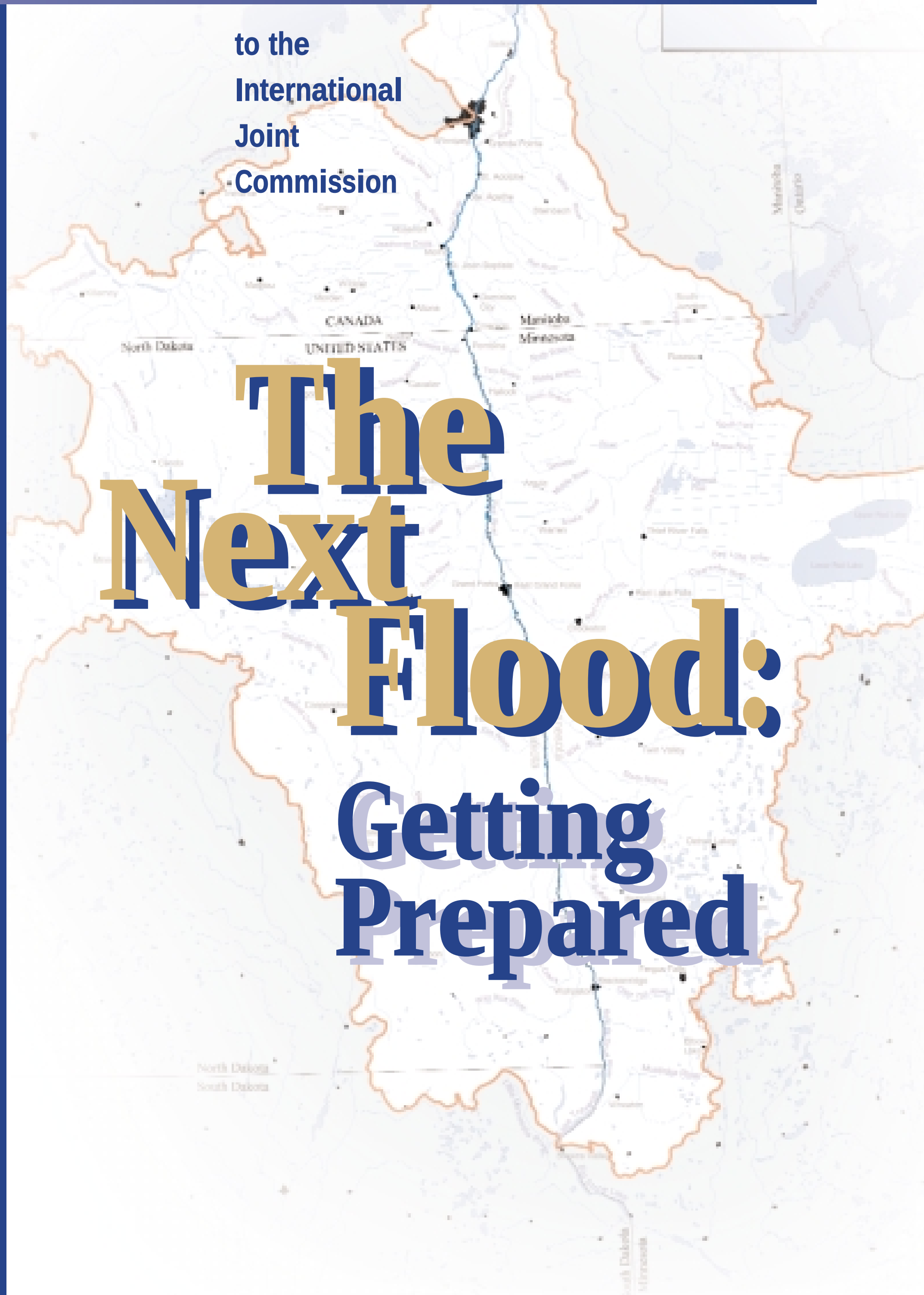
Final Report
of the

International Red River Basin Task Force

to the
International
Joint
Commission



The Next Flood: Getting Prepared

International Joint Commission
Commission mixte internationale

APRIL 2000

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Contents

Executive Summary

Flooding is a fact of life along the Red River. The disastrous flood of 1997, while a rare event, was neither unprecedented nor unforeseen. As the 1997 International Red River Basin Task Force report, *Red River Flooding: Short-Term Measures* concluded, “The flood of 1997 or an even larger one could happen any year.” The Task Force conducted historical, geological and statistical analysis that supports this conclusion. In this report, the Task Force explores the implications associated with large floods—that is, floods of the magnitude of 1997 or larger—for the people, communities, and governments in the Red River basin. It responds to the concerns of the public and experts about the preparation needed to avoid or reduce damage from large floods. The report also discusses issues of particular concern arising from the 1997 flood. While the Task Force studied some aspects of response and recovery issues, this report focuses on preparedness and mitigation for major floods.

In investigating what can be done about flooding in the Red River basin, this report examines the issue of storage—through reservoirs, wetlands, small impoundments or micro-storage, and drainage management. Residents often raised storage and drainage issues in discussions with the International Joint Commission and Task Force. Many people in the basin believe that major floods can be prevented through use of upstream storage. The Task Force considered how much storage would be required to reduce the impact of a major flood on the scale of 1997 and whether there was sufficient potential in the basin to meet that storage requirement. The conclusions are:

> **Conclusion 2:** ***It would be difficult if not impossible to develop enough economically and environmentally acceptable large reservoir storage to reduce substantially the flood peaks for major floods.***
>
> **Conclusion 4:** ***Wetland storage may be a valued component of the prairie ecosystem but it plays an insignificant hydrologic role in reducing peaks of large floods on the main stem of the Red River.***

While the Task Force recognizes the public concern for floods on tributaries or floods smaller than in 1997, it considered the many ideas to mitigate the harmful consequences of these smaller floods only in the context of reducing the flood peaks of major floods. The Task Force focus precluded examination of possibly worthwhile projects that may have tributary flood control, environmental, or other benefits.

