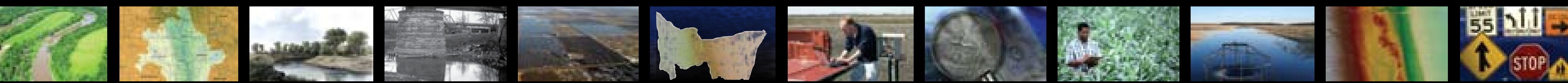
the Waffle®



An Overview of the Waffle Concept:
A Tool for Water Management in the Red River Basin

EERC
Energy & Environmental Research Center®
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Grand Forks

An Overview of the Waffle® Concept

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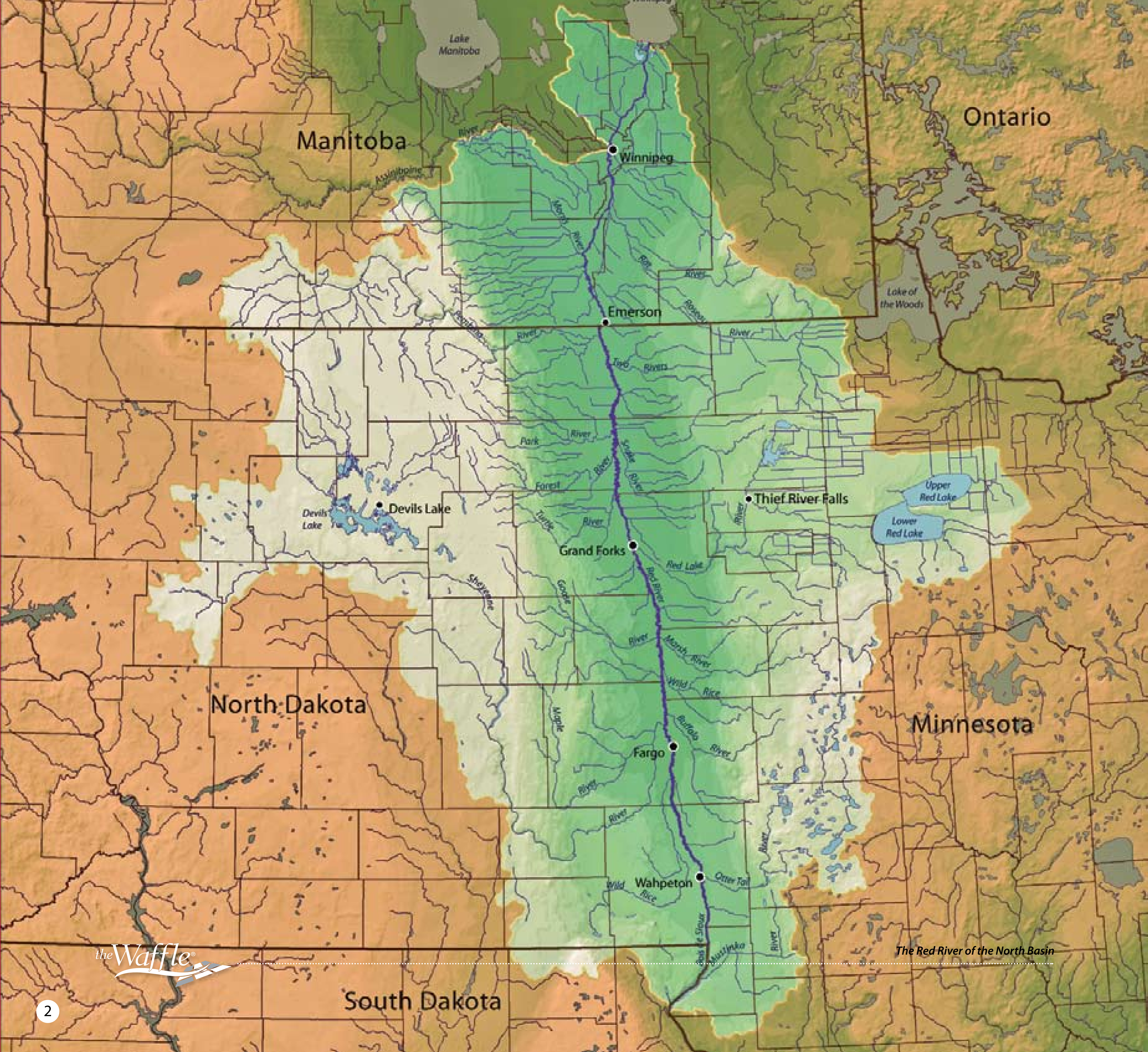
The Waffle project team would like to extend a very special acknowledgment to EERC Director Gerald Groenewold for his vision, dedication, and passion for the Waffle concept. It was through Dr. Groenewold's tireless efforts, fueled by his belief in long-term flood and drought security, that this project was funded.


Close-up

Introduction

The pioneers who opened up the central interior of North America, in what is now eastern North Dakota and western Minnesota, found a region of unprecedented agricultural potential. The deep rich soils eventually provided the raw material that would feed our growing nation and the world. However, those fertile soils would not yield their bounty without sweat, toil, and a struggle against a climate so harsh that it drove some settlers to madness. The hearty folk who remained eventually thrived and developed some of the most productive agricultural land in the world. The Red River of the North flows through these bountiful lands, at the very heart of the continent. The resultant continental climate sees yearly temperature swings between winter and summer of 130°F or more and severe weather in the form of flooding, drought, blizzards, tornadoes, and thunderstorms. Longer-term climate cycles impose their effects on the area's weather as well, resulting in the droughts of the "dirty thirties" and the floods of the past two decades.

