	0	0
Sargent	Cropland	0 - 2	0	1
		2 - 4	8	22
		4 - 10	54	106
	Pasture	0 - 2	0	0
		2 - 4	1	3
		4 - 10	8	15
	Other Land	0 - 2	0	0
		2 - 4	2	2
		4 - 10	2	3
Sheridan	Cropland	0 - 2	0	0
		2 - 4	0	0
		4 - 10	5	9
	Pasture	0 - 2	0	0
		2 - 4	0	0
		4 - 10	5	9
	Other Land	0 - 2	0	0
		2 - 4	0	0
		4 - 10	1	1
Steele	Cropland	0 - 2	0	1
		2 - 4	8	13
		4 - 10	23	44
	Pasture	0 - 2	0	0

Appendix Table A2. Continued

State/County	Land Type	Relief Contour	Waffle Size Half-scale	Full-scale
Steele-cont.	Pasture	2 - 4	0	1
		4 - 10	1	3
	Other Land	0 - 2	0	0
		2 - 4	0	0
		4 - 10	2	2
Towner	Cropland	0 - 2	0	0
		2 - 4	0	1
		4 - 10	8	14
	Pasture	0 - 2	0	0
		2 - 4	0	0
		4 - 10	1	2
	Other Land	0 - 2	0	0
		2 - 4	0	0
		4 - 10	0	1
Traill	Cropland	0 - 2	37	67
		2 - 4	54	100
		4 - 10	44	85
	Pasture	0 - 2	0	1
		2 - 4	1	1
		4 - 10	0	1
	Other Land	0 - 2	0	0
		2 - 4	2	2
		4 - 10	1	1
Walsh	Cropland	0 - 2	18	36
		2 - 4	31	57
		4 - 10	23	48
	Pasture	0 - 2	2	3
		2 - 4	3	5
		4 - 10	2	4
	Other Land	0 - 2	0	0
		2 - 4	0	1
		4 - 10	2	3
Wells	Cropland	0 - 2	0	0
		2 - 4	0	0
		4 - 10	14	26
	Pasture	0 - 2	0	0
		2 - 4	0	0
		4 - 10	5	8
	Other Land	0 - 2	0	0
		2 - 4	0	0

Appendix Table A2. Continued

State/County	Land Type	Relief Contour	Waffle Size Half-scale	Full-scale
Wells-cont.	Other Land	4 - 10	0	0
Minnesota				
Becker	Cropland	0 - 2	0	0
		2 - 4	4	5
		4 - 10	12	26
	Pasture	0 - 2	0	0
		2 - 4	0	0
		4 - 10	1	2
	Other Land	0 - 2	0	0
		2 - 4	0	0
		4 - 10	1	1
Beltrami	Cropland	0 - 2	0	1
		2 - 4	1	3
		4 - 10	0	0
	Pasture	0 - 2	0	0
		2 - 4	1	1
		4 - 10	0	0
	Other Land	0 - 2	4	9
		2 - 4	13	24
		4 - 10	0	0
Big Stone	Cropland	0 - 2	0	0
		2 - 4	1	1
		4 - 10	0	0
	Pasture	0 - 2	0	0
		2 - 4	0	0
		4 - 10	0	0
	Other Land	0 - 2	0	0
		2 - 4	0	0
		4 - 10	0	0
Clay	Cropland	0 - 2	31	62
		2 - 4	41	85
		4 - 10	11	25
	Pasture	0 - 2	1	3
		2 - 4	2	4
		4 - 10	0	1
	Other Land	0 - 2	0	0
		2 - 4	1	2
		4 - 10	0	0
Clearwater	Cropland	0 - 2	1	3
		2 - 4	3	7

Appendix Table A2. Continued

State/County	Land Type	Relief Contour	Waffle Size Half-scale	Full-scale
Clearwater	Cropland	4 - 10	0	0
	Pasture	0 - 2	1	1
		2 - 4	2	4
		4 - 10	0	0
	Other Land	0 - 2	11	19
		2 - 4	16	35
		4 - 10	0	2
Grant	Cropland	0 - 2	2	7
		2 - 4	26	39
		4 - 10	6	13
	Pasture	0 - 2	0	0
		2 - 4	1	1
		4 - 10	0	0
	Other Land	0 - 2	0	0
		2 - 4	1	1
		4 - 10	0	1
Kittson	Cropland	0 - 2	20	39
		2 - 4	33	80
		4 - 10	21	43
	Pasture	0 - 2	2	3
		2 - 4	3	6
		4 - 10	2	4
	Other Land	0 - 2	18	40
		2 - 4	27	50
		4 - 10	5	9
Lake of the Woods	Cropland	0 - 2	0	0
		2 - 4	0	0
		4 - 10	0	0
	Pasture	0 - 2	0	0
		2 - 4	0	0
		4 - 10	0	0
	Other Land	0 - 2	0	1
		2 - 4	1	1
		4 - 10	0	0
Mahnomen	Cropland	0 - 2	0	0
		2 - 4	5	8
		4 - 10	20	35
	Pasture	0 - 2	0	0
		2 - 4	0	1

Appendix Table A2. Continued

State/County	Land Type	Relief Contour	Waffle Size Half-scale	Full-scale
Mahnomen	Pasture	4 - 10	1	2
	Other Land	0 - 2	1	1
		2 - 4	2	4
		4 - 10	3	7
Marshall	Cropland	0 - 2	34	61
		2 - 4	74	151
		4 - 10	16	30
	Pasture	0 - 2	2	3
		2 - 4	3	7
		4 - 10	1	1
	Other Land	0 - 2	8	19
		2 - 4	18	36
		4 - 10	4	9
Norman	Cropland	0 - 2	25	53
		2 - 4	30	65
		4 - 10	35	73
	Pasture	0 - 2	0	1
		2 - 4	1	1
		4 - 10	1	1
	Other Land	0 - 2	0	0
		2 - 4	0	0
		4 - 10	3	3
Otter Tail	Cropland	0 - 2	0	0
		2 - 4	0	1
		4 - 10	2	4
	Pasture	0 - 2	0	0
		2 - 4	0	0
		4 - 10	0	0
	Other Land	0 - 2	0	0
		2 - 4	0	0
		4 - 10	0	0
Pennington	Cropland	0 - 2	17	33
		2 - 4	40	79
		4 - 10	2	3
	Pasture	0 - 2	1	3
		2 - 4	3	7
		4 - 10	0	0
	Other Land	0 - 2	2	5
		2 - 4	3	6
		4 - 10	0	0

Appendix Table A2. Continued

State/County	Land Type	Relief Contour	Waffle Size Half-scale	Full-scale
Polk	Cropland	0 - 2	58	104
		2 - 4	74	151
		4 - 10	32	62
	Pasture	0 - 2	2	4
		2 - 4	3	5
		4 - 10	1	2
	Other Land	0 - 2	2	3
		2 - 4	5	8
		4 - 10	3	3
Red Lake	Cropland	0 - 2	7	11
		2 - 4	17	35
		4 - 10	0	0
	Pasture	0 - 2	0	1
		2 - 4	1	2
		4 - 10	0	0
	Other Land	0 - 2	1	6
		2 - 4	2	5
		4 - 10	0	0
Roseau	Cropland	0 - 2	11	23
		2 - 4	19	43
		4 - 10	0	0
	Pasture	0 - 2	0	1
		2 - 4	1	2
		4 - 10	0	0
	Other Land	0 - 2	9	14
		2 - 4	12	23
		4 - 10	0	1
Stevens	Cropland	0 - 2	2	4
		2 - 4	5	19
		4 - 10	0	0
	Pasture	0 - 2	0	0
		2 - 4	0	1
		4 - 10	0	0
	Other Land	0 - 2	0	0
		2 - 4	0	0
		4 - 10	0	0
Traverse	Cropland	0 - 2	31	52
		2 - 4	49	96
		4 - 10	9	18
	Pasture	0 - 2	1	1

Appendix Table A2. Continued

State/County	Land Type	Relief Contour	Waffle Size Half-scale	Full-scale
Traverse	Pasture	2 - 4	2	4
		4 - 10	0	1
	Other Land	0 - 2	0	0
		2 - 4	0	0
		4 - 10	0	1
Wilkin	Cropland	0 - 2	28	52
		2 - 4	62	139
		4 - 10	16	34
	Pasture	0 - 2	1	1
		2 - 4	1	3
		4 - 10	0	1
	Other Land	0 - 2	1	1
		2 - 4	0	0
		4 - 10	0	0
South Dakota				
Marshall	Cropland	0 - 2	0	0
		2 - 4	0	0
		4 - 10	1	1
	Pasture	0 - 2	0	0
		2 - 4	1	1
		4 - 10	1	2
	Other Land	0 - 2	0	0
		2 - 4	0	0
		4 - 10	0	0
Roberts	Cropland	0 - 2	0	0
		2 - 4	1	2
		4 - 10	16	31
	Pasture	0 - 2	0	0
		2 - 4	1	1
		4 - 10	6	11
	Other Land	0 - 2	0	0
		2 - 4	0	1
		4 - 10	0	4

Source: Kurz et al. (2007).

APPENDIX B

Estimation of Structural and Installation Costs for Culvert Control Devices, Selected Watersheds, Red River Basin, 2005

The following text explains how the structural and installation costs for culvert control devices were estimated. Text and numerical data were provided by the Energy & Environmental Research Center.

1) The permit data from three Watershed Districts (WSD's) were evaluated and compiled into three representative size distributions. The three distributions were titled after their respective WSD's: Pembina County, Two Rivers, and the Red Lake.

The raw data were also adjusted to eliminate non-feasible modifications and to reduce the data set size. This was performed by:

a. Eliminating the excessively large round sizes and all box culverts.
b. Resizing pipe arches to their corresponding round sizes.

2) The expected number of modifications per relief category was determined. The estimated number of modifications per relief category are contained in Appendix Table B1.

3) The WSD distributions were applied to the cost associated with each size of expected modification to determine an average cost for each type of structure modification, whether standpipe or isolation valve.

Example: If 35 percent of the culverts were 24-inch and 65% were 36-inch and the 24-inch valve cost $800 and the 36-inch valve cost $1,200 then by multiplying 0.35 by 800 and adding the result of multiplying 1,200 by 0.65 yields an average cost of a valve to be $1,060.

The stand pipe average was then adjusted to include the costs associated with the anchoring process.

4) The average component cost was applied to the expected number of modifications per relief category which produced an average cost required to modify one section in each relief category (Appendix Table B1).

5) By adding the estimated average contractor's cost, expected cost required to modify sections of each relief category was determined.

6) The EERC Waffle research team questioned the validity of the three distributions, but believed the data were sufficient to determine a safe working value. The Red Lake WSD is the largest of the WSD's used in this analysis and encompasses both areas near and far from the Red River.

7) Possible problems with how representative the sample WSDs are compared to other districts in the Basin:

a. The permit database may not be complete.
b. The data base may not show a true sampling of culvert sizes.
c. The distributions are assumed to be representative for all WSD's including those not located relatively close to the river.
d. The distributions are all from MN WSD's and are being used to approximate ND watersheds.

Appendix Table B1. Cost Factors for Culvert Modifications, per Section of Land, Various Watersheds, Red River Basin, 2005

		Red Lake Watershed	
Relief Category	Description of Structural Modifications	Infrastructure Costs	Installation Costs
0 - 2	2 standpipes with 4 drains	$11,564.01	$1,200.00
2 - 4	2 standpipes with 2 drains	$9,393.87	$1,000.00
4 - 10	1 standpipe with 1 drain	$3,611.87	$800.00
		Pembina County Watershed	
Relief Category	Description of Structural Modifications	Infrastructure Costs	Installation Costs
0 - 2	2 standpipes with 4 drains	$14,844.13	$1,200.00
2 - 4	2 standpipes with 2 drains	$12,312.50	$1,000.00
4 - 10	1 standpipe with 1 drain	$4,890.44	$800.00
		Two Rivers Watershed	
Relief Category	Description of Structural Modifications	Infrastructure Costs	Installation Costs
0 - 2	2 standpipes with 4 drains	$14,844.13	$1,200.00
2 - 4	2 standpipes with 2 drains	$12,312.50	$1,000.00
4 - 10	1 standpipe with 1 drain	$4,890.44	$800.00

Source: Kurz et al. (2007).

APPENDIX C

Cash Rent Data, Population Projections, Aggregate Residential and Commercial Property Values, Consumer Price Index for Housing, and Office of Federal Housing Enterprise Oversight Housing Value Index

Appendix Table C1. Cash Rents, by Land Type, County, and State, 2004 and 2005

State/County	Non-irrigated Cash Rents Cropland	Pasture
North Dakota (2005 data)	- $/acre-	- $/acre-
Barnes	39.7	13.2
Benson	31.1	11.1
Cass	59.2	25
Cavalier	40.6	11.4
Eddy	32.3	11
Foster	36.5	12.3
Grand Forks	49.5	12.3
Griggs	35.8	11.4
McHenry	33.5	12.6
Nelson	32.8	10.9
Pembina	58.5	11
Pierce	31.4	12.6
Ransom	47.1	18.6
Richland	68.2	22.1
Rolette	32	13.7
Sargent	50.5	22.6
Sheridan	28.5	10.9
Steele	43.9	11
Towner	31.8	11.2
Traill	59.8	14.2
Walsh	52.8	$9.50
Wells	33.8	11.8
South Dakota (2005 data)		
Marshall	56.2	22.7
Roberts	67.7	24.3
Minnesota (2004 data)		
Becker	44	14.56
Beltrami	18.82	6.23
Big Stone	64	21.18
Clay	70	23.17
Clearwater	48.02	15.89
Grant	78	25.81
Kittson	32.6	10.79
Lake of the Woods	26.26	8.69
Mahnomen	52	17.21
Marshall	36	11.91
Norman	61	20.19
Otter Tail	42	13.9
Pennington	39.21	12.98
Polk	50	16.55
Red Lake	31.09	10.29
Roseau	28.15	9.32
Stevens	75	24.82
Traverse	71.61	23.7

Sources: National Agricultural Statistics Service (2005a, 2005b) and Hachfeld et al. (2005).