Since, as the Task Force concludes, storage options provide only modest reductions in peak flows for major floods, a mix of structural and non-structural options were examined. The cities of Grand Forks and East Grand Forks are in the process of building dikes and undertaking urban renewal projects in response to the flooding suffered by those cities. Other communities are also taking action, and this report examines some of those undertakings.

Winnipeg, the largest urban area within the basin, remains at risk. The city survived the flood relatively unscathed, but Winnipeg cannot afford complacency. If it had not been favored with fair weather during late April 1997, it could have suffered the fate of its southern neighbors. The Task Force makes a number of recommendations to address the city's vulnerabilities and better prepare it for large floods. The Task Force concludes that:

> **Conclusion 6:** ***Under flow conditions similar to those experienced in 1997, the risk of a failure of Winnipeg's flood protection infrastructure is high.***

The city needs a higher level of flood protection. The Task Force recommends that:

> **Recommendation 4:** ***The design flood used as the standard for flood protection works for Winnipeg should, at a minimum, be the flood of record, the 1826 flood, or higher if economically justified.***

A number of immediate actions were recommended including modifying the east embankment of the Floodway, raising the west dike, and raising the primary diking system where economically feasible to the elevation specified in existing legislation.

However, to achieve the level of protection sufficient to defend against the 1826 or larger floods, major structural measures on a scale equal to the original floodway project are needed to protect the city. Two options are suggested: expansion of the Floodway or construction of a water detention structure near Ste. Agathe to control flood waters for floods larger than 1997. Detailed feasibility studies are required and a federal-provincial-city agreement and protection plan are needed to construct the selected project.

Structural protection measures are only part of the response to living with major floods. The Task Force looked at a wide range of floodplain management issues to see how governments and residents might establish regulatory and other initiatives to mitigate the effects of major floods and to make communities more resilient to the consequences of those floods. It made a number of recommendations on defining the floodplain, adopting and developing building codes appropriate to the conditions in the Red River basin, education, and enforcement. The Task Force supports the acquisition of properties in the greatest danger of being flooded and recommends policy changes in Canada and the United States to allow an acquisition policy to be coordinated with other flood protection measures.