Those who seek to live in the region would do well to learn from climatic history and develop infrastructure and strategies that anticipate the recurrence of extreme climatic conditions. The Waffle® concept was developed in the wake of the most devastating climatic event to hit our valley since the dust bowl, the 1997 flood. Described as "a blinding flash of the obvious" by Energy & Environmental Research Center (EERC) Director Gerald Groenewold, the idea's champion and the person who coined the term "Waffle," the concept uniquely meets three very critical criteria for any practical water management strategy in the region: 1) it has utility for both flooding and drought mitigation, 2) it takes advantage of existing infrastructure and protects both the rural and urban parts of the basin, and 3) it does not threaten the agricultural income that is the region's lifeblood. As residents of the region who were hard hit by the 1997 flood, the EERC and its partners were strongly motivated to find a solution to flooding that would stand the tests of time and economics while securing a long-range future for our children. Armed with a powerful idea and even more powerful motivation, the Waffle team set out to evaluate the feasibility of the concept which could provide an innovative approach for keeping our basin more secure from future extreme weather events. This summary of the Waffle concept, key results, and conclusions, as well as the detailed Waffle report contained on the attached CD-ROM, describes the results of the Waffle evaluation for those interested in implementation of basinwide water management strategies.



The Red River of the North Basin

The Red River Basin

The Red River originates at the confluence of the Bois de Sioux and Otter Tail Rivers, forms the boundary between North Dakota and Minnesota, and enters Canada at Emerson, Manitoba, where it continues northward to Lake Winnipeg, Manitoba. It meanders approximately 548 mi (883 km) through the flat and fertile valley of former glacial Lake Agassiz and drains the 45,000-mi^2 (116,500-km^2) Red River Basin (RRB). Both the river channel and the basin are intersected by the international border between the United States and Canada, with approximately 75% of the RRB located in the United States. The north–south axis of the basin is remarkably flat, with an average gradient of 0.5 feet per mile.[1]

Several major population centers are located on the banks of the Red River, including Wahpeton–Breckenridge with a combined population of 12,000, Fargo–Moorhead at 100,000, Grand Forks–East Grand Forks at 60,000, Winnipeg at 670,000, and Selkirk at 9800.[2] Over 74% of the RRB is conducive to agriculture because of the fertile, black, and fine-grained soils.[3] As such, the region's economy is dominated by agriculture and agriculturally related activities.

From approximately 12,000 to 8000 years ago, the RRB was dominated by the massive glacial Lake Agassiz. This lake was formed as meltwaters from the glaciers that existed to the north pooled in front of the glaciers. Lake Agassiz, and the glaciers that provided the water that formed the lake, are largely responsible for the current topography of the RRB. The flattest regions of the basin, located adjacent to the Red River and often referred to as the Red River Valley, were formerly the floor of Lake Agassiz. The soils and sediments of the Red River Valley are high in clay and silt as a result of the fine-grained sediments deposited on the floor of Lake Agassiz. The valley floor is bounded to the west (in North Dakota) and to the east (in Minnesota) by moderately sloped ridges comprising sand and gravel. These ridges, which typically range in height from 3 to 20 feet, mark the former shorelines of Lake Agassiz.[4] Because the lake increased and decreased in size as the glacial front retreated and advanced, the lake had multiple shoreline positions over its 4000-year lifespan, and successive beach ridges can be detected on either side of the valley. Away from the Red River and beyond the beach-ridge zone, the land is characterized by gently rolling hills and depressions. This landscape was created as glacial deposits of boulders, gravel, sand, and clay were deposited and reworked as glaciers advanced and retreated over the region. These deposits, called glacial till, range in thickness from 5 to 200 feet throughout the RRB.[5]

Development of the Red River Basin

Evidence for settlement of the RRB dates back about 800 years, when native people took advantage of the fertile soils and the abundant game of the region.[6] The first Europeans to explore the RRB were the French voyageur Pierre Gaultier de Varennes, sieur de La Vérendrye, and two fellow Frenchmen.[7] These explorers discovered the Red River in 1732 and subsequently named it "Red" based on its high silt content.

The first permanent European settlement, called Assiniboia, was founded in 1811–1812 on the banks of the Red River near the mouth of the Assiniboine River in Winnipeg, Manitoba.[8] Much of the activity in the region at this time was trapping and trading associated with the Hudson's Bay Company. It was not until the 1860s that settlement and farming really expanded in the region as a result of the Homestead Act passed by Congress in 1862. This act allowed settlers to claim 160-acre plots of land for a nominal fee after a minimum 5 years of settlement.[9]

To farm the region and to take advantage of the organic-rich soils, settlers drained many wetlands and wet areas. In some areas, ditches were constructed, and streams and watercourses were channelized to move water more efficiently downstream. Over time, the drainage systems in the RRB have become one of its most prevalent and widespread features.

Currently, about 74% of the land area in the RRB is used for farming, 12% is forests, and 4% comprises wetlands and water. The remaining 10% includes urban areas and undesignated land use.[10]

Low-flow conditions along the Red River at Fargo during 1910.