Appendix Table C2. Population Projections, Study Cities, 2005 through 2050

City	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
---------- Main Population Projection ----------										
Drayton	920	920	920	920	920	920	920	920	920	920
Fargo	98800	107,100	116,700	126,400	136,900	147400	159,200	171,000	187,700	204,300
Grafton	4,450	4,420	4,410	4,420	4,410	4380	4,330	4,250	4,180	4,130
Grand Forks	52,000	54,800	57,800	61,000	64,300	67800	71,500	75,300	79,400	83,800
Wahpeton	8,940	9,300	9,650	10,010	10360	10720	11,070	11,430	11,780	12,140
Breckenridge	3460	3,360	3,250	3,150	3,050	2,950	2,850	2,740	2,640	2540
East Grand Forks	7700	7,900	8,100	8,300	8,600	8,800	9,000	9,300	9,500	9,800
Moorhead	34,700	35,800	36,800	37,900	38,900	40,000	41,000	42,100	43,100	44,200
Crookston	7826	7,775	7,724	7,674	7,623	7,573	7,522	7,472	7,421	7370
---------- Pessimistic or Low Population Projection ----------										
Drayton	920	889	858	827	796	766	735	704	673	642
Fargo	98,800	109,016	119,232	129,448	139,664	149,879	160,095	170,311	180,527	190,743
Grafton	4,450	4,258	4,066	3,874	3,682	3,490	3,298	3,106	2,914	2,722
Grand Forks	52,000	53,275	54,549	55,824	57,098	58,373	59,647	60,922	62,196	63,471
Wahpeton	8,940	8,824	8,707	8,591	8,474	8,358	8,241	8,125	8,008	7,892
Breckenridge	3,460	3,360	3,250	3,150	3,050	2,950	2,850	2,740	2,640	2,540
East Grand Forks	7,700	7,933	8,167	8,400	8,633	8,867	9,100	9,333	9,567	9,800
Moorhead	34,700	34,499	34,299	34,098	33,898	33,697	33,497	33,296	33,096	32,895
Crookston	8114	8,061	8,008	7,955	7,901	7,848	7,795	7,742	7,689	7636
---------- Optimistic or High Population Projection ----------										
Drayton	920	920	920	920	920	920	920	920	920	920
Fargo	98,800	114,830	130,861	146,891	162,921	178952	194,982	211,012	227,043	243,073
Grafton	4,450	4,649	4,849	5,048	5,247	5,447	5,646	5,845	6,045	6,244
Grand Forks	52,000	56,181	60,362	64,544	68,725	72,906	77,087	81,269	85,450	89,631
Wahpeton	8,940	9,296	9,651	10,007	10,362	10,718	11,073	11,429	11,784	12140
Breckenridge	3,460	3,476	3,491	3,507	3,523	3,538	3,554	3,570	3,585	3,601
East Grand Forks	7,700	8,358	9,015	9,673	10,331	10,988	11,646	12,304	12,961	13,619
Moorhead	34,700	37,168	39,635	42103	44,571	47,038	49,506	51,973	54,441	56,909
Crookston	8,114	8,446	8,778	9110	9,442	9,774	10,107	10,439	10,771	11103

Sources: Minnesota State Demographic Center (2002), Bureau of Reclamation (2005), Northwest Economic Associates (2003).

Appendix Table C3. Aggregate Residential Property Values, Net of Land, Nominal and Real, 1990 through 2004

	Fargo	Moorhead	Grand Forks	East Grand Forks	Wahpeton	Breckenridge	Drayton	Grafton	Crookston
	---------- Nominal Values (000s $) ----------								
1990	811,688	443,318	608,061	106131	74,621	42,381	not available	50,723	not available
1991	841,106	459,386	632,306	110,363	77,597	44,071	not available	50,910	not available
1992	862,656	471,155	639,590	111,634	78,357	44,503	not available	50,941	not available
1993	919,459	502,179	673,047	117,474	79,228	44,998	not available	50,858	86,614
1994	1,007,349	519,937	733,379	126,855	85,634	50,479	not available	51,176	92,132
1995	1,083,054	558,934	803257	137,684	87,010	53,163	11,405	51,800	97,650
1996	1,161,038	582,133	850,741	144,490	95,071	60,134	11,417	52,331	103,168
1997	1,247,400	617,516	817,156	137,506	96,304	62,987	11,543	52,967	108,686
1998	1,328,450	626,711	877,076	146,215	94,225	63,655	12,052	53,919	114,205
1999	1,467,360	575,125	952,771	157,341	96,121	67,005	12,747	55,349	119,723
2000	1,573,578	709,622	994,097	165,884	96,851	68,488	10,736	56,131	121,829
2001	1,666,267	764,420	1,006,598	169,711	97,656	70,039	10,873	60,884	123,936
2002	1,831,160	823,733	1,051,685	179,131	105,632	76,822	11,112	62,005	126,043
2003	1,971,970	896,290	1,117,827	192,329	105,789	78,000	10,962	62,655	128,150
2004	2,124,103	1,030,776	1,220,057	212028	112,018	83,719	10,958	63,470	130,256
	---------- Real Values (000s 2004 $) ----------								
1990	1,034,094	564,789	766,603	133,803	95,616	70,389	not available	64,994	not available
1991	1,079,772	589,737	806,915	140,839	99,695	72,947	not available	65,408	not available
1992	1,089,174	594,872	798,162	139,312	99,184	73,698	not available	64,482	not available
1993	1,149,568	627,857	804,109	140,350	97,423	73,397	not available	62,538	141,280
1994	1,256,030	648,292	816,315	141,201	102,438	81,554	not available	61,218	148,848
1995	1,330,236	686,498	906,113	155,314	102,154	83,036	13,390	60,815	152,521
1996	1,431,845	717,913	969,447	164,652	111,090	92,798	13,341	61,149	159,207
1997	1,508,295	746,670	902,947	151,943	111,325	94,360	13,343	61,229	162,823
1998	1,562,758	737,248	974,432	162,445	106,783	92,216	13,659	61,105	165,445
1999	1,731,936	678,825	1,092,427	180,404	110,766	90,784	14,689	63,781	162,211
2000	1,862,594	839,957	1,150,125	191,921	111,700	86,842	12,382	64,736	154,479
2001	1,934,396	887427	1,146,685	193,329	111,510	83,865	12,416	69,522	148,401
2002	2,041,952	918556	1,167,097	198,788	116,554	86,437	12,261	68,416	141,818
2003	2,077,381	944201	1,203,938	207,145	112,798	82,633	11,688	66,806	135,762
2004	2,124,103	1030776	1220057	212,028	112,018	83,719	10,958	63470	130256

Sources: Nominal values obtained from various city and county agencies.

Appendix Table C4. Aggregate Commercial Property Values, Net of Land, Nominal and Real, 1990 through 2004

	Fargo	Moorhead	Grand Forks	East Grand Forks	Wahpeton	Breckenridge	Drayton	Grafton	Crookston
Nominal Values (000s $)									
1990	733940	95,558	446,503	31,766	53,658	6,682	not available	28,411	not available
1991	759,699	98,912	451,900	32,150	52,183	6,498	not available	28,359	not available
1992	826,785	107,646	470,723	33,489	52,454	6,532	not available	27,697	not available
1993	853,311	111,100	491,902	34,995	53,496	6,662	not available	27,626	19,297
1994	884,654	116,905	500,509	34,754	53,653	7,072	not available	26,752	21,022
1995	971,222	123,762	525,921	35,621	55,666	7,743	3,728	26,985	22,747
1996	1,015,578	126,515	543,304	35,872	59,058	8,645	3,724	27,579	24,472
1997	1,065,395	128,728	554,315	35,653	63,030	9,686	3,779	26,238	26,197
1998	1,132,425	131,127	591,619	37,043	62,136	10,001	3,875	26,672	27,922
1999	1,199,264	136,574	626,100	38,134	65,445	11,011	3,703	28,981	29,647
2000	1,312,767	145,186	689,383	41,673	68,266	11,535	4,019	29,094	31,237
2001	1,454,791	153,679	723,171	43,383	69,728	11,832	3,987	29,301	32,827
2002	1,509,339	172,244	742,887	44,226	70,369	11,992	3,943	29,927	34,417
2003	1,595,699	190,274	786,323	46,451	77,079	13,191	3,915	32,015	36,007
2004	1,678,186	201,590	841,330	49,315	79,050	13,586	3,808	31364	37597
Real Values (000s 2004 $)									
1990	532126	69,282	323,727	26,521	38904	4,845	not available	20,599	not available
1991	634,269	82,581	377,289	26,842	43,567	5,425	not available	23,677	not available
1992	793,911	103,366	452,007	32,157	50,369	6,272	not available	26,596	not available
1993	915,894	119,248	527,978	37,562	57,420	7,150	not available	29,652	20,713
1994	979,126	129,389	553,958	38,465	59,382	7,827	not available	29,608	23,267
1995	1,064,955	135,706	576,678	39,059	61,039	8,490	4,088	29,589	24,943
1996	1,089,162	135,682	582,669	38,471	63,337	9,272	3,994	29,577	26,245
1997	1,091,799	131,918	568,053	36,537	64,593	9,926	3,873	26,888	26,846
1998	1,102,984	127,718	576,239	36,080	60,520	9,741	3,774	25,978	27,196
1999	1,155,137	131,549	603,063	36,731	63,037	10,605	3,567	27,915	28,556
2000	1,232,848	136,348	647415	39,136	64,110	10,832	3,775	27,323	29,335
2001	1,394,851	147,348	693,375	41,596	66,855	11,345	3,823	28,094	31,474
2002	1,504,831	171,729	740,668	44,094	70,159	11,956	3,932	29,838	34314
2003	1,623,657	193,608	800,100	47,265	78,429	13,422	3,984	32,576	36,638
2004	1,678,186	201,590	841,330	49315	79,050	13,586	3,808	31,364	37597

Sources: Nominal values obtained from various city and county agencies.

Appendix Table C5. Office of Federal Housing Enterprise Oversight Housing Price Index, Nominal and Real, 1990 through 2004

	Fargo/Moorhead		Grand Forks/E.G.Forks		North Dakota		Minnesota	
	Nominal	Real	Nominal	Real	Nominal	Real	Nominal	Real
1990	85.55	126.16	79.98	117.95	114.33	168.60	139	204.98
1991	88.27	125.20	82.15	116.52	118.55	168.15	145.01	205.68
1992	92.37	127.30	86.46	119.16	123.84	170.67	149.17	205.58
1993	95.79	128.56	92.74	124.46	130.91	175.69	155.52	208.72
1994	98.50	128.91	102.08	133.59	138.00	180.60	161.02	210.73
1995	102.55	130.86	103.30	131.82	144.20	184.01	170.81	217.97
1996	105.09	130.33	105.22	130.49	149.08	184.89	177.89	220.62
1997	109.99	132.93	111.35	134.57	154.64	186.89	188.04	227.25
1998	115.65	136.63	113.29	133.84	161.36	190.63	198.92	235.01
1999	117.78	136.18	112.17	129.69	162.15	187.48	217.33	251.28
2000	121.53	135.79	115.03	128.53	167.65	187.32	240.30	268.50
2001	128.88	138.45	121.51	130.53	176.12	189.20	264.67	284.33
2002	137.14	144.14	127.49	134.00	186.29	195.80	287.89	302.58
2003	148.79	152.57	134.64	138.06	197.59	202.62	313.39	321.36
2004	160.73	160.73	148.7	148.7	216.04	216.04	340.45	340.45

Notes: Real values expressed in 2004 dollars. Nominal values converted to real values using Consumer Price Index for Housing. Values for each year are fourth quarter figures.
Source: Office of Federal Housing Enterprise Oversight (2006).

Appendix Table C6. Consumer Price Index for Housing, United States, 1990 through 2004

Year	Index
1990	128.5
1991	133.6
1992	137.5
1993	141.2
1994	144.8
1995	148.5
1996	152.8
1997	156.8
1998	160.4
1999	163.9
2000	169.6
2001	176.4
2002	180.3
2003	184.8
2004	189.5

Source: U.S. Department of Labor (2006).

Appendix Table C7. Gross Domestic Product-Implicit Price Deflator, United States, 1990 through 2004

Year	Index
1990	81.59
1991	84.444
1992	86.385
1993	88.381
1994	90.259
1995	92.106
1996	93.852
1997	95.414
1998	96.472
1999	97.868
2000	100.000
2001	102.399
2002	104.187
2003	106.305
2004	109.099

Source: U.S. Department of Commerce (2006).

Appendix Table C8. Index of Cash Rent Paid for Farmland, United States, 1990 through 2004

Year	Nominal	Real
1990	92.0	123.0
1991	108.0	139.5
1992	100.0	126.3
1993	110.0	135.8
1994	115.0	139.0
1995	126.0	149.2
1996	129.0	150.0
1997	135.0	154.4
1998	135.0	152.7
1999	137.0	152.7
2000	139.0	151.6
2001	143.0	152.4
2002	143.0	149.7
2003	145.0	148.8
2004	145.0	145

Notes: Nominal cash rent index adjusted for inflation using Gross Domestic Product-Implicit Price Deflator.
Source: U.S. Department of Agriculture (1997, 2005).