FEMA and Emergency Preparedness Canada should develop an integrated approach to mitigation initiatives based on a comprehensive mitigation strategy for the basin. In the United States, the strategy should be integrated within the National Mitigation Strategy. The Task Force found the lack of flood mitigation strategy in Canada an obstacle in the way of developing a more flood resilient basin and recommended that:

> **Recommendation 23:** ***The Canadian federal government should establish a national flood mitigation strategy, or a broader disaster mitigation strategy, and support it with comprehensive mitigation programs.***

Flood insurance is an integral part of the U.S. approach to flood preparedness yet the program attracts far too few people at risk. The Task Force recommends that:

> **Recommendation 24:** ***In the U. S. portion of the Red River basin, FEMA should expand current efforts to market the sale and retention of flood insurance both within and outside the 100-year floodplain. Innovative marketing should be considered to attract and retain policy holders, including increasing the waiting period from 30 days to 60 days before flood insurance comes into effect.***

An issue that received some attention in 1997 and which has troubled transboundary relations is flooding in the lower Pembina basin. Here local groups are taking the initiative to resolve long-standing transboundary diking and drainage issues. The Commission strongly supports this initiative and has committed funds and lent the expertise of the Task Force to aid in coming to a common understanding of the technical issues. The Task Force initiated leading-edge laser and radar digital mapping of the area and made special runs for the lower Pembina River of the hydraulic models it has created for the Red River. Local groups are working with Task Force consultants exploring various scenarios that may help resolve the issues. The Task Force is also using the basin as a prototype for demonstrating a transboundary virtual database and decision-support system. The Task Force concluded that

Conclusion 7: ***There is general recognition in the region that flooding in the lower Pembina River basin has been profoundly affected by the construction of dikes and of roads that act as dikes on both sides of the boundary. Rectifying the transboundary flooding consequences of these structures will require action in both countries and there appears to be a general readiness to take such action.***

To address the issues the Task Force recommends that:

Recommendation 27: ***The International Technical Working Group, formed in 1996 but currently inactive, should be re-activated to examine the findings of the hydrodynamic model. Working with local interests, such as the Pembina River Basin Advisory Board, it should develop, implement, and fund a solution that is sustainable in the long term.***

Recommendation 28: ***Given the transboundary nature of the basin and the potential for federal involvement in funding and monitoring any agreement, federal agencies from both countries should be engaged in this process as well.***

The Task Force is convinced that the mapping and modeling work it has initiated in the lower Pembina River basin should be maintained and continue to be used to ensure that there are no unintended consequences arising out of future construction. Also, the virtual database and decision support system prototype that the Task Force has begun to develop for the Pembina River basin should be continued by relevant agencies in Canada and the United States.

Another flood issue that arose in 1997 concerned breakout flows on the Little Minnesota River in the Mississippi basin near Browns Valley, Minnesota to Lake Traverse in the Red River basin. These high-flow conditions occasionally provide a hydraulic connection between the Mississippi and the Hudson Bay drainage systems and open the way for the migration of aquatic species between watersheds. After investigating the issue, the Task Force recommended that:

Recommendation 31: ***Engineering studies should be immediately undertaken to examine all means of eliminating the potential for the hydraulic inter-basin connection in the vicinity of Browns Valley.***

Governments should implement the most feasible option. In the interim, if undesirable species appear in the Little Minnesota River system, immediate action should be taken to prevent their transfer to the Red River basin. While the U.S. Army Corps of Engineers will need to take the lead role to implement this recommendation, cost-sharing options should be negotiated with Canada because of the basin-wide benefits. The Task Force also recommended that any modification to existing operating plans or physical structures associated with Lake Traverse that could increase pool elevation must be accompanied by features to eliminate the southward movement of water into the Little Minnesota River.