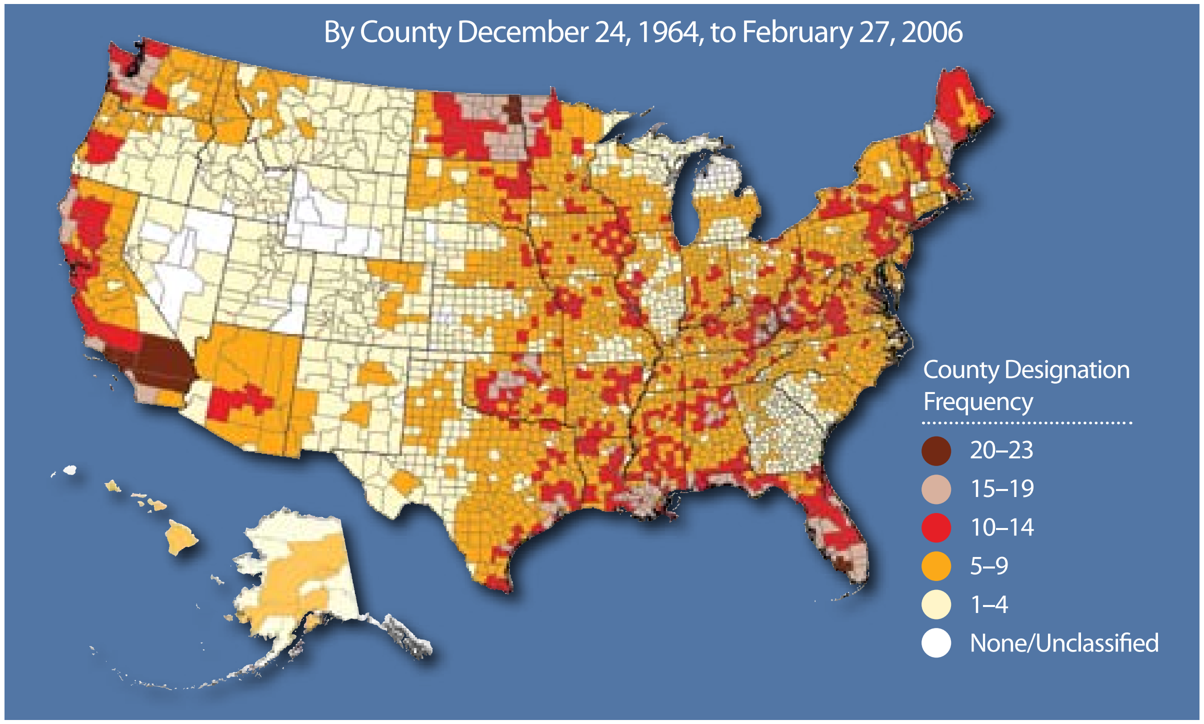
Climate of the Red River Basin

As with many areas of the country, the only thing certain about the climate of the RRB is that one can never be certain what is going to occur next. From extreme droughts to extreme flooding, the region has experienced it all. The short-term weather extremes, such as hot summers, cold winters, and relatively low average annual precipitation (about 20 inches a year), are primarily a result of the continental climate; however, explaining the cyclicity of long-term wet and dry cycles in the region is vastly more complicated.

Since official record keeping began in 1882, major floods affecting large areas of the basin have occurred once in about every 4 to 6 years, with a devastating flood about every decade.[11,12] The major historical floods occurred in 1826, 1852, 1861, 1897, 1950, 1966, 1969, 1975, 1978, 1979, and 1997. The 1826 flood is the worst flood known based on historical accounts; unfortunately, there are no detailed data on this event. During the 1897 flood, a strip of land 30 mi (50 km) wide and 150 mi (240 km) long was inundated.[13] While the other floods caused severe damage, the 1997 flood is the worst in the official record and forced the evacuation of entire cities in the RRB.[14]

The worst drought to hit our region since widespread settlement was in the 1930s. This far-reaching drought lasted over a decade and forced many farmers to move to more temperate climates. While the 1930s drought is almost inconceivable in present times, EERC research focused on the reconstruction of paleoclimatic conditions suggests that frequent climatic fluctuations resulting in alternating periods of drought and wet conditions are typical for the northern Great Plains. Although many of us have come to think of the 1930s drought and the 1997 flood as worst-case scenarios, this research suggests the recurrence interval of wet and dry conditions averages about 150 years and the severity and length of extremes exceed those on modern record.[15] Because we are unable to predict droughts and floods with certainty, it is imperative that we be prepared for both.

PRESIDENTIAL DISASTER DECLARATIONS[16]



The concentration of Presidential disaster declarations per county in the Red River Basin is greater than many other regions of the country. Most of these disaster declarations have been a result of floods and severe storms.

Spring 1997 flood on the Red River of the North in Grand Forks, North Dakota (photograph taken by Steven Norbeck, U.S. Geological Survey, Grand Forks, North Dakota).

A Potential Solution

Motivated by the devastation of the 1997 flood, in 2002, the EERC began investigating the concept of small-scale, distributed storage to augment conventional flood mitigation measures such as dikes and diversions. Although it is often said that the RRB is as "flat as a pancake," the raised road structures actually make it more of a waffle. Just as the raised ridges of waffles store syrup, the raised road network in the RRB can be used to temporarily store water. Thus the Waffle flood mitigation concept would be accomplished utilizing existing "depressions" within the basin, such as low-relief fields bounded by roads, ditches, and/or wetlands. The storage areas, raised roads, and drainage structures would act as a network of channels and control structures to temporarily store water until the Red River flood crest passes. Although by no means a natural system, the Waffle could work with existing infrastructure to mimic a natural system by slowing the progress of water to the main stem. This flood mitigation concept addresses excess runoff before it enters the Red River and becomes a problem, thereby reducing the volume of water needed to be retained by dikes or redirected by diversions downstream.

To investigate the technical, economic, and social feasibility of the concept, the EERC conducted an extensive 4-year study funded by the U.S. Department of Agriculture Natural Resources Conservation Service (NRCS). The overarching goals of the project were to address the following key questions.

Technical Questions

- Where can water be stored in the RRB?
- How much water can be stored?
- How should the existing culverts be modified to retain water?
- How much can stream and river flows be reduced on a local and regional level by employing this storage concept?
- By utilizing existing roads to temporarily retain water in the springtime, would road stability be affected?
- Would this approach cause a delay in planting, and if so, how would this affect crop yields?
- Could the additional soil moisture provide a benefit to crops during dry years?

Economic Questions

- What would it cost to implement and maintain Waffle storage?
- What are the current estimated damage costs as a function of flood height for major cities and towns in the RRB?
- Would the flood damage mitigated by Waffle storage be enough to offset costs of implementing the practice?

Social Questions

- How is this concept perceived by residents of the RRB?
- What are the key social concerns that should be considered when implementing the Waffle?
- Are there political or social issues that could be obstacles to implementation?
- How receptive would farmers or landowners be toward implementing this practice on their land?