APPENDIX D

Original and Projected Flood-stage Damage Functions, Flood Frequencies, and Crest Elevations, Various Years

Appendix Table D1. Flood-stage Damage Function, Fargo/Moorhead/Oakport Township, 2004

	Flood-related Damages			
Elevation[a]	Public	Residential	Commercial[b]	Total
– msl --	-- 000s 2004 $ --			
894				
895	516.8	863.1	3,047.4	4,427.3
896	1,641.9	1,948.8	3,983.3	7,574.0
897	3,650.0	5,312.7	4,745.1	13,707.8
898	5,450.9	25,162.1	8,610.1	39,223.1
899	7,556.9	82,890.7	16,576.6	107,024.2
900	9,382.5	230,416.6	35,397.1	275,196.2
901[c]	11,297.4	445,676.4	76,595.9	533,569.7
902	23,572.3	822,461.3	303,080.8	1,149,114.4
903	41,475.4	1,183,082.6	501,615.6	1,726,173.6
904	61,972.3	1,551,302.7	729,867.4	2,343,142.4
905	83,971.6	1,899,011.3	967,155.6	2,950,138.5
906	114,779.0	2,258,988.0	1,205,649.0	3,579,416.0

[a] Reference height (mean sea level) of the Red River at Main Avenue, Fargo, ND.
[b] Includes damages to apartment buildings.
[c] Reference height for a 100-year flood.
Source: U.S. Army Corps of Engineers (2005).

Appendix Table D2. Flood-stage Damage Function, Grand Forks and East Grand Forks, 1997

	Flood-related Damages		
Elevation[a]	Residental	Commercial[b]	Total
– msl --	-------------------------- 000s 1997 $	-----------------------------	
823.54			
824.54	1,145.8	35.3	1,181.1
825.54	2,503.6	77.3	2,580.9
826.54	68,901.5	26,065.9	94,967.4
827.54	104,887.5	40,131.9	145,019.4
828.54	133,229.5	50,227.9	183,457.4
829.54	242,652.9	82,437.3	325,090.2
830.54	297,081.9	120,667.8	417,749.7
831.54	359,408.8	188,031.7	547,440.5
832.54	465,028.7	263,043.6	728,072.3
833.54[c]	603,999.9	325,752.0	929,751.9
834.54	709,359.5	385,995.3	1,095,354.8
835.54	769,288.0	436,206.6	1,205,494.6
836.54	817,576.2	481,307.4	1,298,883.6
837.54	860,740.4	517,015.4	1,377,755.8
838.54	902,503.2	551,859.2	1,454,362.4

[a] Reference height (mean sea level) of the Red River in Grand Forks, ND.
[b] Includes public infrastructure and apartment building damages.
[c] Maximum height for the 1997 flood in Grand Forks, ND.
Source: U.S. Army Corps of Engineers (1998).

Appendix Table D3. Flood-stage Damage Function, Wahpeton, 1999

Reference Height[a]	Flood-related Damages		
	Residental	Commercial[b]	Total
– feet --	------------------------- 000s 1999 $ -----------------------------		
-7	0.0	0.0	0.0
-6	20.8	0.0	20.8
-5	47.7	0.0	47.7
-4	9,324.1	49.5	9,373.6
-3	12,889.2	117.2	13,006.4
-2	17,366.3	272.9	17,639.2
-1	22,592.6	771.8	23,364.4
0[c]	33,815.2	2,366.4	36,181.6
1	41,668.5	6,841.0	48,509.5
2	50,229.4	13,811.7	64,041.1
3	64,379.3	23,362.2	87,741.5
4	76,938.0	36,003.3	112,941.3
5	86,164.1	48,764.5	134,928.6
6	95,614.9	62,630.8	158,245.7
7	114,363.3	75,810.5	190,173.9

[a] Reference heights are indicated as 1-foot intervals above or below the crest elevation of the Red River in a 100-year flood. Separate flood-stage damage functions were prepared for various areas within the city of Wahpeton with each area having a slightly different crest height for a 100-year flood. The various areas were combined using reference heights above and below a 100-year flood.

[b] Includes public infrastructure and apartment building damages.

[c] Zero elevation refers to the height of the Red River in a 100-year flood.

Source: U.S. Army Corps of Engineers (2000b).

Appendix Table D4. Flood-stage Damage Function, Breckenridge, 1999

Reference Height[a]	Flood-related Damages		
	Residental	Commercial[b]	Total
– feet --	------------------------- 000s 1999 $ -----------------------------		
-7	0.0	0.0	0.0
-6	0.0	0.0	0.0
-5	1,334.9	0.5	1,335.4
-4	1,894.1	83.7	1,977.8
-3	4,361.5	350.2	4,711.7
-2	10,178.3	4,434.7	14,613.0
-1	17,452.8	6,406.7	23,859.5
0[c]	26,334.9	10,586.7	36,921.6
1	32,165.6	16,750.5	48,916.1
2	40,457.9	21,524.3	61,982.2
3	51,215.6	25,843.2	77,058.8
4	59,436.5	29,280.2	88,716.7
5	65,029.1	30,194.0	95,223.1
6	68,821.7	34,868.7	103,690.4
7	72,484.0	37,048.2	109,532.2

[a] Reference heights are indicated as 1-foot intervals above or below the crest elevation of the Red River in a 100-year flood. Separate flood-stage damage functions were prepared for various areas within the city of Breckenridge with each area having a slightly different crest height for a 100-year flood. The various areas were combined using reference heights above and below a 100-year flood.

[b] Includes public infrastructure and apartment building damages.

[c] Zero elevation refers to the height of the Red River in a 100-year flood.

Source: U.S. Army Corps of Engineers (2000a).

Appendix Table D5. Flood-stage Damage Function, Grafton, 2002

	Flood-related Damages			
Elevation[a]	Public	Residential	Commercial[b]	Total
– msl --	---------- 000s 2002 $ ----------			
820	0.0	0.0	0.0	0.0
821	12.5	0.0	0.0	12.5
822	34.0	0.0	0.0	34.0
823	55.4	455.4	1.6	512.4
824	101.2	1,358.1	3.1	1,462.4
825	522.8	3,109.4	5.8	3,638.0
826	1,458.7	6,203.9	24.1	7,686.7
827	2,457.3	12,474.0	67.9	14,999.2
828	4,163.0	21,688.6	173.0	26,024.6
829	5,560.5	31,027.8	449.2	37,037.5
830[c]	7,047.1	40,691.8	1,426.0	49,164.9
831	9,327.0	55,044.1	3,943.0	68,314.1

[a] Reference height (mean sea level) of the Park River in Grafton, ND.
[b] Includes damages to apartment buildings.
[c] Reference height for a 100-year flood.
Source: U.S. Army Corps of Engineers (2003).

Appendix Table D6. Flood-stage Damage Function, Drayton, 2003

	Flood-related Damages			
Elevation[a]	Public	Residential	Commercial[b]	Total
– msl --	---------- 000s 2003 $ ----------			
792.8	34.5	47.2	2.8	84.4
795.24	91.3	125.0	7.3	223.6
796.97	228.0	312.3	18.2	558.4
798.83	1,120.6	1,535.5	89.3	2,745.4
800.06[c]	2,773.0	3,799.5	221.0	6,793.5
802.87	5,763.3	7,896.7	459.4	14,119.3

[a] Reference height (mean sea level) of the Red River in Drayton, ND.
[b] Includes damages to apartment buildings.
[c] Reference height for a 100-year flood.
Source: U.S. Army Corps of Engineers (2004).

Appendix Table D7. Flood-stage Damage Function, Crookston, 1997

Reference Height[a]	Flood-related Damages		
	Residental	Commercial[b]	Total
– feet --	------------------------- 000s 1995 $	-----------------------------	
-13	0.0	0.0	0.0
-12	247.0	0.0	247.5
-11	804.6	0.0	804.6
-10	1,100.6	0.0	1,100.6
-9	1,707.6	0.0	1,707.6
-8	2,532.7	3.4	2,536.1
-7	3,177.1	9.1	3,186.2
-6	4,339.1	14.9	4,353.9
-5	5,611.7	18.5	5,630.2
-4	7,690.2	69.5	7,729.8
-3	9,188.9	106.7	9,295.6
-2	10,693.9	198.5	10,892.4
-1	12,293.1	323.8	12,616.9
0[c]	14,071.5	652.0	14,723.6
1	16,789.7	1,128.8	17,918.5
2	18,765.4	1,674.4	20,439.8
3	20,657.9	2,357.9	23,015.9
4	22,152.6	3,062.3	25,215.0
5	23,381.8	3,890.1	27,271.9

[a] Reference heights are indicated as 1-foot intervals above or below the crest elevation of the Red Lake River in a 100-year flood. Separate flood-stage damage functions were prepared for various areas within the city of Crookston with each area having a slightly different crest height for a 100-year flood. The various areas were combined using reference heights above and below a 100-year flood.

[b] Includes public infrastructure and apartment building damages.

[c] Zero refers to the crest height of the Red Lake River in a 100-year flood.

Source: U.S. Army Corps of Engineers (1997).

Appendix Table D8. Flood Frequency and Crest Heights for Flood-stage Damage Function, Grand Forks and East Grand Forks, 2005

U.S. Army Corps of Engineers Data			Flood-Stage Damage Function[a]		
Recurrence Interval	Flood Frequency	Crest Height (msl)	Crest Height (msl)	Flood Damages (000s $)	Interpolated/ Extrapolated Flood Frequency
			823.54	0	0.10659
10-year	0.1	823.78	824.54	1335	0.08628
			825.54	2916	0.06823
20-year	0.05	826.55	826.54	117412	0.05018
			827.54	179436	0.04113
			828.54	226761	0.03218
50-year	0.02	829.9	829.54	398969	0.02322
			830.54	519095	0.01697
			831.54	693255	0.01223
100-year	0.01	832.01	832.54	927641	0.00897
			833.54	1244748	0.00702
200-year	0.005	834.58	834.54	1504872	0.00508
			835.54	1677575	0.00404
			836.54	1823938	0.00303
500-year	0.002	837.57	837.54	1947620	0.00203
			838.54	2067745	0.00103

[a] Function has not been adjusted for structural protections added since 1997.
Source: U.S. Army Corps of Engineers (1998).

Appendix Table D9. Flood Frequency and Crest Heights for Flood-stage Damage Function, Wahpeton, 2005

U.S. Army Corps of Engineers Data			Flood-Stage Damage Function[a]		
Recurrence Interval	Flood Frequency	Crest Height (ft)[b]	Crest Height (ft)[b]	Flood Damages (000s $)	Interpolated/ Extrapolated Flood Frequency
			-7	0	0.25147
5-year	0.2	-6.437	-6	24	0.17043
10-year	0.1	-4.96	-5	56	0.10271
			-4	10947	0.0653
20-year	0.05	-3.577	-3	15194	0.04104
			-2	20615	0.02549
50-year	0.02	-1.647	-1	27340	0.01607
100-year	0.01	0	0	57333	0.01
			1	82516	0.00769
200-year	0.005	2.163	2	112580	0.00538
			3	159811	0.00403
500-year	0.002	4.757	4	206930	0.00288
			5	245883	0.00159
			6	286777	0.00125
			7	350013	0.00086

[a] Function has not been adjusted for structural protections added since 1997.
[b] Crest heights shown are 1 foot increments above and below 100-year reference elevation.
Source: U.S. Army Corps of Engineers (2000b).

Appendix Table D10. Flood Frequency and Crest Heights for Flood-stage Damage Function, Breckenridge, 2005

U.S. Army Corps of Engineers Data			Flood-Stage Damage Function[a]		
Recurrence Interval	Flood Frequency	Crest Height (ft)[b]	Crest Height (ft)[b]	Flood Damages (000s $)	Interpolated/ Extrapolated Flood Frequency
			-7	0	0.25865
5-year	0.2	-6.435	-6	0	0.16965
10-year	0.1	-5.002	-5	1719	0.09994
			-4	2545	0.06431
20-year	0.05	-3.598	-3	6061	0.04066
			-2	18746	0.02505
50-year	0.02	-1.677	-1	30620	0.01596
100-year	0.01	0	0	47961	0.01
			1	63694	0.0077
200-year	0.005	2.178	2	80991	0.00541
			3	101046	0.00392
500-year	0.002	4.452	4	116547	0.0026
			5	125280	0.00128
			6	136359	0.001
			7	144089	0.0008

[a] Function has not been adjusted for structural protections added since 1997.
[b] Crest heights shown are 1 foot increments above and below 100-year reference elevation.
Source: U.S. Army Corps of Engineers (2000a).

Appendix Table D11. Flood Frequency and Crest Heights for Flood-stage Damage Function, Drayton, 2005

U.S. Army Corps of Engineers Data			Flood-Stage Damage Function		
Recurrence Interval	Flood Frequency	Crest Height (msl)	Crest Height (msl)	Flood Damages (000s $)	Interpolated/ Extrapolated Flood Frequency
			790.36	0	0.30000
5-year	0.2	792.8	792.80	85	0.20000
10-year	0.1	795.24	795.24	224	0.10000
20-year	0.05	796.97	796.97	559	0.05000
50-year	0.02	798.83	798.83	2746	0.02000
100-year	0.01	800.06	800.06	7144	0.01000
500-year	0.002	802.87	802.87	15103	0.002

Source: U.S. Army Corps of Engineers (2004).