Water quality studies undertaken during the 1997 Red River flood identified several concerns that the Task Force pursued in follow-up studies in 1998 and 1999. The studies focused on persistent toxic materials that may have been transported to Lake Winnipeg. Additional work was also done on the potential damage to the lake from increased deposits of fertilizers and on contaminants associated with suspended sediments. While there is currently no public health concern, the potential during a major flood for damage from the release of substances harmful to the aquatic ecosystem including the Lake Winnipeg fisheries, and to public health remains an issue. The Task Force recommended that:

> **Recommendation 33:** ***Governments should take immediate steps to ensure that all banned materials such as toxaphene are removed from storage areas in the Red River basin and that potentially hazardous materials are not stored in the 500-year floodplain. Reasonable quantities of such substances could be maintained in the floodplain for immediate use.***

In an effort to gain a better understanding of the flooding issues and in recognition of weaknesses in technological infrastructure within the basin, the Task Force devoted much of its energy and resources to data issues and computer modeling. On reviewing current data availability, the Task Force concluded that further improvement and maintenance of the Red River floodplain management database is required. Federal, state and provincial governments and local authorities must maintain a high level of involvement in further database development and in improving data accessibility.

In partnership with the Global Disaster Information Network (GDIN), the Task Force established the basis for a virtual database and a decision-support system. It will take some time to complete this promising initiative.

The database, computer models, and decision-support system will remain as a legacy to aid flood fighters and planners with the latest computer models and information base for effective planning and real-time decision-making during flood crises. Recommendations of the Task Force include:

> **Recommendation 35:** ***Hydrometric and meteorological data networks necessary for flood forecasting should be improved and maintained in a state of readiness to forecast future floods.***

Recommendation 41: ***Development of the digital elevation model for the Red River Basin should be completed by collaborative initiatives of the relevant agencies.***

Recommendation 42: ***Relevant federal, provincial, state agencies and transboundary agencies should meet to determine the interest in continuing the work of the Red River Basin Disaster Information Network (RRBDIN) and draw up a funding and action plan to ensure its continuation.***

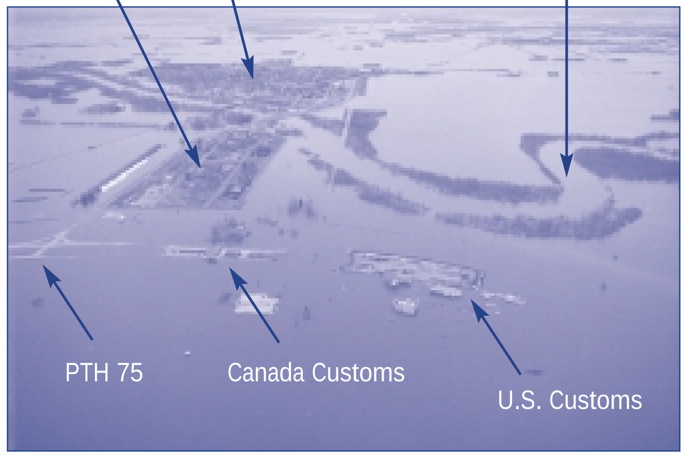
The Task Force found difficulty in securing public access from Canadian agencies for data and other flood-management related information. Policies that restrict access to flood-related data frustrate the development of a basin-wide virtual database and can endanger effective response to flood fighting and management efforts. The Task Force recommended making Canadian data available at no cost and with no restrictions for flood management, emergency response, and regional or basin-wide modeling activities.

The Task Force has created "unsteady flow" hydraulic models that can simulate floodwater flows. It also reviewed the other modeling activity in the basin, particularly U.S. hydrologic models. These models will be in the forefront of future floodplain planning and real-time flood fighting. The Task Force recommends that the U.S. National Weather Service implement its Advanced Hydrologic Prediction System in the Red River basin as an early priority. It also recommends a basin-wide coupled atmospheric-hydrologic model in the Red River basin as a long-term priority for government and academic research. Concerning its own hydraulic models, the Task Force recommends a secondary roads survey and that the data generated be incorporated into the models. As for maintenance of the Task Force-developed hydraulic models, the Task Force recommends that:

Recommendation 49: ***The U.S. Army Corps of Engineers and the Manitoba Department of Conservation, operators of the UNET and MIKE 11 models respectively, should maintain the existing models and continue to seek improvements through collaboration with other agencies.***

Many people in the basin are interested in the institutions that should be involved in water issues. The Task Force advocates a two-tier institutional approach to flood-related arrangements. A tier-one organization established within the basin by governments, or perhaps the IJC, would work with tier-two grass-roots organizations. The tier-one organization would ensure that flood-related issues receive the continuing attention they require and to assume responsibility for carrying out the vision that the Task Force sees for preparing the Red River basin for the next major flood.