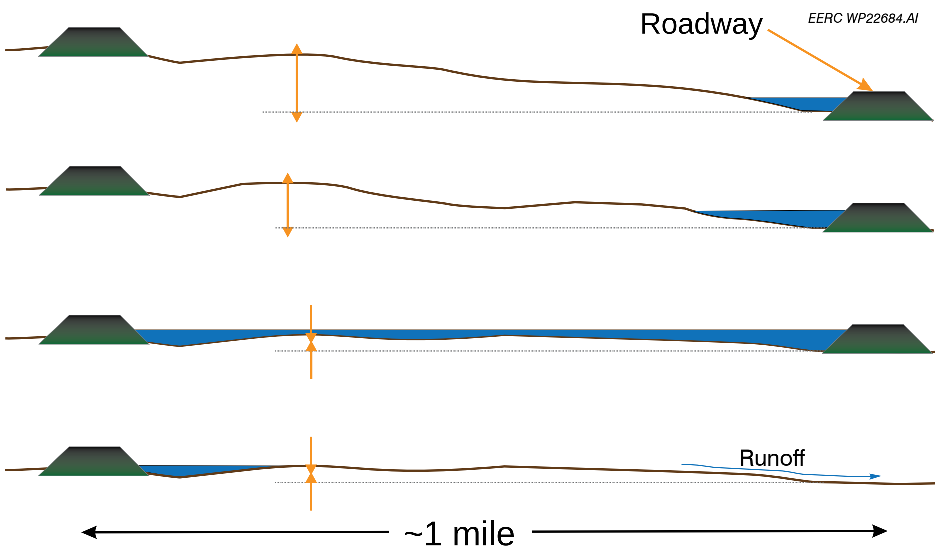
An illustration of how water might be retained in Waffle storage areas. Existing culverts would be outfitted with a standpipe (or vertical riser) and an adjustable canal gate. The top of the standpipe would be set at the desired water storage elevation to maintain some degree of freeboard between the stored water surface and the lowest point on adjacent roads. Once a storage section was filled to the desired level, excess water would flow into the standpipe and travel through the existing drainage system. The adjustable canal gate would typically be fully open in the summer months to allow for immediate drainage of planted fields unless the landowner had a desire to store water.

*The location of potential Waffle storage areas within the Forest River Watershed, totaling an estimated 45,000 acre-feet.**

Identification of Potential Waffle Storage Areas

With nearly 36,000 square miles of the RRB to assess with regard to water storage potential, identifying storage areas suitable for the Waffle concept was a challenge. After conducting a survey of existing data, the EERC determined that the most expedient method of identifying storage areas was to use geographic information systems (GIS) coupled with the best available digital data sets. The primary topographic data set used in the effort was the U.S. Geological Survey's National Elevation Dataset (NED).

Because the Waffle concept entails utilization of existing section line roads, potential storage locations and volumes were evaluated on a 1-square-mile basis, corresponding to individual sections within the township and range system. A total of 3732 randomly selected sections were evaluated for water storage potential, and the results were statistically extrapolated to the remaining areas of the RRB. The preliminary storage volume estimate for the U.S. portion of the RRB was 3,296,000 acre-feet*; however, this volume was reduced to account for 1 foot of freeboard between the stored water surface and the lowest point on the surrounding roads. In addition, this initial storage volume estimate had to be reduced to account for natural storage—or the water that does not contribute to downstream flooding because it remains trapped in small pools on the landscape. Two methods were used to reduce the original storage volume estimate: a conservative estimate that included maximum volume reductions to account for freeboard and natural storage and a moderate estimate that included smaller volume reductions to account for freeboard and natural storage. The conservative RRB storage estimate of 583,400 acre-ft and the moderate RRB storage estimate of 2,188,400 acre-ft were used in estimating the potential flood mitigation effect of the Waffle. These volume estimates assume that water storage occurs on land surrounded by existing roads; however, the study results also indicate that dispersed storage volumes could be significantly increased (perhaps doubled or tripled) if the lowest points along the roads surrounding storage sections were raised by 1 or 2 feet.



The importance of local relief and raised roadways in identifying potential storage areas.

Acre-feet is a volume commonly used in hydrology. It refers to the equivalent of 1 foot of water stored over a certain land area (in acres). For example, 20 acre-feet is equivalent to 1 foot of water stored over 20 acres. A volume of 1 acre-foot is equivalent to approximately 326,000 gallons, or 43,600 cubic feet of water.

Collection of soil moisture and temperature data from the Shelly, Minnesota, field trial site.