Appendix Table D12. Flood Frequency and Crest Heights for Flood-stage Damage Function, Crookston, 2005

U.S. Army Corps of Engineers Data			Flood-Stage Damage Function[a]		
Recurrence Interval	Flood Frequency	Crest Height (ft)[a]	Crest Height (ft)[a]	Flood Damages (000s $)	Interpolated/ Extrapolated Flood Frequency
2-year	0.5	-13.183	-13	0	0.48969
			-12	340	0.43344
			-11	525	0.37719
			-10	667	0.32094
			-9	1,146	0.26469
			-8	1,924	0.20844
5-year	0.2	-7.85	-7	2,454	0.16277
			-6	3169	0.11898
10-year	0.1	-5.567	-5	4126	0.08903
			-4	5006	0.06968
			-3	6078	0.05032
50-year	0.02	-1.433	-2	7151	0.03097
			-1	8301	0.01698
100-year	0.01	0	0	9853	0.01000
			1	26669	0.00718
			2	30,601	0.00435
500-year	0.002	2.833	3	34,637	0.00153
			4	38,098	0.001
			5	41360	0.0005

[a] Crest heights shown are 1 foot increments above and below 100-year reference elevation.
Source: U.S. Army Corps of Engineers (1997).

Appendix Table D13. Flood-stage Damage Function, Flood Frequency and Crest Heights for Grafton, 2005

U.S. Army Corps of Engineers Data			Flood-Stage Damage Function		
Recurrence Interval	Flood Frequency	Crest Height (msl)	Crest Height (msl)	Flood Damages (000s $)	Interpolated/ Extrapolated Flood Frequency
2-year	0.5	817.57	820	0	0.36888
			821	13	0.31493
			822	36	0.26097
5-year	0.2	823.13	823	533	0.20701
			824	1519	0.16848
10-year	0.1	825.89	825	3784	0.13225
			826	8003	0.09643
20-year	0.05	827.43	827	15608	0.06396
50-year	0.02	829.02	828	27080	0.03925
100-year	0.01	829.93	829	38536	0.02038
200-year	0.005	830.41	830	51486	0.00927
500-year	0.002	830.45	831	71924	0.0002

Source: U.S. Army Corps of Engineers (2003).

Appendix Table D14. Projected Residential Damages for Flood-stage Damage Function, Fargo/Moorhead/Oakport Township, Baseline Population, Selected Years, 2006 through 2055

Elevation	2006	2015	2025	2035	2045	2055
- (ft msl) -	--	---------	000s 2004 $	---------	--	
894	0	0	0	0	0	0
895	886	992	1,108	1,225	1,342	1,459
896	2002	2,239	2,502	2,766	3,030	3,293
897	5456	6,103	6,822	7,541	8,259	8,978
898	25843	28,906	32,310	35,714	39,117	42,521
899	85133	95,225	106,438	117,651	128,863	140,076
900	236650	264,703	295,872	327,041	358,210	389,379
901	476161	593,391	739,222	897,799	1,081,493	1,288,494
902	895393	1,168,718	1,515,251	1,896,840	2,347,509	2,862,280
903	1296640	1,719,364	2,257,990	2,853,022	3,559,213	4368553
904	1706343	2,281,613	3,016,379	3,829,353	4,796,450	5,906,565
905	2093223	2,812,542	3,732,522	4,751,297	5,964,768	7,358,902
906	2493753	3,362,204	4,473,932	5,705,771	7,174,307	8862482

Source: Adapted from U.S. Army Corps of Engineers (2005).

Appendix Table D15. Projected Residential Damages for Flood-stage Damage Function, Fargo/Moorhead/Oakport Township, Optimistic Population, Selected Years, 2006 through 2055

Elevation	2006	2015	2025	2035	2045	2055
- (ft msl) -	--	---------	000s 2004 $	---------	--	
894	0	0	0	0	0	0
895	886	992	1,108	1,225	1,342	1,459
896	2002	2,239	2,502	2,766	3,030	3,293
897	5,456	6,103	6,822	7,541	8,259	8,978
898	25,843	28,906	32,310	35,714	39,117	42,521
899	85,133	95,225	106,438	117,651	128,863	140,076
900	236,650	264,703	295,872	327,041	358,210	389,379
901	476161	627,412	811,471	1,008,792	1,216,759	1,433,483
902	895393	1,262,288	1,713,961	2,202,110	2,719,541	3,261,054
903	1,296,640	1,869,929	2,577,735	3,344,236	4,157,855	5,010,224
904	1,706,343	2,490,374	3,459,710	4,510,428	5,626,476	6,796,251
905	2,093,223	3,076,257	4,292,556	5,611,658	7,013,288	8,482,789
906	2,493,753	3,682,812	5,154,786	6,751,742	8,449,031	10228833

Source: Adapted from U.S. Army Corps of Engineers (2005).

Appendix Table D16. Projected Residential Damages for Flood-stage Damage Function, Fargo/Moorhead/Oakport Township, Pessimistic Population, Selected Years, 2006 through 2055

Elevation	2006	2015	2025	2035	2045	2055
- (ft msl) -	--	----------	000s 2004 $	----------	----------	--
894	0	0	0	0	0	0
895	886	992	1,108	1,225	1,342	1,459
896	2002	2,239	2,502	2,766	3,030	3,293
897	5456	6,103	6,822	7,541	8,259	8,978
898	25843	28,906	32,310	35,714	39,117	42,521
899	85133	95,225	106,438	117,651	128,863	140,076
900	236650	264,703	295,872	327,041	358,210	389,379
901	473151	592,000	730,776	875,336	1,024,748	1,178,336
902	887116	1,164,892	1,492,021	1,835,055	2,191,437	2,559,304
903	1283323	1,713,208	2,220,610	2,753,605	3,308,077	3,881,031
904	1687878	2273078	2,964,551	3,691,509	4,448,246	5,230,608
905	2069897	2,801,760	3,667,051	4,577,168	5,524,902	6,505,007
906	2465396	3349096	4,394,337	5,494,075	6,639,546	7,824,371

Source: Adapted from U.S. Army Corps of Engineers (2005).

Appendix Table D17. Projected Residential Damages for Flood-stage Damage Function, Grafton, Baseline Population, Selected Years, 2006 through 2055

Elevation	2006	2015	2025	2035	2045	2055
- (ft msl) -	--	----------	000s 2004 $	----------	----------	--
822	0	0	0	0	0	0
823	478	533	594	656	717	778
824	1,427	1591	1773	1,955	2,137	2,320
825	3,266	3,642	4059	4,476	4,894	5,311
826	6,517	7,266	8099	8,931	9,764	10,596
827	13,104	14,610	16284	17958	19,632	21,305
828	22,783	25,402	28,313	31223	34,133	37,044
829	32,594	36,341	40,504	44668	48831	52995
830	43,012	47497	52,611	57,532	62252	67129
831	58483	64065	70592	76636	82183	88119

Source: Adapted from U.S. Army Corps of Engineers (2003).

Appendix Table D18. Projected Residential Damages for Flood-stage Damage Function, Grafton, Optimistic Population, Selected Years, 2006 through 2055

Elevation	2006	2015	2025	2035	2045	2055
- (ft msl) -	----------------------	----------------------	---------------------- 000s 2004 $	----------------------	----------------------	----------------------
822	0	0	0	0	0	0
823	478	533	594	656	717	778
824	1,427	1591	1773	1,955	2,137	2,320
825	3,266	3,642	4059	4,476	4,894	5,311
826	6,517	7,266	8099	8931	9,764	10,596
827	13,104	14,610	16,284	17958	19,632	21,305
828	22,783	25,402	28,313	31223	34133	37,044
829	32,594	36,341	40,504	44,668	48831	52995
830	43,119	48,547	54,663	60,864	67144	73499
831	58751	66674	75691	84918	94342	103951

Source: Adapted from U.S. Army Corps of Engineers (2003).

Appendix Table D19. Projected Residential Damages for Flood-stage Damage Function, Grafton, Pessimistic Population, Selected Years, 2006 through 2055

Elevation	2006	2015	2025	2035	2045	2055
- (ft msl) -	----------------------	----------------------	---------------------- 000s 2004 $	----------------------	----------------------	----------------------
822	0	0	0	0	0	0
823	478	533	594	656	717	778
824	1,427	1591	1,773	1,955	2,137	2,320
825	3,266	3642	4059	4,476	4,894	5,311
826	6,517	7,266	8099	8,931	9,764	10,596
827	13,104	14,610	16284	17958	19,632	21,305
828	22,783	25,402	28,313	31223	34,133	37,044
829	32,594	36,341	40,504	44668	48831	52,995
830	42,936	46,669	50,796	54,870	58862	62743
831	58294	62008	66081	70021	73757	77220

Source: Adapted from U.S. Army Corps of Engineers (2003).

Appendix Table D20. Projected Residential Damages for Flood-stage Damage Function, Grand Forks/East Grand Forks, by Population Scenario for Selected Years, 2006 through 2055

Elevation	2006	2015	2025	2035	2045	2055
- (ft msl) -	--		000s 2004 $		--	
Baseline Scenario						
836.54	0	0	0	0	0	0
837.54	1,174,449	1,446,267	1,772,607	2,122,155	2,500,316	2913057
838.54	1,242,993	1,538,213	1,893,122	2,273,689	2,685,888	3136317
Optimistic Scenario						
836.54	0	0	0	0	0	0
837.54	1178484	1,491,761	1,865,526	2,261,390	2,675,611	3,105,373
838.54	1247454	1,588,509	1,995,848	2,427,619	2,879,684	3,348,930
Pessimistic Scenario						
836.54	0	0	0	0	0	0
837.54	1,171,307	1,406,737	1,669,645	1,933,582	2,198,491	2,464,431
838.54	1,239,519	1,494,512	1,779,294	2,065,214	2,352,209	2,640,344

Source: Adapted from U.S. Army Corps of Engineers (1998).

Appendix Table D21. Projected Residential Damages for Flood-stage Damage Function, Wahpeton, by Population Scenario for Selected Years, 2006 through 2055

Elevation[a]	2006	2015	2025	2035	2045	2055
	----	----	---- 000s 2004 $ ----	----	----	----
Baseline Scenario						
1	0	0	0	0	0	0
2	96,960	111,777	128,816	146,414	164,534	183,256
3	132,925	153,755	177,771	202,630	228,281	254,841
4	164,844	191,012	221,220	252,525	284,859	318,376
5	188,294	218,382	253,139	289,180	326,423	365,051
6	212,315	246,419	285,836	326,727	369,000	412,864
7	259,967	302,039	350,700	401,213	453,463	507,713
Optimistic Scenario						
1	0	0	0	0	0	0
2	96960	111777	128,816	146,414	164,534	183,256
3	132,925	153755	177,771	202,630	228,281	254,841
4	164,844	191012	221220	252,525	284,859	318,376
5	188,294	218,382	253139	289,180	326,423	365,051
6	212,315	246,419	285836	326727	369,000	412,864
7	259,967	302,039	350,700	401213	453463	507713
Pessimistic Scenario						
1	0	0	0	0	0	0
2	96217	104137	112,889	121,553	130,095	138,490
3	131,801	142202	153,689	165,041	176,209	187,155
4	163,383	175,987	189901	203,638	217,137	230,347
5	186,584	200,807	216503	231993	247,204	262,078
6	210,351	226,231	243,753	261039	278004	294,581
7	257,499	276,668	297,812	318,660	339105	359062

[a] Numbers in the table correspond to one foot increments above a reference elevation. The elevation of the Red River for the same flood-event size changes at different locations within the city. The FSDFs were developed for portions of the city and combined using common reference elevations above and below the 100-year event.
Source: Adapted from U.S. Army Corps of Engineers (2000b).

Appendix Table D22. Projected Residential Damages for Flood-stage Damage Function, Breckenridge, by Population Scenario for Selected Years, 2006 through 2055

Elevation[a]	2006	2015	2025	2035	2045	2055
	----------	----------	---------- 000s 2004 $	----------	----------	----------
Baseline Scenario						
1	0	0	0	0	0	0
2	54,506	62,952	73,039	83,312	93,381	103,378
3	69,175	78,770	90,462	102,426	114,091	125,652
4	80,385	90,858	103,776	117,033	129,918	142,673
5	88,011	99,081	112,834	126,970	140,685	154,253
6	93,182	104,657	118,976	133,708	147,986	162,105
7	98,176	110,042	124,907	140,215	155,037	169,688
Optimistic Scenario						
1	0	0	0	0	0	0
2	54,718	65,189	77,612	90,576	103,930	115,672
3	69,485	82,053	97,173	113,087	129,574	143,695
4	80,771	94,940	112,121	130,289	149,171	165,110
5	88,448	103,707	122,291	141,992	162,502	179,678
6	93,654	109,653	129,187	149,928	171,543	189,557
7	98,682	115,394	135,846	157,592	180,273	199,097
Pessimistic Scenario						
1	0	0	0	0	0	0
2	54,506	62952	73,039	83,312	93,381	103,378
3	69,175	78,770	90462	102,426	114,091	125,652
4	80,385	90,858	103776	117,033	129,918	142,673
5	88,011	99,081	112,834	126970	140,685	154,253
6	93,182	104,657	118,976	133708	147986	162,105
7	98176	110042	124907	140215	155037	169688

[a] Numbers in the table correspond to one foot increments above a reference elevation. The elevation of the Red River for the same flood-event size changes at different locations within the city. The FSDFs were developed for portions of the city and combined using common reference elevations above and below the 100-year event.
Source: Adapted from U.S. Army Corps of Engineers (2000a).