The Task Force considers that such a tier-one organization, if established, might appropriately be assigned a mandate to advocate and report on flood-related issues, including the progress of governments in implementing the recommendations in this report and in maintaining and advancing the work of the Task Force's legacy projects. More particularly, this mandate could include the following flood-related functions:



Emerson Border Crossing

1. Ensure ongoing institutional support and full multi-jurisdictional participation for legacy projects, the distributed data base, and computer models.
2. Monitor implementation of recommendations designed to ensure basin-wide flood preparedness and community resiliency.
3. Monitor and report on the implications of specific flood-related recommendations.
4. Promote a culture of flood preparedness and flood resiliency in the basin.
5. Support early warnings and early action in the face of impending major floods.
6. Ensure coordination of flood forecasting information.
7. Provide a forum for multi-jurisdictional problem solving.
8. Provide a forum for the exchange of best-practices information.
9. Provide knowledgeable and credible advocates to interact with the highest levels of government in order to make decision-makers aware of the requirements of the people of the basin on flood-related issues and associated issues of water management.

Given these functions, the Task Force advocates including the following in the organizations's structure and reporting responsibilities:

- A membership of 10 to 12 members, with representatives from the states of North Dakota and Minnesota, the province of Manitoba, and the two federal governments, plus outside experts as appropriate
- Regular formal and informal consultation with other basin organizations and local governments
- Reporting to the two federal governments and, as appropriate, the state and provincial governments
- Direct communication with the public and media

In summary, the Task Force recommends:

> **Recommendation 51:** ***If the International Joint Commission pursues [its] watershed board concept, the Commission should consider establishing its initial board in the Red River Basin and assigning to this board the flood-related responsibilities outlined above.***

Preface

After the devastating floods of 1997 in the Red River basin, the governments of Canada and the United States asked the International Joint Commission (IJC) to investigate the causes and effects of the flooding and to recommend ways to reduce the impact of major floods. Specifically the Commission was asked to report on the:

1. history, extent, and effects of flooding in the Red River basin, with particular emphasis on the 1997 flood;
2. relationship of the 1997 flood to past and future Red River floods;
3. effects on flood conditions of flood control and other structures, changing land use and land management practices, and any other pertinent factors;
4. current state of flood forecasting practices, capabilities, and technologies, including data sharing among agencies;
5. policies, programs and mechanisms for emergency preparedness and response, risk reduction, floodplain management, and flood damage control;
6. potential effects of weather variability on flood frequency, peak and duration;
7. water quality issues associated with floods; and
8. other matters that the IJC deemed relevant to the purpose of this study.

In September 1997, the Commission established the International Red River Basin Task Force to carry out investigations and provide advice to the Commission on the above matters. In keeping with IJC tradition, members of the International Red River Basin Task Force were appointed to serve in their personal and professional capacities, rather than as representatives of their countries, agencies, or organizations.

In December 1997, the Commission presented an interim report on flooding to the governments, in which it endorsed the report prepared by the Task Force, *Red River Flooding: Short-Term Measures*. The report made 40 recommendations on how to improve preparedness (see Appendix 5). The recommendations were directed to governments at various levels in both countries, stressing that a significant risk of flooding will always remain and that action was required to:

- improve, clarify and coordinate various flood policies;
- simplify and clarify flood forecast information released to the public;
- enforce and adhere to floodplain management policies;

- improve emergency management coordination and plans;
- ensure support for affected families and individuals;
- make major technical improvements in forecasting and water flow models, gaging networks and surveys, and ice management; and
- address environmental concerns such as hazardous products, groundwater contamination, and considerations in levee/dike design.