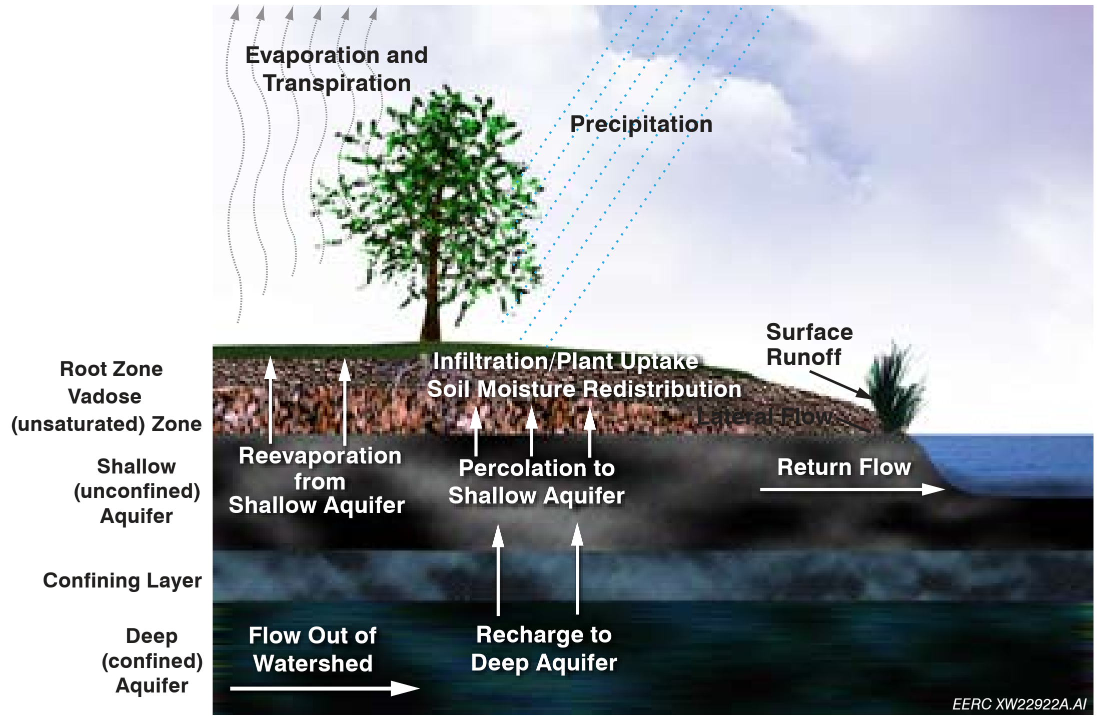
Computer Modeling of the Waffle Effects

Based on the conservative and moderate storage volume estimates and the average depth of water contained in individual storage sections, an estimated 334,200 to 1,170,500 acres of land would be temporarily flooded during the early spring if the Waffle were fully implemented. This corresponds to 1.5% to 5.2% of the RRB total land area (excluding the Devils Lake Basin).

The Waffle storage volume estimates determined in this study were modeled using the Soil and Water Assessment Tool (SWAT) and the Hydrologic Engineering Center's River Analysis System (HEC–RAS) to evaluate peak flow reductions in the Red River and its tributaries and peak stage reductions along the Red River. The results from the model evaluation indicate that Waffle storage could significantly reduce peak stream flows and stages during major springtime flood events. The SWAT model results predicted that conservative Waffle storage volumes could reduce 1997-magnitude peak flows along the tributaries by an average of 13%, with a range from less than 1% to as high as 59.2%. The moderate Waffle storage volumes were estimated to reduce 1997-type peak flows by an average of approximately 33%, with a range from 6% to 96%.

The peak flow reductions along the tributaries were used as input into the HEC–RAS model to determine peak flow and stage reductions along the Red River as a result of implementing Waffle storage during a 1997-type flood event. For a 1997-type flood, the estimated stage reductions as a result of implementing 100% of moderate and conservative Waffle storage volumes, respectively, ranged from 0.3 to 2 feet at Wahpeton–Breckenridge, 3.6 to 6.2 feet at Fargo–Moorhead, 2 to 5 feet at Grand Forks–East Grand Forks, and 1 to 2.4 feet at Drayton. In addition to the 1997 flood, several hypothetical flood events with flows smaller or larger than 1997 were evaluated, including 50%, 125%, 150%, and 200% of 1997 flows. Estimated stage reductions for the various flood events and Waffle storage volumes ranged from 0 to 2.43 feet at Wahpeton–Breckenridge, 2.4 to 7.7 feet at Fargo–Moorhead, 0.1 to 9.2 feet at Grand Forks–East Grand Forks, and 0.2 to 3.7 feet at Drayton.

Two types of computer models were used in the study to estimate the impacts of Waffle storage on flows in the tributaries of the Red River and along the Red River itself. One type, called a hydrologic model, was used to estimate where rainfall or snowmelt travels within a watershed as a function of topography, soil type, land use, land cover, and climatic conditions, such as temperature, wind speed, and humidity. Many processes were considered in the model, such as infiltration, uptake by vegetation and crops, evaporation, and runoff over the land and into stream channels (figure below). Hydrologic models are often used to predict how land management practices or installation of flood control structures (dams, on- and off-channel impoundments, retention ponds, Waffle storage areas, etc.…) affect flows to and within the streams and rivers of a watershed. The second type of model used in the Waffle study is referred to as a hydraulic model. A hydraulic model was used to investigate the routing of water within the Red River and to predict what the height (or stage) of the river would be based upon its flow. The major factors considered in hydraulic models include the dimensions, shape, and characteristics of the river channel, the river gradient, inflows from tributaries and from overland runoff, and flows within the river itself. Hydraulic models are often used to estimate how changes in tributary flow may affect the water level in the channel of the main stem river (in this case, the Red River).



Physical processes considered within the SWAT model.[17]

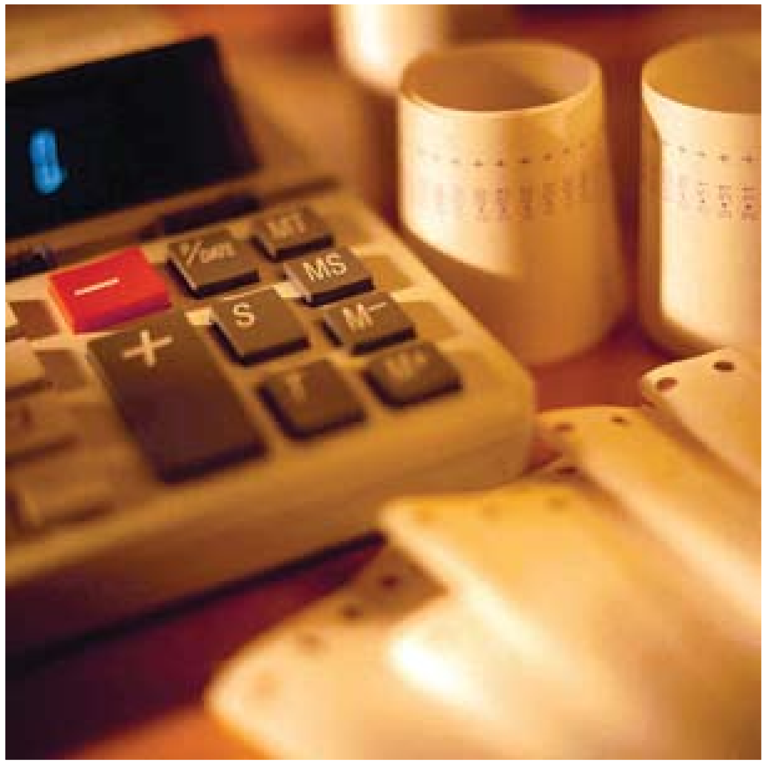

WAFFLE

Economic Evaluation of the Waffle

One of the key goals of the Waffle project was to determine if distributed, basinwide storage is a cost-effective means of mitigating large springtime floods. To evaluate the economic feasibility of the Waffle concept, the EERC subcontracted the North Dakota State University (NDSU) Department of Agribusiness and Applied Economics to conduct an initial assessment of the Waffle's cost-effectiveness in mitigating springtime flood damages in the RRB. The specific objectives of the evaluation were to estimate 1) the costs of maintaining and operating the Waffle, 2) the mitigated flood damages (benefits) from Waffle storage, and 3) the benefit–cost ratio of the Waffle over a reasonable range of physical and economic values.