Appendix Table D23. Projected Residential Damages for Flood-stage Damage Function, Drayton, by Population Scenario for Selected Years, 2006 through 2055

Elevation	2006	2015	2025	2035	2045	2055
- (ft msl) -	-------------------	-------------------	------------------- 000s 2004 $	-------------------	-------------------	-------------------
Baseline Scenario						
792.8	48	54	60	66	73	79
795.24	128	143	159	176	192	209
796.97	320	357	398	439	480	521
798.83	1,575	1,756	1,958	2,159	2,360	2,561
800.06	4,212	4,373	4,585	4,823	5,080	5,352
802.87	8,984	9,107	9,340	9,645	10,004	10,404
Optimistic Scenario						
792.8	48	54	60	66	73	79
795.24	128	143	159	176	192	209
796.97	320	357	398	439	480	521
798.83	1,575	1,756	1,958	2,159	2,360	2,561
800.06	4,212	4,373	4,585	4,823	5,080	5,352
802.87	8,984	9,107	9,340	9,645	10,004	10,404
Pessimistic Scenario						
792.8	48	54	60	66	73	79
795.24	128	143	159	176	192	209
796.97	320	357	398	439	480	521
798.83	1,575	1,756	1,958	2,159	2,360	2,561
800.06	4,194	4,205	4,266	4,360	4,476	4,603
802.87	8,934	8,637	8,444	8,344	8,305	8,298

Source: Adapted from U.S. Army Corps of Engineers (2004).

Appendix Table D24. Projected Residential Damages for Flood-stage Damage Function, Crookston, Baseline Population, Selected Years, 2006 through 2055

Elevation[a]	2006	2015	2025	2035	2045	2055
	---------- 000s 2004 $ ----------					
-13	0	0	0	0	0	0
-12	350	441	542	643	743	844
-11	540	680	835	991	1,146	1,302
-10	687	864	1,062	1,259	1,457	1,654
-9	1,180	1485	1824	2,164	2,503	2,842
-8	1,975	2487	3055	3,623	4,191	4,759
-7	2,511	3161	3883	4,605	5,327	6,049
-6	3,237	4075	5006	5,937	6,868	7,799
-5	4,216	5308	6520	7,733	8,946	10,158
-4	5,093	6411	7876	9,341	10,806	12,271
-3	6,120	7704	9464	11,224	12,985	14,745
-2	7,127	8972	11022	13,071	15,121	17,171
-1	8,174	10289	12640	14,991	17,342	19,693
0	9,461	11599	14035	16500	18,985	21,483
1	24,988	27404	30,856	34699	38,804	43,079
2	28,003	30473	34,124	38234	42,653	47,274
3	30,892	33414	37253	41620	46,341	51,292
4	33,174	35,736	39725	44294	49253	54466
5	35050	37646	41758	46493	51648	57076

[a] Numbers in the table correspond to one foot increments above a reference elevation. The elevation of the Red River for the same flood-event size changes at different locations within the city. The FSDFs were developed for portions of the city and combined using common reference elevations above and below the 100-year event.
Source: Adapted from U.S. Army Corps of Engineers (1997).

Appendix Table D25. Projected Residential Damages for Flood-stage Damage Function, Crookston, Optimistic Population, Selected Years, 2006 through 2055

Elevation[a]	2006	2015	2025	2035	2045	2055
	-- 000s 2004 $ --					
-13	0	0	0	0	0	0
-12	350	441	542	643	743	844
-11	540	680	835	991	1,146	1,302
-10	687	864	1,062	1,259	1,457	1,654
-9	1,180	1485	1,824	2,164	2,503	2,842
-8	1,975	2487	3055	3,623	4,191	4,759
-7	2,511	3,161	3883	4,605	5,327	6,049
-6	3,237	4,075	5006	5,937	6,868	7,799
-5	4,216	5,308	6520	7,733	8,946	10,158
-4	5,093	6,411	7876	9,341	10,806	12,271
-3	6,120	7,704	9464	11224	12,985	14,745
-2	7,127	8,972	11,022	13071	15,121	17,171
-1	8,174	10,289	12,640	14991	17,342	19,693
0	9,470	11,678	14,177	16704	19249	21,808
1	25,108	28,435	32,719	37369	42259	47,322
2	28,145	31,690	36,321	41,383	46729	52278
3	31,055	34,808	39,771	45,228	51010	57026
4	33,353	37,270	42,496	48,265	54391	60775
5	35242	39295	44737	50,762	57172	63858

[a] Numbers in the table correspond to one foot increments above a reference elevation. The elevation of the Red River for the same flood-event size changes at different locations within the city. The FSDFs were developed for portions of the city and combined using common reference elevations above and below the 100-year event.
Source: Adapted from U.S. Army Corps of Engineers (1997).

Appendix Table D26. Projected Residential Damages for Flood-stage Damage Function, Crookston, Pessimistic Population, Selected Years, 2006 through 2055

Elevation[a]	2006	2015	2025	2035	2045	2055
	---------- 000s 2004 $ ----------					
-13	0	0	0	0	0	0
-12	350	441	542	643	743	844
-11	540	680	835	991	1,146	1,302
-10	687	864	1,062	1,259	1,457	1,654
-9	1,180	1,485	1,824	2,164	2,503	2,842
-8	1,975	2,487	3,055	3,623	4,191	4,759
-7	2,511	3,161	3,883	4,605	5,327	6,049
-6	3,237	4,075	5,006	5,937	6,868	7,799
-5	4,216	5,308	6,520	7,733	8,946	10,158
-4	5,093	6,411	7,876	9,341	10,806	12,271
-3	6,120	7,704	9,464	11,224	12,985	14,745
-2	7,127	8,972	11,022	13,071	15,121	17,171
-1	8,174	10,289	12,640	14,991	17,342	19,693
0	9,457	11,569	13,976	16,415	18,873	21,343
1	24,948	27,012	30,087	33,595	37,348	41,250
2	27,956	30,012	33,217	36,932	40,937	45,116
3	30,838	32,885	36,215	40,129	44,374	48,820
4	33,115	35,154	38,582	42,654	47,089	51,745
5	34,987	37,020	40,529	44,730	49,322	54,151

[a] Numbers in the table correspond to one foot increments above a reference elevation. The elevation of the Red River for the same flood-event size changes at different locations within the city. The FSDFs were developed for portions of the city and combined using common reference elevations above and below the 100-year event.
Source: Adapted from U.S. Army Corps of Engineers (1997).

Appendix Table D27. Projected Commercial Damages for Flood-stage Damage Function, Fargo/Moorhead/Oakport Township, Baseline Population, Selected Years, 2006 through 2055

Elevation	2006	2015	2025	2035	2045	2055
- (ft msl) -			000s 2004 $			
894	0	0	0	0	0	0
895	4040	6040	8815	12,238	16,724	22,357
896	6376	9,532	13912	19,315	26,395	35,285
897	9515	14,226	20,762	28826	39,392	52,659
898	15937	23,827	34,774	48280	65979	88,199
899	27353	40,895	59,684	82,865	113242	151,380
900	50753	75,880	110,744	153,756	210120	280,884
901	99,618	148,936	217,368	301,792	412423	551,319
902	370228	553,518	807,843	1,121,602	1532760	2,048,964
903	615538	920,274	1,343,114	1,864,767	2548355	3,406,592
904	897470	1,341,782	1,958,293	2,718,875	3715563	4,966,893
905	1191346	1,781,148	2,599,535	3,609,170	4932222	6,593,300
906	1496571	2237481	3265541	4533846	6195866	8282516

Source: Adapted from U.S. Army Corps of Engineers (2005).

Appendix Table D28. Projected Commercial Damages for Flood-stage Damage Function, Fargo/Moorhead/Oakport Township, Optimistic Population, Selected Years, 2006 through 2055

Elevation	2006	2015	2025	2035	2045	2055
- (ft msl) -			000s 2004 $			
894	0	0	0	0	0	0
895	4,099	6747	10456	14,972	20,294	26,424
896	6,469	10,649	16502	23,629	32,030	41,703
897	9,654	15,892	24,628	35265	47,801	62,238
898	16,170	26,618	41,250	59,065	80,062	104,243
899	27,753	45,685	70,799	101,376	137415	178,916
900	51,495	84,768	131,368	188,102	254972	331,978
901	101,074	166,383	257,848	369,207	500459	651,605
902	375,640	618,359	958,285	1,372,146	1,859,942	2421673
903	624,536	1,028,079	1,593,238	2,281,320	3,092,326	4,026,255
904	910,588	1,498,964	2,322,979	3,326,220	4,508,686	5,870,377
905	1,208,759	1,989,799	3,083,638	4,415,389	5985053	7792629
906	1,518,446	2499589	3873671	5546620	7518434	9789115

Source: Adapted from U.S. Army Corps of Engineers (2005).

Appendix Table D29. Projected Commercial Damages for Flood-stage Damage Function, Fargo/Moorhead/Oakport Township, Pessimistic Population, Selected Years, 2006 through 2055

Elevation	2006	2015	2025	2035	2045	2055
- (ft msl) -	000s 2004 $					
894	0	0	0	0	0	0
895	4050	6119	8879	12123	15852	20,065
896	6393	9,658	14013	19,133	25,018	31,668
897	9,540	14,413	20913	28,554	37,337	47262
898	15,979	24,141	35,027	47825	62,536	79,159
899	27426	41,434	60,118	82084	107,333	135864
900	50,888	76,881	111,548	152,306	199,156	252096
901	99883	150,902	218,947	298,947	390902	494813
902	371214	560,823	813,709	1,111,028	1452778	1838960
903	617,177	932,419	1,352,867	1,847,187	2,415,378	3057441
904	899859	1,359,490	1,972,513	2,693,242	3,521,679	4457822
905	1194517	1,804,654	2,618,411	3,575,143	4,674,851	5917534
906	1500555	2267010	3289253	4491102	5872557	7433618

Source: Adapted from U.S. Army Corps of Engineers (2005).

Appendix Table D30. Projected Commercial Damages for Flood-stage Damage Function, Grafton, Baseline Population, Selected Years, 2006 through 2055

Elevation	2006	2015	2025	2035	2045	2055
- (ft msl) -	000s 2004 $					
820	0	0	0	0	0	0
821	13	16	18	20	22	23
822	37	42	49	55	59	64
823	61	71	82	91	99	107
824	112	130	150	167	181	195
825	569	657	761	848	916	990
826	1596	1,844	2,133	2,379	2,570	2777
827	2,718	3,141	3,633	4,051	4,378	4729
828	4667	5,393	6,239	6,956	7,517	8,119
829	6469	7,474	8,647	9,641	10,418	11253
830	9120	10,538	12,191	13,593	14688	15866
831	14283	16504	19093	21288	23004	24849

Source: Adapted from U.S. Army Corps of Engineers (2003).

Appendix Table D31. Projected Commercial Damages for Flood-stage Damage Function, Grafton, Optimistic Population, Selected Years, 2006 through 2055

Elevation	2006	2015	2025	2035	2045	2055
- (ft msl) -	------------------------	------------------------	------------------------ 000s 2004 $	------------------------	------------------------	------------------------
820	0	0	0	0	0	0
821	14	17	21	26	31	37
822	37	46	58	71	85	101
823	62	78	98	119	143	169
824	113	143	179	218	261	308
825	575	723	905	1106	1,325	1,563
826	1,613	2,028	2,538	3,102	3,717	4,385
827	2,746	3,453	4,323	5,282	6,330	7,468
828	4,715	5,929	7,423	9,070	10870	12,822
829	6535	8,218	10,288	12,571	15065	17772
830	9214	11,586	14,506	17,724	21241	25057
831	14431	18146	22718	27758	33266	39242

Source: Adapted from U.S. Army Corps of Engineers (2003).

Appendix Table D32. Projected Commercial Damages for Flood-stage Damage Function, Grafton, Commercial Damages, Optimistic Population, Selected Years, 2006 through 2055

Elevation	2006	2015	2025	2035	2045	2055
- (ft msl) -	------------------------	------------------------	------------------------ 000s 2004 $	------------------------	------------------------	------------------------
820	0	0	0	0	0	0
821	13	14	15	15	15	15
822	36	39	41	42	41	39
823	61	65	68	70	69	66
824	111	120	125	127	126	121
825	565	606	635	646	639	614
826	1,584	1,700	1,781	1,812	1,792	1,722
827	2,698	2,896	3,033	3085	3052	2,932
828	4,633	4,972	5,209	5,298	5,240	5,035
829	6,421	6,891	7,219	7,343	7,263	6978
830	9,054	9,716	10,178	10,353	10,240	9839
831	14,179	15217	15941	16214	16,037	15409

Source: Adapted from U.S. Army Corps of Engineers (2003).

Appendix Table D33. Projected Commercial Damages for Flood-stage Damage Function, Grand Forks/East Grand Forks, by Population Scenario for Selected Years, 2006 through 2055

Elevation	2006	2015	2025	2035	2045	2055
- (ft msl) -	-------------------	-------------------	000s 2004 $	-------------------	-------------------	-------------------
	Baseline Scenario					
836.54	0	0	0	0	0	0
837.54	839,348	1202784	1683007	2252224	2923335	3715829
838.54	895,915	1,283,844	1,796,431	2,404,010	3,120,350	3966254
	Optimistic Scenario					
836.54	0	0	0	0	0	0
837.54	844,058	1260274	1809412	2449788	3,181,403	4,004,257
838.54	900,942	1,345,209	1,931,356	2614890	3395811	4274120
	Pessimistic Scenario					
836.54	0	0	0	0	0	0
837.54	834,779	1139047	1503769	1896541	2317362	2766232
838.54	891038	1215812	1605115	2024357	2473539	2952660

Source: Adapted from U.S. Army Corps of Engineers (1998).