The governments in the basin have substantially implemented all the recommendations. See Appendix 5 for a list of the recommendation and summary discussion of the responses to them. A more detailed review of the government responses can be found on the IJC/Task Force Web site: http://www.ijc.org/boards/rrbtf.html.

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This final Task Force report follows through on the work plan outlined in the December 1997 interim report. The focus is on preparedness and mitigation for floods as large as 1997 or larger. Not all the work envisioned in the work plan could be finished because the United States government was unable to provide its full share of the funding needed for completion of the Task Force's work. Nevertheless, the Task Force has completed major technical studies that provide a firm foundation for advancing flood management in the basin. The Task Force believes that its recommendation can make a substantial contribution to helping prepare the governments and residents for the next major flood.

The Task Force established three subgroups to assist with its studies: the Database, Tools and Strategies subgroups. The members who contributed to the work of the Task Force were: **Database**: Slobodan Simonovic[1] (co-leader), University of Manitoba; Terry Birkenstock (co-leader), U.S. Army Corps of Engineers; Rick Bowering, Manitoba Conservation (Water Resources); Alf Warkentin, Manitoba Conservation (Water Resources); Glenn Radde, Minnesota Natural Resources; Randy Gjestvang, ND State Water Commission; Russ Harkness, U.S. Geological Survey; Ron Wencl, U.S. Geological Survey; Mike Anderson U.S. National Weather Service. **Tools**: Robert Halliday[1] (co-leader), R. Halliday & Associates; Scott Jutila (co-leader), U.S. Army Corps of Engineers; Rick Bowering, Manitoba Conservation (Water Resources); Alf Warkentin, Manitoba Conservation (Water Resources); Jim Solstad, Minnesota Natural Resources; Tim Faye, ND State Water Commission. **Strategies**: Bruce Rawson[1] (co-leader), Rawson Group Initiatives; Lou Kowalski (co-leader), Contractor w/U.S. Army Corps of Engineers; Larry Whitney[1], Manitoba Conservation (Water Resources); Dwight Williamson[1], Manitoba Conservation (Water Quality); Mel Sinn, Minnesota Natural Resources; Dale Frink, ND State Water Commission. The Task Force would also like to acknowledge the contribution of Paul Bourget, representing the Global Disaster Information Network. As well, the Task Force recognizes that its work could not have proceeded without the contributions of many members of the public who provided information and ideas to the Task Force, public servants at all levels of government, and the many contractors to the Task Force.

Note: The report uses U.S. spelling throughout, except for proper names in Canada. Dollars are stated in the currency of the country under discussion, unless otherwise noted. In the United States, the river is called the Red River of the North; in Canada, the Red River. This report uses the short name. In Canada, the term "dike" is commonly used for riverside flood control works; in the United States, the term is "levee." In this report, the terms are used interchangeably.

U.S. and metric measurement equivalents are used except where in common practice within the basin one or the other measure is used. For example, acre-foot is used throughout and no metric equivalent is provided (1 acre-foot of water equals 1,233 cubic metres).

1

Introduction

Flooding is a fact of life along the Red River. The disastrous flood of 1997, while a rare event, was neither unprecedented nor unforeseen. As the 1997 International Red River Basin Task Force report, *Red River Flooding: Short-Term Measures*,[2] concluded and the International Joint Commission endorsed, “The flood of 1997 or an even larger one could happen any year.” In this report, the Task Force explores the implications associated with large floods—that is, floods of the magnitude of 1997 or larger—for the people, communities, and governments in the Red River basin. It considers what can be done to manage flood risks and prepare for major floods.

The International Joint Commission (IJC) and the Task Force have held public hearings and talked with residents and experts concerned about Red River flooding. Many people have offered ideas on better ways of responding to future floods and on preventing flooding and lessening its consequences. This report focuses on getting ready for the next major flood and responds to the concerns of the public and experts about the preparation needed to avoid or reduce future flood damage in a flood as large as or larger than the 1997 flood. The report also discusses issues of special concern arising from the 1997 flood.

This report focuses on getting ready for the next major flood.