The costs and benefits of the Waffle were evaluated over a 50-year period from 2006 through 2055. The cost estimates of the Waffle included the estimated expenses for structural modification and maintenance of the storage sites, reimbursement costs for landowners/operators who participate in Waffle storage, administrative costs, and enrollment expenses. The benefits of the Waffle were evaluated in terms of the damage that could be mitigated at several key points along the Red River during major springtime floods.

The net benefits of the Waffle were positive in 106 of the 108 scenarios evaluated by NDSU, with Fargo being the primary beneficiary. Of the scenarios evaluated, 85% resulted in net benefits over $300 million, and nearly half the scenarios had net benefits in excess of $500 million. These results suggest that the Waffle would offer significant economic benefits if used to mitigate large spring floods for the major cities of the RRB. It is important to note that the potential environmental benefits and flood mitigation benefits for smaller communities, farmsteads, rural infrastructure, and agricultural land were not included in the economic evaluation; however, mitigation of these damages could also be significant. For example, during major spring floods, it is not uncommon for individual counties to spend upwards of $1 million to repair damaged roads. The Waffle approach could provide a means of supplementing the income of landowners and/or operators during major flood years, while averting hundreds of millions, if not billions, of dollars in flood damages.



Waffle Field Trials

One of the goals of the Waffle project was to investigate how temporary, springtime water storage would impact the land, roads, and downstream flows. To gain a better understanding of these factors, four field trials were implemented within the RRB from 2004 to 2006. The sites were established by outfitting existing culverts with overflow standpipes and canal gates. In the fall before the sites were used for water storage, each site was instrumented with a series of sensors to determine flow in and out of the site, soil moisture, soil temperature, and climatic conditions (rainfall/snowfall, wind speed, temperature). Individual sites stored up to 200 acre-feet of water for a period ranging from 5 to 14 days. At the end of the temporary water storage period, the canal gates were opened slightly to allow for gradual drainage of the sites. Each site took 1 to 2 days to drain.

Several additional factors were investigated at each site, including soil chemistry before and after storage at flooded and nonflooded locations within the site; water quality at the site and in adjacent ditches before and after water storage; planting delays, if any; and crop yield estimates between wet and dry areas of the site and in adjacent nonstorage sites. Road stability adjacent to the Lake Bronson site was investigated during 2005 and 2006 by monitoring soil temperature and moisture at several locations within the road base.

A road stability control site located 1 mile south of the Lake Bronson site and adjacent to a non-Waffle site was also monitored.

The field trial results were positive, showing that the Waffle concept is a viable water management option. Because the climate of the RRB varies considerably from year to year and even between regions of the RRB within a single year, additional field testing of Waffle storage impacts should be conducted to fully test the system. Some of the key results of the field trials include the following:

- Peak flow reductions in waterways immediately downstream of the storage sites ranged from 12% to 15%.
- No adverse impacts to water quality occurred as a result of water storage.
- Soil moisture was maintained at a higher level longer into the growing season on the wet portions of the field sites.
- Soil temperature evaluations indicated a significant increase in frost thaw rates in the soil where water was stored.
- Road stability evaluations indicated that frost depths in the roads adjacent to the site are thick enough to prevent water seepage into the road.
- Crop yield estimates at the Shelly site were almost identical to those from adjacent, nonflooded fields.

Approximate Site Location	Land Use	Trial Years	Estimated Storage Capacity, acre-feet
Shelly, Minnesota	Agriculture	2004, 2005	150
Lake Bronson, Minnesota	CRP*	2005, 2006	145
Gilby, North Dakota	CRP	2005	200
Holt, Minnesota	CRP	2005	150

