

An Innovative, Basinwide Approach to Flood Mitigation: The Waffle Project

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Abstract: Flooding on the Red River of the North in 1997 was severe and established the need for a new approach to flood protection in this region to augment existing flood control measures. One strategy being investigated by the Energy & Environmental Research Center (EERC) is the feasibility of temporary storage of springtime runoff to augment existing flood control structures and help mitigate flooding throughout the Red River Basin. This project, commonly referred to as the Waffle Project, is evaluating the water storage potential of preexisting “depressions” within the Red River Basin. These preexisting storage areas, supplemented by roads and drainage structures, could act as a network of channels and control structures to slowly release stored water into the Red River and its tributaries as the flood crest passes. An important goal of the Waffle Project is to develop a comprehensive basinwide model that will help stakeholders of the region better understand the hydrology of the basin, including the effects of microstorage on flooding events. This paper summarizes the activities from the first phase of the project.

Key words: watershed modeling; flood mitigation; flooding; water management

1 BACKGROUND

The Red River of the North originates in Minnesota, forms the boundary between North Dakota and Minnesota, and enters Canada at Emerson, Manitoba, where it continues northward to Lake Winnipeg, Manitoba (Figure 1). It meanders approximately 548 mi (883 km) through the flat and fertile valley of former glacial Lake Agassiz, forming the 45,000 mi² (116,500 km²) Red River Basin. Both the river channel and the basin are intersected by the international border between the United States and Canada, with approximately 75% of the Red River Basin located in the United States. The basin is remarkably flat, as reflected by the 0.5 ft per mile gradient of the Red River (International Joint Commission, 1997). Over 66% of the basin is conducive to agriculture and productive cropland because of the fertile, black, fine-grained soils (Stoner et al., 1993). In

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addition to farmland, several major population centers (cities) are located on the banks of the Red, including Wahpeton–Breckenridge with a population of 12,000, Fargo–Moorhead with 100,000, Grand Forks–East Grand Forks with 60,000, Selkirk with 9800, and Winnipeg with 670,000 (International Joint Commission, 2000).

The Red River Basin is subject to frequent damaging inundation from major flood events. Since official record keeping began in 1882, major floods affecting large areas of the basin have occurred once about every 4 to 6 years, with a truly devastating flood occurring, on average, about every decade (LeFever et al., 1999; International Joint Commission, 1997). Major historical floods occurred in 1826, 1897, 1950, 1966, 1969, 1975, 1978, 1979, and 1997. Based on historical accounts, the 1826 flood is the worst flood known. Unfortunately, there are no detailed data on this flood. While all of the other floods caused severe damage, the 1997 flood is the worst in the official record and forced the evacuation of many families in most of the cities mentioned above (International Joint Commission, 1997).

To mitigate flooding loss, various measures have been taken (International Joint Commission, 1997, 2000; Red River Basin Board, 2000; Kingery et al., 1999; Dyhouse, 1995). LeFever et al. (1999) categorized the various flood protection measures proposed for the Red River Basin as structural and nonstructural. Construction of levees and reservoirs, enlargement and straightening of channels, and installation of channel bypasses are structural measures, whereas nonstructural measures consist of regulating development, improving operation of the structures, establishing policies for emergency and loss protection, and employing new concepts such as mitigating flooding at its source. Both types of measures are generally needed for most of the basin, as nonstructural measures augment the flood mitigation capacities of structural measures (International Joint Commission, 1997, 2000).

After the 1997 flood, the Energy & Environmental Research Center (EERC) recognized the need for alternative methods of flood protection to augment existing flood protection measures. This sentiment was mirrored by other major organizations and agencies in the Red River Basin, and it was determined that innovative concepts of nonstructural measures should be explored to augment the design capacities of structural measures planned to protect against future floods similar in scope to, or greater than, the 1997 flood (International Joint Commission, 2000). As a result, the EERC proposed to investigate the technical feasibility of utilizing the Red River Basin's existing gridlike infrastructure of fields bounded by raised roads as a means to temporarily hold water for both flood and drought mitigation. This project became known as "The WaffleK" because of the resemblance of farm fields bounded by raised roads to the squares on breakfast waffles and the ability of waffle squares and/or roads to retain fluid. Other potential storage areas include ditches, wetlands, or any type of natural depression. These storage areas, supplemented by roads and drainage structures, could act as a network of channels and control structures to hold and slowly release water into the Red River as the flood crest passes. Although the main goal of this concept is flood and drought mitigation, it is also recognized that this approach could have multiple environmental benefits, including improvements to water quality, decreased soil erosion, and increased groundwater recharge. The EERC first received funding through the U.S. Department of Agriculture Natural Resources Conservation Service to investigate the feasibility of this approach in April 2002. The Waffle Project approach, goals, and objectives will be further discussed below.