Appendix Table D34. Projected Commercial Damages for Flood-stage Damage Function, Wahpeton, by Population Scenario for Selected Years, 2006 through 2055

Elevation[a]	2006	2015	2025	2035	2045	2055
	---------- 000s 2004 $ ----------					
Baseline Scenario						
1	0	0	0	0	0	0
2	17877	23907	31350	39,572	48,573	58,400
3	30238	40,439	53028	66,936	82,161	98,783
4	46600	62,320	81,722	103154	126,618	152,234
5	63117	84,409	110,688	139717	171,497	206,192
6	81064	108,411	142,162	179,445	220262	264,823
7	98123	131,224	172,078	217207	266613	320,552
Optimistic Scenario						
1	0	0	0	0	0	0
2	17,877	23907	31,350	39,572	48,573	58400
3	30,238	40,439	53028	66936	82161	98,783
4	46600	62,320	81,722	103154	126,618	152234
5	63117	84,409	110,688	139,717	171497	206192
6	81064	108,411	142,162	179,445	220262	264823
7	98,123	131,224	172,078	217,207	266613	320552
Pessimistic Scenario						
1	0	0	0	0	0	0
2	17688	21571	25,644	29,461	33022	36328
3	29918	36488	43,376	49,832	55856	61448
4	46107	56,231	66,846	76796	86,079	94696
5	62450	76,161	90,540	104016	116,589	128261
6	80207	97,818	116,285	133,593	149742	164732
7	97086	118402	140,755	161705	181253	199398

[a] Numbers in the table correspond to one foot increments above a reference elevation. The elevation of the Red River for the same flood-event size changes at different locations within the city. The FSDFs were developed for portions of the city and combined using common reference elevations above and below the 100-year event.
Source: Adapted from U.S. Army Corps of Engineers (2000b).

Appendix Table D35. Projected Commercial Damages for Flood-stage Damage Function, Breckenridge, by Population Scenario for Selected Years, 2006 through 2055

Elevation[a]	2006	2015	2025	2035	2045	2055
	---- 000s 2004 $ ----					
Baseline Scenario						
1	0	0	0	0	0	0
2	28,419	37,053	45,412	52,376	57,726	61,865
3	34,121	44,487	54,524	62,886	69,309	74,278
4	38,659	50,404	61,776	71,249	78,527	84,157
5	39,865	51,977	63,703	73,473	80,978	86,783
6	46,037	60,024	73,566	84,848	93,515	100,219
7	48,915	63,776	78,164	90,151	99,360	106483
Optimistic Scenario						
1	0	0	0	0	0	0
2	28,610	39,804	52,450	65,314	78,397	88,766
3	34,350	47,791	62,974	78,419	94,127	106,577
4	38,919	54,147	71,349	88,849	106,646	120,751
5	40,134	55,837	73,576	91,622	109,974	124,519
6	46,347	64,481	84,967	105,807	127,000	143798
7	49,244	68,512	90,278	112,420	134,939	152786
Pessimistic Scenario						
1	0	0	0	0	0	0
2	28415	37,116	45,429	52,315	57,775	61,865
3	34117	44,563	54,544	62,812	69,367	74,278
4	38,654	50,490	61,798	71,166	78,593	84157
5	39,860	52,066	63,727	73,387	81,046	86783
6	46032	60,127	73,593	84,749	93,593	100219
7	48909	63,885	78,193	90,046	99,444	106483

[a] Numbers in the table correspond to one foot increments above a reference elevation. The elevation of the Red River for the same flood-event size changes at different locations within the city. The FSDFs were developed for portions of the city and combined using common reference elevations above and below the 100-year event.
Source: Adapted from U.S. Army Corps of Engineers (2000a).

Appendix Table D36. Projected Commercial Damages for Flood-stage Damage Function, Drayton, by Population Scenario for Selected Years, 2006 through 2055

Elevation	2006	2015	2025	2035	2045	2055
- (ft msl) -	----------------------------	----------------------------	000s 2004 $	----------------------------	----------------------------	----------------------------
	Baseline Scenario					
792.8	37	37	37	37	37	37
795.24	97	97	97	97	97	97
796.97	242	242	242	242	242	242
798.83	1,191	1,191	1,191	1,191	1,191	1,191
800.06	2,948	2,948	2,948	2,948	2948	2,948
802.87	6,127	6,127	6,127	6,127	6,127	6127
	Optimistic Scenario					
792.8	37	37	37	37	37	37
795.24	97	97	97	97	97	97
796.97	242	242	242	242	242	242
798.83	1,191	1,191	1,191	1,191	1,191	1,191
800.06	2,948	2,948	2,948	2,948	2,948	2,948
802.87	6,127	6,127	6,127	6,127	6,127	6127
	Pessimistic Scenario					
792.8	36	34	32	29	27	24
795.24	96	91	84	78	71	64
796.97	241	226	210	194	177	161
798.83	1183	1,111	1,031	951	871	791
800.06	2,928	2,750	2,552	2,354	2,156	1958
802.87	6085	5,715	5,304	4,892	4,481	4070

[a] Elevation of Red River in mean sea level.
Source: Adapted from U.S. Army Corps of Engineers (2004).

Appendix Table D37. Projected Commercial Damages for Flood-stage Damage Function, Crookston, Baseline Population, Selected Years, 2006 through 2055

Elevation[a]	2006	2015	2025	2035	2045	2055
	---------- 000s 2004 $ ----------					
-9	0	0	0	0	0	0
-8	6	8	10	13	15	18
-7	16	21	27	34	40	47
-6	26	34	45	55	65	76
-5	32	43	55	68	81	95
-4	61	82	106	131	156	181
-3	139	187	241	296	353	411
-2	237	318	411	505	602	701
-1	377	504	651	801	954	1,112
0	649	870	1,123	1,381	1,645	1,917
1	1,956	2,620	3,382	4,159	4,957	5,774
2	2,902	3,886	5,017	6,169	7,352	8565
3	4,086	5,472	7,065	8,688	10,354	12061
4	5307	7,107	9,175	11,283	13,447	15664
5	6741	9,028	11,655	14,333	17,081	19898

[a] Numbers in the table correspond to one foot increments above a reference elevation. The elevation of the Red River for the same flood-event size changes at different locations within the city. The FSDFs were developed for portions of the city and combined using common reference elevations above and below the 100-year event.
Source: Adapted from U.S. Army Corps of Engineers (1997).

Appendix Table D38. Projected Commercial Damages for Flood-stage Damage Function, Crookston, Optimistic Population, Selected Years, 2006 through 2055

Elevation[a]	2006	2015	2025	2035	2045	2055
	------------	------------	------ 000s 2004 $ ------	------------	------------	------------
-9	0	0	0	0	0	0
-8	6	8	12	15	19	23
-7	16	23	31	40	50	62
-6	26	37	50	65	82	100
-5	32	46	63	82	102	125
-4	62	88	120	156	196	239
-3	140	199	273	354	444	542
-2	239	340	465	604	756	923
-1	379	539	737	957	1,200	1,465
0	654	929	1,271	1,651	2,069	2,525
1	1,970	2,798	3,828	4,972	6,232	7,606
2	2,922	4,151	5,678	7,376	9,244	11,283
3	4,115	5,845	7,996	10,386	13,017	15,889
4	5,345	7,591	10,384	13,489	16,906	20635
5	6,789	9,643	13,191	17,135	21,476	26213

[a] Numbers in the table correspond to one foot increments above a reference elevation. The elevation of the Red River for the same flood-event size changes at different locations within the city. The FSDFs were developed for portions of the city and combined using common reference elevations above and below the 100-year event.
Source: Adapted from U.S. Army Corps of Engineers (1997).

Appendix Table D39. Projected Commercial Damages for Flood-stage Damage Function, Crookston, Pessimistic Population, Selected Years, 2006 through 2055

Elevation[a]	2006	2015	2025	2035	2045	2055
	---------- 000s 2004 $ ----------					
-9	0	0	0	0	0	0
-8	6	8	10	12	14	15
-7	16	21	26	31	36	41
-6	26	34	42	50	59	66
-5	32	42	53	63	73	83
-4	61	80	101	120	140	158
-3	139	182	228	273	317	359
-2	237	310	389	465	540	612
-1	376	492	617	738	857	971
0	648	847	1,063	1,273	1,477	1,674
1	1,952	2,553	3,203	3,835	4,449	5,044
2	2,895	3,786	4,751	5,689	6,599	7,482
3	4,077	5,332	6,691	8,011	9,292	10,536
4	5,294	6,925	8,690	10,404	12,068	13,683
5	6,725	8,797	11,038	13,216	15,330	17,381

[a] Numbers in the table correspond to one foot increments above a reference elevation. The elevation of the Red River for the same flood-event size changes at different locations within the city. The FSDFs were developed for portions of the city and combined using common reference elevations above and below the 100-year event.
Source: Adapted from U.S. Army Corps of Engineers (1997).

APPENDIX E

Waffle Costs by Expense Category for Baseline, Optimistic, and Pessimistic Cost Scenarios

Appendix Table E1. Present Value of Waffle Costs, Baseline Projections, Full-scale Waffle, 2006 through 2055

	Acreage Option for Full-Scale Waffle		
Item	Minimum	Moderate	Maximum
Acreage	405,312	872,256	1,414,560
Sections	4,789	4,789	4,789
	-----------------------	000s $	-----------------------
Enrollment Expenses	9,174	9,174	9,174
Retainer Payments	63,763	136,971	222,812
Landowner Payments (water storage payments)	68,205	146,511	238,331
Culvert Devices and Installation	43,599	43,599	43,599
Maintenance of Culvert Devices	13,458	13,458	13,458
Administration	9,732	12,478	15,666
Total	207,931	362,191	543,040
Cost per Year	4,159	7,244	10,861
Cost per Acre ($ per acre)	513	415	384

Appendix Table E2. Present Value of Waffle Costs, Baseline Projections, Half-scale Waffle, 2006 through 2055

	Acreage Option for Half-Scale Waffle		
Item	Minimum	Moderate	Maximum
Acreage	203,872	436,800	708,800
Sections	2,396	2,396	2,396
	-----------------------	000s $	-----------------------
Enrollment Expenses	4,590	4,590	4,590
Retainer Payments	32,023	68,485	111,540
Landowner Payments (water storage payments)	34,254	73,255	119,309
Culvert Devices and Installation	21,815	21,815	21,815
Maintenance of Culvert Devices	6,734	6,734	6,734
Administration	8,548	9,918	11,517
Total	107,964	184,797	275,505
Cost per Year	2,159	3,670	5,510
Cost per Acre ($ per acre)	530	423	389

Appendix Table E3. Present Value of Waffle Costs, Optimistic Projections, Full-scale Waffle, 2006 through 2055

	Acreage Option for Full-Scale Waffle		
Item	Minimum	Moderate	Maximum
Acreage	405,312	872,256	1,414,560
Sections	4,789	4,789	4,789
	-----------------------	000s $	-----------------------
Enrollment Expenses	5,494	5,494	5,494
Retainer Payments	50,113	107,651	174,997
Landowner Payments (water storage payments)	47,860	102,812	167,131
Culvert Devices and Installation	39,697	39,697	39,697
Maintenance of Culvert Devices	5,838	5,838	5,838
Administration	6,737	8,045	9,564
Total	155,739	269,537	402,721
Cost per Year	3,115	5,391	8,054
Cost per Acre ($ per acre)	384	309	285

Appendix Table E4. Present Value of Waffle Costs, Optimistic Projections, Half-scale Waffle, 2006 through 2055

	Acreage Option for Half-Scale Waffle		
Item	Minimum	Moderate	Maximum
Acreage	203,872	436,800	708,800
Sections	2,396	2,396	2,396
	-----------------------	000s $	-----------------------
Enrollment Expenses	2,749	2,749	2,749
Retainer Payments	25,171	53,820	87,602
Landowner Payments (water storage payments)	24,039	51,400	83,664
Culvert Devices and Installation	19,862	19,862	19,862
Maintenance of Culvert Devices	2,921	2,921	2,921
Administration	6,173	6,826	7,588
Total	80,915	137,578	204,386
Cost per Year	1,618	2,752	4,088
Cost per Acre ($ per acre)	397	315	288

Appendix Table E5. Present Value of Waffle Costs, Pessimistic Projections, Full-scale Waffle, 2006 through 2055

	Acreage Option for Full-Scale Waffle		
Item	Minimum	Moderate	Maximum
Acreage	405,312	872,256	1,414,560
Sections	4,789	4,789	4,789
	----------------------- 000s $ -----------------------		
Enrollment Expenses	14,099	14,099	14,099
Retainer Payments	77,863	1,675,253	272,253
Landowner Payments (water storage payments)	99,151	212,980	346,685
Culvert Devices and Installation	49,526	49,526	49,526
Maintenance of Culvert Devices	32,122	32,122	32,122
Administration	14,565	18,892	23,917
Total	287,326	494,872	738,602
Cost per Year	5,747	9,897	14,772
Cost per Acre ($ per acre)	709	567	522

Appendix Table E6. Present Value of Waffle Costs, Pessimistic Projections, Half-scale Waffle, 2006 through 2055