** Conservation Reserve Program.*

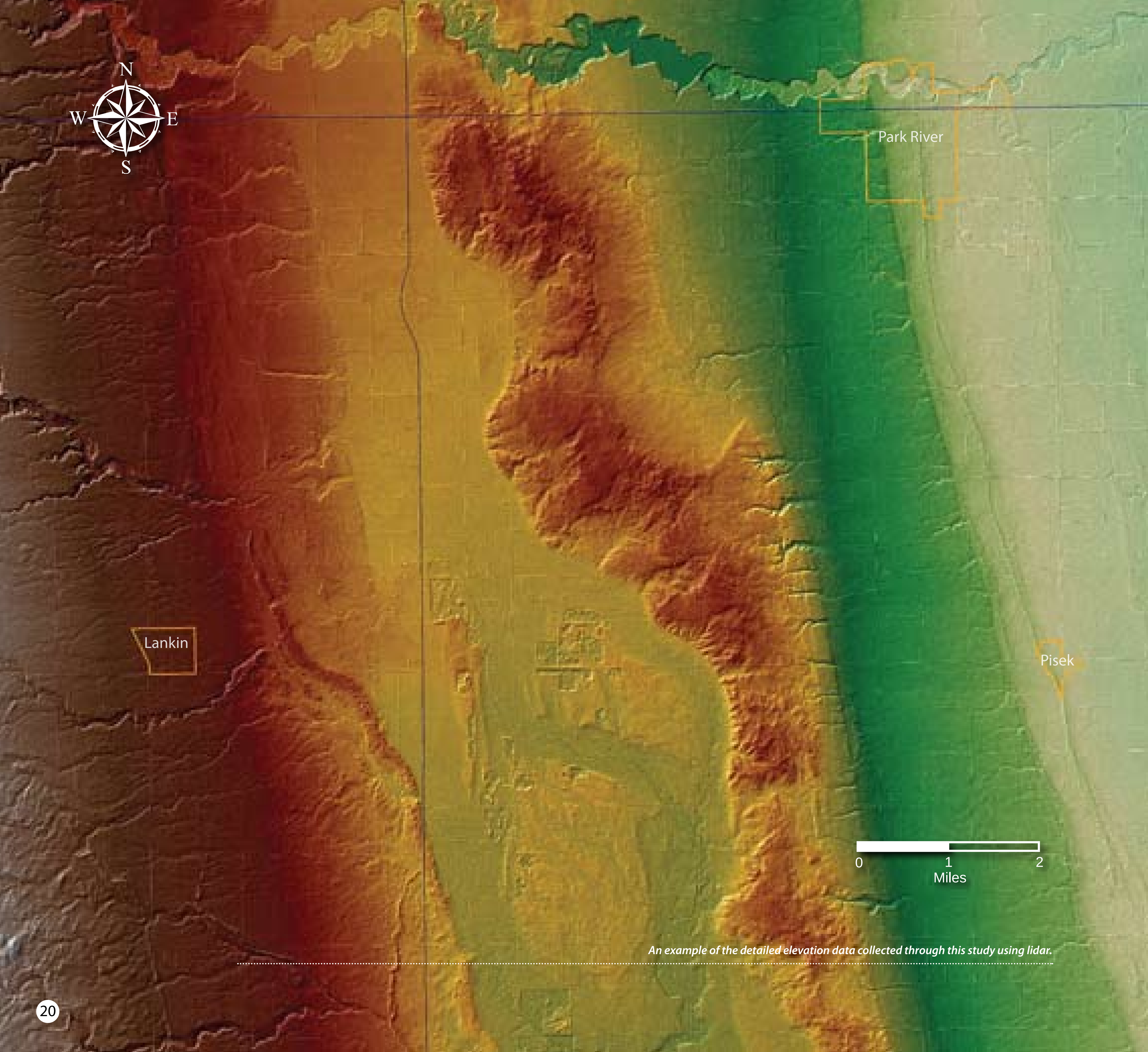
The Waffle trial site located near Holt, Minnesota.

A New Paradigm

As our knowledge of natural resources and environmental systems expands, we have come to realize that changes in one system often have adverse impacts on others. This becomes especially apparent if we begin thinking in terms of drainage basins or watersheds. Historically, our society has been built on and accustomed to political boundaries that were often established without consideration of watershed boundaries; however, if we begin thinking in terms of watersheds, we soon realize that the water and land management decisions we make may potentially affect our neighbors downstream. Water management decisions, in particular, should be based on the watershed as a whole and ideally should incorporate plans to deal with both flooding and drought.

The Waffle concept is one tool for managing water on a watershed basis. It would allow for additional control of water flow during major springtime floods, and its implementation during periods of drought could significantly increase vital soil moisture. However, much of the responsibility for water storage would lie with farmers. Because farming is the backbone of the economy in our region, flood or land management practices that adversely affect farming should not be implemented. Considering the challenges that farmers face from year to year, whether it be uncertainty with regard to weather or agricultural commodity markets, farmers need water management solutions that reduce, not increase, risk. Because the concept of temporary springtime water storage goes against the convention of drainage in the agricultural community, many landowners and producers have questions about the Waffle concept. Therefore, a critical goal of this project was to communicate the concept and to collect and incorporate input from farmers and all stakeholders in the RRB to evaluate the social feasibility of implementing such a practice. For this reason, the EERC conducted an extensive outreach campaign to explain the concept and to collect ideas, concerns, and input related to the implementation of Waffle storage.

Hundreds of meetings were held with a wide variety of entities, including individual farmers, Township Officer Associations, Watershed Districts, Water Resource Boards, Soil and Water Conservation Districts, agricultural growers associations, and a variety of miscellaneous groups and organizations. In addition, two mail surveys were conducted to better determine the key flooding concerns and issues of landowners and farmers in the region. The input gained from these groups helped the EERC gain a better understanding of the key issues and challenges facing Waffle implementation and helped focus the direction of this study.



An example of the detailed elevation data collected through this study using lidar.

Ancillary Benefits of This Study

The Waffle study has shown that the concept of controlled, coordinated release of water from agricultural areas can be a valuable water management tool. The concept has the potential to reduce local and watershed-scale flooding, reduce the washout of roads and culverts, and increase soil moisture in times of drought. The Waffle concept is a tool that water management professionals and landowners should consider when developing water management practices.

Although the EERC's evaluation of the Waffle concept focused on a specific concept for flood mitigation, many of the tools and data produced by this study have benefits for other natural resource applications in the RRB. The following summarizes the major useful products generated through this study and their potential future applications.

Hydrologic and Hydraulic Models

The SWAT models developed by the EERC have a multitude of uses above and beyond the evaluation of Waffle storage. While the SWAT models developed through this project focused on the evaluation of small-scale, distributed storage, SWAT models can be used to predict the effects of any natural or engineered impoundments on water flows (i.e., on- or off-channel dams, wetlands, impoundments, etc.). SWAT is increasingly being used to evaluate water quality issues, such as assessing sediment and nutrient transport within a watershed for establishment of total maximum daily loads (TMDLs). SWAT can also be used to examine the effects of climate change on surface and groundwater supplies, surface water quality, and crop growth. The HEC–RAS model developed jointly by the EERC and the U.S. Army Corps of Engineers is also a very useful tool to evaluate the impacts of droughts, floods, or various flood reduction measures on Red River water levels.