2 PROJECT APPROACH AND GOALS

The Waffle Project is proceeding in a series of six main components, including 1) preliminary storage volume calculations, 2) model development, 3) data survey and database development, 4) public outreach, 5) a field trial/demonstration of the concept, and 6) an economic analysis of the Waffle approach.

The ultimate goal of the project is the development of a flood mitigation tool to augment existing flood control measures, such as dikes, diversions, and large- and small-scale impoundments. The models and tools developed by the project will have multiple benefits including:

- Development of a comprehensive water management model that will have applications for flood and drought mitigation, water quality, wetland restoration, riparian restoration, groundwater replenishment, and erosion control.
- Development of a detailed basinwide model to assist decision makers in addressing nonstructural and structural water management scenarios.
- Compilation of existing Red River Basin culvert and bridge data into a user-friendly database that can be utilized and updated by local, state, and federal entities within the Red River Basin.

3 OVERVIEW OF YEAR ONE ACTIVITIES

3.1 Storage Volume Calculations

In order to estimate the upstream storage volumes needed to mitigate large-scale springtime floods along the Red River, preliminary calculations were conducted using existing models. Along the Red River of the North, the U.S. Army Corps of Engineers has designated major flood stage elevations at points where cities or towns and U.S. Geological Survey gauging stations are located. In addition to these gauging stations, the U.S. Geological Survey has published both flow hydrographs and crest heights observed for historical floods at the gauging stations located on the major tributaries of the Red River. Using the Corps' HEC-2 and HEC-RAS hydraulic models, the maximum allowable discharges to have kept the observed 1997 flood crests below major flood stages were estimated. Based on a storage algorithm and a release algorithm, and by specifying a storage volume amount, the observed flow hydrographs were reshaped. The storage algorithm assumed that the storage will be used to reduce the peaks as much as possible, whereas the release algorithm assumed that the stored water should be released at the earliest feasible time. These two algorithms incorporated both the attenuation of the storage and the effects of timing. This calculation was iterated until the adjusted flow hydrographs had peaks lower than the determined maximum peak discharges. The final storage volumes of this manipulation were the reductions in flood volume needed upstream of these select points in order to have kept the 1997 flood crest below the major flood stages. The volume of water storage needed upstream of those points was then distributed among the contributing subbasins to determine the depth of water storage needed per square mile of land. The area of land covered by roads, towns, lakes, swamps, rivers, and flood zones was subtracted from the area of the catchments to yield an

adjusted area more representative of what might actually be available for storage. Storage amounts range from 0.3 to 2.6 inches of water per square mile for the various watersheds below Drayton, North Dakota. With those volumes of water stored upstream of Drayton, no additional storage between Drayton and Emerson, Manitoba, Canada, would be needed to keep Emerson below the major flood stage during a 1997-type event. Although cities or major towns were used as a measure of necessary volume of water storage, this project in no way focuses on flood protection measures solely for the urban areas of the basin.

As part of an ongoing effort to determine the volume of storage available in fields and depressions throughout the Red River Basin, the reliability of the elevation data contained within the U.S. Geological Survey National Elevation Dataset (NED) is being evaluated. The NED values were compared to elevation values collected by light detection and ranging (LIDAR), which are much more accurate but only available for a few select areas within the Red River Basin. Using Geographic Information Systems (GIS), initial results show that approximately 70% of the NED data points are within 1 meter of the LIDAR elevation values, and although 1 meter of absolute error could be significant considering the flatness of the Red River Basin, relative elevation differences between adjacent raster cells were much closer in agreement. Detailed statistical analyses between the two datasets will be conducted once a methodology is developed for extracting the enormous volumes of data (over 100,000 data points per square mile) from the GIS layers.