	Acreage Option for Half-Scale Waffle		
Item	Minimum	Moderate	Maximum
Acreage	203,872	436,800	708,800
Sections	2,396	2,396	2,396
	----------------------- 000s $ -----------------------		
Enrollment Expenses	7,053	7,053	7,053
Retainer Payments	39,099	83,634	136,293
Landowner Payments (water storage payments)	49,789	106,499	173,555
Culvert Devices and Installation	24,781	24,781	24,781
Maintenance of Culvert Devices	16,073	16,073	16,073
Administration	12,699	14,857	17,377
Total	149,494	252,897	375,132
Cost per Year	2,990	5,058	7,503
Cost per Acre ($ per acre)	733	579	529

Appendix Table E7. Present Value of Waffle Costs, Full-scale Waffle, Baseline Cost Assumptions, Used Only for Events Larger than 100-year Floods, 2006 through 2055

	Acreage Option for Full-Scale Waffle		
Item	Minimum	Moderate	Maximum
Acreage	405,312	872,256	1,414,560
Sections	4,789	4,789	4,789
	-----------------------	000s $	-----------------------
Enrollment Expenses	9,174	9,174	9,174
Retainer Payments	63,763	136,971	222,812
Landowner Payments (water storage payments)	7,428	15,957	25,957
Culvert Devices and Installation	43,599	43,599	43,599
Maintenance of Culvert Devices	13,458	13,458	13,458
Administration	9,732	12,478	15,666
Total	147,154	231,637	330,666
Cost per Year	2,943	4,633	6,613
Cost per Acre ($ per acre)	363	266	234

Appendix Table E8. Present Value of Waffle Costs, Half-scale Waffle, Baseline Cost Assumptions, Used Only for Events Larger than 100-year Floods, 2006 through 2055

	Acreage Option for Half-Scale Waffle		
Item	Minimum	Moderate	Maximum
Acreage	405,312	872,256	1,414,560
Sections	4,789	4,789	4,789
	-----------------------	000s $	-----------------------
Enrollment Expenses	4,590	4,590	4,590
Retainer Payments	32,023	68,485	111,540
Landowner Payments (water storage payments)	3,731	7,978	12,994
Culvert Devices and Installation	21,815	21,815	21,815
Maintenance of Culvert Devices	6,734	6,734	6,734
Administration	8,548	9,918	11,517
Total	77,441	119,520	169,190
Cost per Year	1,549	2,390	3,384
Cost per Acre ($ per acre)	380	274	239

APPENDIX F

Documentation on Waffle Water Storage Procedures and Outcomes of Water Storage Scenarios on Crest Height Reductions

Evaluation of Waffle Storage Effects

One of the key pieces of information needed for the economic analysis was an evaluation of the Waffle effects for various magnitude floods, both smaller and larger than 1997. Although the effects of the conservative storage estimates on the 1997 flood were explicitly modeled using the Soil and Water Assessment Tool (SWAT) and the Hydrologic Engineering Center's River Analysis System (HEC-RAS), it was beyond the scope of the Waffle study to calibrate the models for a variety of hypothetical flood events. Thus, the modeling results alone did not provide sufficient information to evaluate the economic feasibility of a wide range of Waffle storage scenarios for various-sized flood events.

In order to quickly evaluate a variety of different storage and flood magnitude scenarios, an algorithm was developed based on the relationship between storage volume and peak flow reductions observed through the SWAT modeling effort. This relationship for a given watershed (i.e., U.S. Geological Survey 8-digit hydrologic cataloging unit) can be expressed by:

$$Y = 1.4638 + 4.6063 \cdot X + 2.8622 \cdot X^2 \qquad (R^2 = 0.84) \qquad (1)$$

where Y is the peak reduction (%), and X is an independent variable.

Using $Q^{p}_{pre\text{-}waffle}$ and $Q^{p}_{post\text{-}waffle}$, in ft^3/sec, to signify the pre- and post-waffle peaks, respectively, Y is computed as:

$$Y = \frac{Q^{p}_{pre\text{-}waffle} - Q^{p}_{post\text{-}waffle}}{Q^{p}_{pre\text{-}waffle}} \times 100\% \qquad (2)$$

X is formulated as:

$$X = \ln\left(\frac{V_{waffle}}{Q^{p}_{pre\text{-}waffle}}\right) \qquad (3)$$

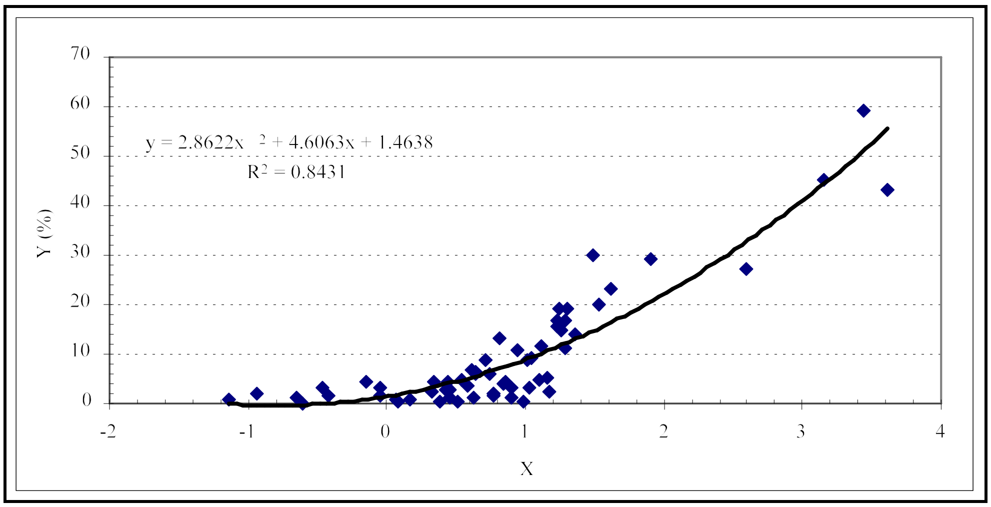
where V_{waffle} is the volume of waffle storage in the watershed (ac-ft).

The 95% confidence interval for Equation (1) is determined as:

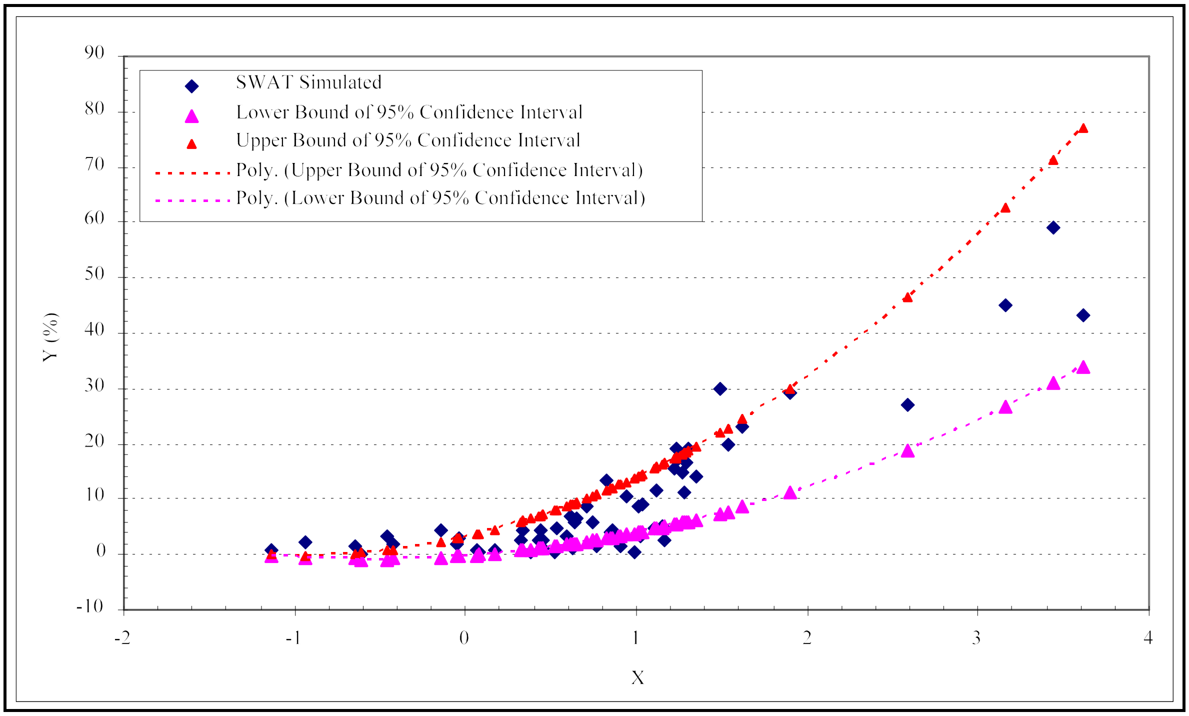
$$[-0.2659 + 2.1626 \cdot X + 2.0098 \cdot X^2, \quad 3.1935 + 7.0500 \cdot X + 3.7146 \cdot X^2] \qquad (4)$$

Prediction Accuracy

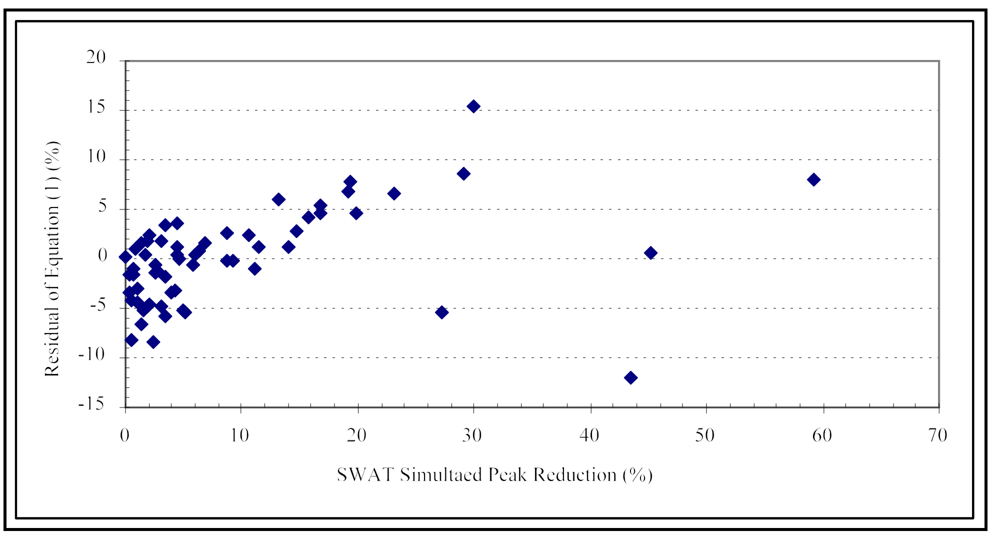
Equation (1) has a coefficient of determination (R^2) of 0.84, indicating a good prediction performance. Based on Figure 1, this equation can satisfactorily reflect the relationship between X and Y exhibited by the SWAT simulated data points (Figure 1). In addition, the statistical performance is verified by the fact that more than 62% of the data points fall in the 95% confidence interval computed using Equation (4) (Figure 2). Further, the prediction residuals from Equation (1) do not exhibit any clear pattern, i.e., the residuals do not have a consistent relationship with the SWAT simulated peak reductions (Figure 3). Therefore, Equation (1) may be a reliable model for use in estimating the peak reduction from a flood event with a peak discharge $Q^{p}_{pre\text{-}waffle}$ as a result of the waffle storage volume V_{waffle}.



Appendix Figure F1. SWAT Simulated Data Points and Regression Curve.



Appendix Figure F2. SWAT Simulated Data Points and 95 Percent Confidence Interval.



Appendix Figure F3. Pattern of Residuals.

Determination of Peak Reductions for Arbitrary Flood Events

Equation (1) was used to estimate the peak flow reduction for arbitrary flood events (e.g., flows twice as large as 1997), given various Waffle storage estimates for each watershed (moderate, conservative, etc…). For example, given that the 1997 peak discharge in the Rabbit River watershed was 6185 ft^3/sec, to approximate the flow reduction for a flood event

200% larger than 1997 (double the flows) if 100% of conservative Waffle storage estimates (22,784 ac-ft) were used, the following calculation was conducted:

$$X = 1n\left(\frac{22784}{2 \times 6185.00} \right) = 0.61078$$

$$Y = 1.4638 + 4.6063 \times 0.61078 + 2.8622 \times 0.61078^2 = 5.3\ \%$$

Thus, a 5.3% reduction in peak flows would be expected at the mouth of the Rabbit River by implementing 100% of the Waffle storage determined from conservative volume estimates.

The validity of this approach can be evaluated by comparing the predicted reduction in flows estimated by the above methodology to the flows predicted using the SWAT models (Table 1). Since only the conservative storage estimates were explicitly modeled using SWAT, the moderate storage estimates could not be used for comparison. The results compare well for most of the watersheds; however, in the comparison of revised flows for 100% of the conservative storage volume estimates, five watersheds have % errors larger than 15% (no errors were larger than 25%). These five watersheds include the Upper Red, Marsh, Grand Marais, and Lower Red in Minnesota and the Lower Sheyenne in North Dakota. In the comparison of revised flows for 50% of the conservative storage estimates, two watersheds, the Grand Marais in Minnesota and the Bois de Sioux in North Dakota, have % errors greater than 15%. Although these errors are larger than the preferred range of ± 15%, the flow rates in the Upper Red and Grand Marais are so low after accounting for Waffle storage, that they have minimal impact on the flows within the Red River. The remaining four watersheds with errors larger than ± 15% for both storage scenarios have low to moderate flows, and, therefore, slightly larger errors in these systems should not overly impact the relative storage reduction results.