Metadata Web Site

The Waffle metadata Web site (figure below), located at www.undeerc.org/Waffle, is a compilation of information on natural resource data that existed for the RRB at the time of the study. The interactive database allows the user to search for data based on political boundaries (such as states or counties), natural boundaries (such as watersheds), or data type. For example, a user could search for soils and land use data for Walsh County and/or the Forest River Watershed. Multiple combinations of location and/or data type can be performed in the search. The results display the type, location, and reliability of the data. If the data are available over the Internet, a Web site link is provided.

Literature Database

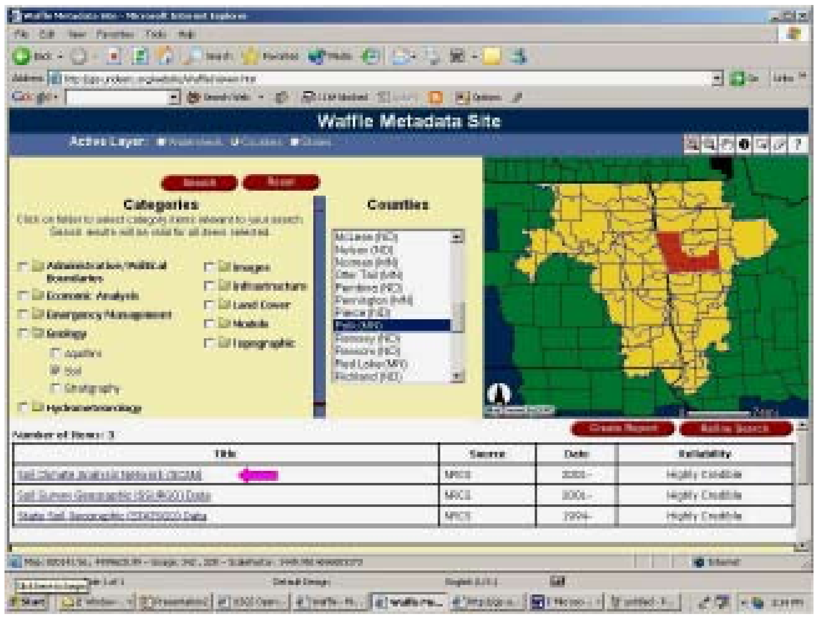
The literature database located on the Waffle Web site allows the user to view a collection of articles related to RRB flooding and related subjects. These references were used directly and indirectly throughout the course of the Waffle project. The user can search the database based on keyword, author, or title. Customized reference lists or bibliographies can be generated from the search results.

Landowner Surveys

The opinions and input regarding flooding and flood mitigation measures collected from the two landowner/farmer surveys contain a wealth of information. These results would be particularly useful to any group or agency interested in implementing flood protection measures within the RRB. For example, the responses contain information regarding what types of structural or nonstructural flood mitigation measures are most or least supported by the public, how people perceive future flood risk, and what practices are believed by the public to most exacerbate flooding problems in the region.

Lidar Data

As part of the study, detailed elevation data from a 1600-square-mile area that includes Walsh County and the Forest River Watershed were collected using light detection and ranging (lidar). These data have a vertical accuracy of ± 6 inches and have already proven useful in the RRB. Walsh County is actively utilizing the data to better understand drainage and to more accurately evaluate who does or does not benefit from legal drains. Similar studies could be conducted to better understand the drainage within the Forest River Watershed.

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Where Do We Go from Here?

Increased security from flooding and drought is critical for the socioeconomic vitality of our region. The Waffle concept could be implemented for both flood and drought mitigation on a local (subwatershed), regional (watershed), or basinwide scale. To facilitate implementation of the concept and to take advantage of the tools developed through this study, the EERC recommends the following:

- High-resolution elevation data should be collected for the RRB. This would be extremely useful for quickly and efficiently evaluating the storage volume and location of potential Waffle storage sections. It would also be of tremendous use to county and city engineers and planners, as well as those involved in water and natural resource management.
- A digital, basinwide culvert inventory is needed to better evaluate the localized impacts of the Waffle. These data, coupled with detailed elevation data, could be used to better model the localized flood reduction impacts of the Waffle. This would also provide water managers with the ability to better understand and assess drainage patterns throughout the region.
- One of the key benefits of this study was the development of hydrologic models for each of the RRB's subwatersheds (except Devils Lake) using SWAT and the development of a hydrodynamic model of the Red River using HEC–RAS. Both models could be expanded by validation with flood events other than those investigated, especially for more recent years. This would allow for evaluation of the Waffle, as well as any other type of flood mitigation practice (i.e., on- and off-channel dams, retention ponds, restored wetlands) over a broader range of flood events and melting conditions.
- Now that a comprehensive, detailed model has been developed for the entire RRB using a consistent framework, this tool can and should be used to evaluate a variety of water management strategies to support basinwide flood and drought planning, water quality improvement, and sustainable water use.
- The economic evaluation of the Waffle concept focused on the flood reduction benefits for larger cities and communities along the Red River because there is a lack of flood damage cost data for rural areas and smaller communities. An evaluation of the economic benefits of the Waffle to rural areas is needed, especially since implementation of the Waffle at the local level may be more desirable and more manageable than basinwide implementation.
- If the Waffle is adopted, intensive public outreach efforts should continue to gather additional input on socially acceptable implementation scenarios to ensure reasonable public acceptance of the program guidelines and participant contracts.

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Page 14 Photo of EERC employee collecting data: Marc Kurz, EERC.

Page 15 Image of model processes: revised from Neitsch et al., 2002, by Earl Battle, EERC.

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Page 20 Photo of culvert on Waffle field trial site: Kirk Williams, EERC.

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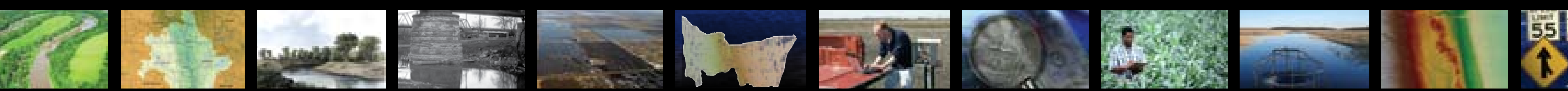

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