Assuming the NED data are statistically acceptable for conducting volume estimates, the next step will be the development of a GIS program to automatically calculate storage volumes for all of the viable areas within the Red River Basin. Initially, this will be done by extracting road elevation data from topographic maps to create a preliminary road network database (RND). If necessary, detailed global positioning system surveying will be conducted to obtain accurate elevation values. Based upon the RND, a grid structure of raised roads will be identified to serve as the basis for storage sections, and a system to automatically calculate storage volumes will be constructed.

3.2 Modeling Activities

In order to evaluate the Waffle Project, a key activity is the development of a series of coupled hydrologic–hydraulic computer models that will allow for better prediction of the location, duration, and hydraulic effects of water retention on the Red River and its tributaries. An integrative model will be developed that will combine the individual models developed to characterize the hydrologic responses of the subbasins of the Red River Basin with a main-stem Red River model, the end result of which will be the development of a model that will show the effects of various storage scenarios in each of the subbasins on the major tributaries and on the Red River.

3.3 GIS-Based Identification of Storage Areas

In order to identify or eliminate potential storage areas based on physical properties, GIS is being used to develop several map layers to more efficiently accomplish this task. The parameters being investigated with GIS include, but are not limited to, elevation, slope, location of cultural

features (farmsteads, churches, cemeteries, etc.), land use/cover, soil type and soil drainage properties, and land productivity. The ultimate goal of the development of GIS maps based on multiple themes is the compilation and overlay of these maps to identify storage areas based on a combination of “most suitable” factors for water storage or eliminate storage areas by a combination of “least suitable” factors. For example, an ideal section might be well-drained soil that is not prime farmland, contains no cultural features and, based on topography, is capable of storing water.

3.4 Data Survey

The purpose of conducting a data survey during the first phase of the project was to identify existing sources of data related to topography, hydrology, meteorology, infrastructure, imagery, and models in order to identify data gaps and determine the amount of surveying and data collection that will be needed to conduct the evaluation of the project. The data survey is largely complete except for efforts in determining the availability of culvert data in the Red River Basin.

Also ongoing is a survey of past and present studies involving flooding and water management within the Red River Basin. All papers, reports, and presentation abstracts that were collected for this project are inventoried in a database. This database is updated as new reports are obtained and will be made available for public use on the Waffle Project Web site and, if possible, the Red River Basin Decision Information Network (RRBDIN) Web site. Currently, hundreds of references are in the database.

3.5 Public Outreach

Stakeholder understanding and acceptance of the Waffle concept and the way it may operate if implemented are critical to the success of the project. An Agency Advisory Board (AAB) and a Citizen’s Advisory Board (CAB) were established to provide objective input related to the project goals and activities. The AAB comprises individuals from local, state, and federal agencies that have jurisdiction over water management issues. Members of the CAB include local citizens and landowners, many of whom are in positions involving public outreach or political involvement. These boards have provided valuable input to the project, and they will continue to be active throughout the remainder of the project.

Additional activities related to public outreach have been meetings with the water resource boards of North Dakota and the watershed districts of Minnesota. The purpose of these meetings is to communicate our project activities and gather input from the board members regarding our general activities and the subbasin models that we will develop. This will help ensure that, in addition to meeting the needs of the Waffle Project, the models will incorporate features that will better aid the water resource boards and watershed districts in making water management decisions.

4 CONCLUSIONS

The preliminary efforts conducted during the first phase of this project have demonstrated the feasibility of utilizing the existing infrastructure of the Red River Basin to help mitigate large-

scale spring flooding. The focus of our initial activities was a general overview of the feasibility of the Waffle concept. The work conducted during the next phase of the project will be narrowed down to watershed scales in order to better evaluate the details of the concept. The main activities for this phase include refining water storage estimates; locating potential storage areas based on volume estimates and further narrowing down storage sections based on physical properties, such as land use, land cover, and soil characteristics; developing subbasin models that will allow for the evaluation of small-scale, distributed storage in each of the watersheds; evaluation of the structural and agricultural economics of the approach; field-scale demonstration of the concept in at least one watershed subbasin; and continued public outreach, including AAB and CAB meetings, public meetings, public surveys, Web site and newsletter development, and meetings with various state, federal, and local agencies in the basin.

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