To estimate the reduced peak flows at various locations along the mainstem as a result of implementing Waffle storage, the adjusted flows from the tributaries upstream of various mainstem points were added together. Rating curves obtained from the USGS and USACE were then used to estimate the corresponding stage at each mainstem location. While this is not as accurate as using a hydraulic model, like HEC-RAS, to calculate the revised flows, it was sufficient for generating ballpark estimates. The effects of various Waffle storage estimates applied to floods smaller and larger than the 1997 flood (in terms of flows) were evaluated for Wahpeton/Breckenridge, Fargo/Moorhead, Grand Forks/East Grand Forks, and Drayton. (Tables 2 through 5).

Appendix Table F1. Comparison of Flow Reductions Predicted using the SWAT Models Versus the Empirical Equation Methods

	Watershed Name	USGS HUC	Revised Flows: 100% of Conservative Storage Estimates			Revised Flows: 50% of Conservative Storage Estimates		
			Equation-Predicted Flows (cfs)	SWAT-Predicted Flows (cfs)	% Error	Equation-Predicted Flows (cfs)	SWAT-Predicted Flows (cfs)	% Error
MN Watersheds	Rabbit	9020101	5,422	5,000	-8.4	5,854	5,458	-7.3
	Mustinka	9020102	9,915	9,735	-1.8	9,915	9,830	-0.9
	Otter Tail	9020103	1,556	1,610	3.3	1,615	1,615	0.0
	Upper Red	9020104	611	510	-19.7	804	910	11.7
	Buffalo	9020106	8,006	8,575	6.6	8,477	8,640	1.9
	Marsh	9020107	6,750	5,540	-21.8	7,361	7,215	-2.0
	Wild Rice MN	9020108	10,139	10,095	-0.4	10,735	10,405	-3.2
	Sandhill	9020301	3,970	4,015	1.1	4,282	4,250	-0.7
	Red Lake	9020303	18,051	19,090	5.4	19,296	19,540	1.2
	Grand Marais	9020306	303	385	21.3	413	500	17.4
	Snake	9020309	14,480	13,835	-4.7	14,480	14,175	-2.2
	Lower Red	9020311	3,890	3,190	-21.9	3,890	3,480	-11.8
	Two Rivers	9020312	4,158	4,100	-1.4	4,501	4,445	-1.3
ND Watersheds	Bois de Sioux	9020101	2,351	2,080	-13.0	2,428	2,090	-16.2
	Wild Rice	9020105	7,627	8,084	5.6	8,172	8,296	1.5
	Elm	9020107	3,880	3,460	-12.2	4,338	4,120	-5.3
	Goose	9020109	6,609	7,430	11.1	7,190	7,554	4.8
	Lower Sheyenne	9020204	3,907	4,708	17.0	4,324	4,747	8.9
	Maple	9020205	6,146	6,488	5.3	6,466	6,537	1.1
	Wilson	9020301	5,086	4,780	-6.4	5,471	5,477	0.1
	Turtle	9020307	2,095	2,168	3.4	2,213	2,207	-0.3
	Forest	9020308	2,790	2,768	-0.8	2,956	2,906	-1.7
	Park	9020310	6,498	6,286	-3.4	7,003	7,335	4.5
	Lower Red	9020311	2,928	2,770	-5.7	3,201	2,999	-6.7

Limitations and Empirical Adjustments

In the event that the equations, discussed above, are used in the future, it is worth mentioning some of the limitations of the approach and a correction factor used to account for attenuation of flows along the mainstem. For a location of interest along the mainstem, this procedure does not consider timing of the peaks from the corresponding contributing watersheds. In addition, between two adjacent locations (e.g., from Fargo to Halstad), the procedure assumes no attenuation of the peaks. These assumptions could result in either the overestimation or underprediction of the peak at the location of interest. To address this issue, a HEC-RAS model was used to evaluate the attenuation effects along the mainstem. The evaluation indicates that for the existing or pre-Waffle conditions, the attenuation effects are negligible for the 1997 flood. That is, the attenuation coefficients are close to a factor of "one". For post-Waffle conditions, the attenuation effects for most reaches of the mainstem (i.e., from Fargo to Halstad, Halstad to Grand Forks, Grand Forks to Drayton, and Drayton to Emerson) were small; however, this was not the case with the reach between Wahpeton and Fargo/Moorhead. The attenuation coefficient for the reach from Wahpeton to Fargo/Moorhead was determined to be approximately 0.72 after implementation of 100% of conservative storage estimates, whereas, the coefficients for the other reaches were determined to be greater than 0.95. These attenuation effects would be a result of altered timing, friction along the river banks, and the width of the inundated flood plain. Therefore, it is recommended that the computed peaks at Fargo/Moorhead, using the equation approach, be multiplied by a coefficient of 0.72. Because attenuation effects along the other reaches were within a 5% margin of error, an attenuation coefficient was not applied to the other mainstem reaches.

The procedure described above was mainly designed to predict overall trends and relative changes between existing and post-Waffle conditions. It was used mainly to extrapolate the results for the 1997 flood to larger floods and to evaluate various Waffle storage volumes to provide a range of Waffle effects for use in the economic analysis. For those purposes, the procedure is sufficiently accurate. However, to more accurately predict "true" peak discharges along the mainstem, a hydraulic model such as HEC-RAS should be used.

Appendix Table F2. Estimated Red River Flow and Stage Reductions at Wahpeton as a Result of Various Waffle Storage Estimates

	50% of 1997 Flows (cfs) (Flow w/out storage: 10,072 cfs)		1997 Flows (cfs) (Flow w/out storage: 20,143 cfs)		125% of 1997 Flows (cfs) (Flow w/out storage: 25,179 cfs)		150% of 1997 Flows (cfs) (Flow w/out storage: 30,215 cfs)		200% of 1997 Flows (cfs) (Flow w/out storage: 40,286 cfs)	
	Reduced Flows	Stage Reduction	Reduced Flows	Stage Reduction	Reduced Flows	Stage Reduction	Reduced Flows	Stage Reduction	Reduced Flows	Stage Reduction
Moderate Storage Estimates	7097	2.34	16430	1.92	21290	1.82	26222	1.66	36225	1.41
50% of Moderate Storage Estimate	8215	1.40	18113	1.02	23170	0.94	28394	0.75	38488	0.63
Conservative Storage Estimate	9056	0.73	19241	0.43	24319	0.40	29409	0.33	39625	0.23
50% of Conservative Storage Estimate	9622	0.31	19812	0.16	24894	0.12	29980	0.09	40286	0.0

Appendix Table F3. Estimated Red River Flow and Stage Reductions at Fargo as a Result of Various Waffle Storage Estimates

	50% of 1997 Flows (cfs) (Flow w/out storage: 14,961 cfs)		1997 Flows (cfs) (Flow w/out storage: 29,922 cfs)		125% of 1997 Flows (cfs) (Flow w/out storage: 37,402 cfs)		150% of 1997 Flows (cfs) (Flow w/out storage: 44,882 cfs)		200% of 1997 Flows (cfs) (Flow w/out storage: 59,843 cfs)	
	Reduced Flows	Stage Reduction	Reduced Flows	Stage Reduction	Reduced Flows	Stage Reduction	Reduced Flows	Stage Reduction	Reduced Flows	Stage Reduction
Moderate Storage Estimates	6760	7.69	16117	6.18	21084	5.66	26153	4.75	36495	3.69
50% of Moderate Storage Estimate	8059	5.75	18247	5.13	23509	4.48	28924	3.69	39574	3.01
Conservative Storage Estimate	9124	4.52	19785	4.38	25164	3.75	30573	3.05	41455	2.59
50% of Conservative Storage Estimate	9894	3.81	20728	3.92	26165	3.37	31611	2.65	42673	2.42

Appendix Table F4. Estimated Red River Flow and Stage Reductions at Grand Forks as a Result of Various Waffle Storage Estimates

	50% of 1997 Flows (cfs) (Flow w/out storage: 55,769 cfs)		1997 Flows (cfs) (Flow w/out storage: 111,537 cfs)		125% of 1997 Flows (cfs) (Flow w/out storage: 139,421 cfs)		150% of 1997 Flows (cfs) (Flow w/out storage: 167,306 cfs)		200% of 1997 Flows (cfs) (Flow w/out storage: 223,074 cfs)	
	Reduced Flows	Stage Reduction	Reduced Flows	Stage Reduction	Reduced Flows	Stage Reduction	Reduced Flows	Stage Reduction	Reduced Flows	Stage Reduction
Moderate Storage Estimates	31030	9.18	77665	4.97	102616	4.63	128211	3.43	180757	2.12
50% of Moderate Storage Estimate	38833	4.85	90378	2.97	117273	2.64	144723	1.58	200054	1.15
Conservative Storage Estimate	45189	2.54	100024	1.50	128057	1.28	156309	0.55	213457	0.48
50% of Conservative Storage Estimate	50014	1.21	106729	0.67	135400	0.46	163784	0.18	221140	0.10

Appendix Table F5. Estimated Red River Flow and Stage Reductions at Drayton as a Result of Various Waffle Storage Estimates

	50% of 1997 Flows (cfs) (Flow w/out storage: 69,646 cfs)		1997 Flows (cfs) (Flow w/out storage: 139,292 cfs)		125% of 1997 Flows (cfs) (Flow w/out storage: 174,115 cfs)		150% of 1997 Flows (cfs) (Flow w/out storage: 208,938 cfs)	
	Reduced Flows	Stage Reduction	Reduced Flows	Stage Reduction	Reduced Flows	Stage Reduction	Reduced Flows	Stage Reduction
Moderate Storage Estimates	40269	3.73	99336	2.36	130842	2.11	163110	1.90
50% of Moderate Storage Estimate	49668	2.06	114617	1.39	148401	1.19	182803	1.06
Conservative Storage Estimate	57309	1.20	126067	0.70	161161	0.58	196425	0.50
50% of Conservative Storage Estimate	63097	0.61	133794	0.30	169484	0.22	204843	0.17

Note: The estimates for 200% of 1997 flows were not determined for this location because the flows far exceeded those on the USGS rating curve, and, therefore, accurate stage reductions could not be determined.

Appendix Table F6. Estimated Change in Crest Heights of Red River With the Waffle at Key Locations, by Waffle Scale, Flood Event Size, and Water Storage Scenarios

		Reduction in Red River Crest Heights (feet)			
		Conservative Water Storage		Moderate Water Storage	
Flood Event Size	Crest Height No Waffle	Half-scale	Full-scale	Half-scale	Full-scale
	----------------------------- Wahpeton/Breckenridge -----------------------------				
50% of 1997	17.54	0.31	0.73	1.40	2.34
1997	23.43	0.15	0.42	1.01	1.92
125% of 1997	25.8	0.13	0.40	0.94	1.83
150% of 1997	27.89	0.09	0.33	0.75	1.66
200% of 1997	31.56	0.00	0.23	0.63	1.42
	--------------------------------- Fargo/Moorhead ----------------------------------				
50% of 1997	33.01	3.82	4.52	5.75	7.69
1997	39.94	3.91	4.37	5.13	6.17
125% of 1997	41.87	3.37	3.76	4.48	5.67
150% of 1997	43.25	2.66	3.06	3.69	4.76
200% of 1997	45.35	2.41	2.59	3	3.68
	------------------------- Grand Forks/East Grand Forks --------------------------				
50% of 1997	45.22	1.21	2.54	4.86	9.19
1997	54.2	0.67	1.5	2.97	4.97
125% of 1997	57.61	0.46	1.28	2.64	4.62
150% of 1997	59.77	0.18	0.55	1.58	3.44
200% of 1997	62.55	0.09	0.48	1.15	2.11
	------------------------------------- Drayton --------------------------------------				
50% of 1997	42.63	0.61	1.2	2.05	3.72
1997	47.31	0.3	0.7	1.38	2.36
125% of 1997	48.96	0.22	0.58	1.19	2.11
150% of 1997	50.37	0.17	0.51	1.06	1.9
200% of 1997	na	na	na	na	na

Source: Kurz et al. (2007).

APPENDIX G

Gross Benefits by Location

Appendix Table G1. Present Value of Gross Benefits of the Waffle, by City, Waffle Scale, Water Storage Capacity, and Population Scenario, 2006 through 2055

Scale, Water Storage Estimate, and City	Population Scenario		
	Baseline	Optimistic	Pessimistic
	---------------------------- 000s $ ----------------------------		
Full-scale			
Moderate			
Fargo/Moorhead	729,478	826,239	715,666
Grand Forks/East Grand Forks	155,331	163,736	142,062
Wahpeton/Breckenridge	26,335	27,238	23,883
Drayton	3,647	3,647	3,408
Total	914,790	1,020,861	885,019
Conservative			
Fargo/Moorhead	621,817	704,135	610,059
Grand Forks/East Grand Forks	37,734	39,800	34,478
Wahpeton/Breckenridge	7,025	7,260	6,372
Drayton	1,651	1,651	1,536
Total	668,226	752,846	652,444
Half-scale			
Moderate			
Fargo/Moorhead	672,423	761,612	659,695
Grand Forks/East Grand Forks	120,687	127,235	110,355
Wahpeton/Breckenridge	15,780	16,313	14,309
Drayton	2,739	2,739	2,556
Total	811,629	907,900	786,914
Conservative			
Fargo/Moorhead	588,128	666,026	577,004
Grand Forks/East Grand Forks	14,139	14,912	12,921
Wahpeton/Breckenridge	2,491	2,575	2,264
Drayton	796	796	741
Total	605,554	684,309	592,929