In investigating what can be done about flooding in the Red River basin, this report examines the issue of storage—through reservoirs, wetlands, small impoundments or micro-storage, and drainage management. Residents often raised storage and drainage issues in discussions with the Commission and Task Force. Feelings are strong within the basin that major floods can be prevented through use of upstream storage. The Task Force considered how much storage would be required to reduce the impact of a major flood on the scale of 1997 and whether there was sufficient potential in the basin to meet that storage requirement. Some of the public concern and proposed solutions are for floods on tributaries or floods smaller than in 1997.
The Task Force considered the many ideas to mitigate the harmful consequences of smaller floods only to the extent that they may prove effective in reducing the flood peaks of major floods on the Red River. The Task Force focus precludes examination of many possibly worthwhile projects that may have tributary flood control, environmental, or other benefits.

The Task Force looked at the levels of storage needed to make a noticeable difference in flood peak levels at Grand Forks and other communities, and to reduce the risk to Winnipeg. It also examined the hydrologic regime within the basin to see whether modern land-use practices, such as wetland and other drainage, can contribute to major flooding. In addition alternative water storage and management strategies were explored, including the use of reservoirs, on-land storage, and wetlands.

The Task Force concluded that not enough economically feasible storage potential exists in the Red River basin to reduce major floods substantially. The effect on smaller floods was not investigated. Some storage projects may reduce local tributary flooding and have an effect on smaller floods in the Red River itself. Storage initiatives, such as wetland restoration, may have other non-flood-related benefits worth considering.

If, as the Task Force concludes, storage options offer no practical way to substantially reduce the risk from major floods on the Red River, then a mix of structural and non-structural options must be examined. The cities of Grand Forks and East Grand Forks are in the process of building dikes and undertaking urban renewal projects in response to the flooding suffered by those cities. Other communities are also taking action, and this report examines some of those undertakings. Winnipeg, the largest urban area within the basin, remains at risk. The city survived the 1997 flood relatively unscathed, but Winnipeg cannot afford complacency. If it had not been favored with fair weather during late April 1997, it could have suffered the fate of its southern neighbors. This report finds Winnipeg's flood defenses vulnerable and recommends actions to remedy the weaknesses.

Structural protection measures are only part of the response to living with major floods. The Task Force looked at a wide range of floodplain management issues to see how governments and residents might establish regulatory and other initiatives to mitigate the effects of major floods and to make the communities more resilient to the consequences of those floods.

An issue that received some attention in 1997 and which has troubled transboundary relations is flood control in the lower Pembina River, where local groups are taking the initiative to resolve long-standing transboundary diking and drainage issues. The Commission strongly supports this initiative and has lent the expertise of the Task Force to aid in coming to a common understanding of the technical issues. The Task Force initiated leading-edge laser and radar digital mapping of the area. In addition, it produced special runs of the hydraulic models it has created for the Red River to simulate flooding in the lower Pembina River under alternative flow and flood protection conditions. Local groups are working with Task Force consultants in exploring various scenarios that may help resolve the issues. This and other work the Task Force has undertaken to get at the facts and to find possible solutions for Pembina River flooding are described in this report. The Task Force has also used the basin as a prototype for demonstrating a transboundary virtual database and decision-support system.

Another flood issue that arose in 1997 concerned high reservoir levels at Lake Traverse and breakout flows on the Little Minnesota River near Browns Valley, Minnesota. These conditions could establish a hydraulic connection between the Mississippi and the Hudson Bay drainage systems and open the way for the migration of alien invasive aquatic species between watersheds. The Task Force examined the probable frequency of inter-basin connection, considered whether flood control infrastructure at Lake Traverse affected the frequency of this connection, and reviewed what might be done to prevent the future transfer of water at this site.

Eugene Kozera

Primary Dike

In an effort to gain a better understanding of the flooding issues and in recognition of some weaknesses in technological infrastructure within the basin, the Task Force devoted much of its energy and resources to computer modeling and data issues. The Task Force has created “unsteady flow” hydraulic models that can simulate floodwater flows. These models will be in the forefront of future flood forecasting, floodplain planning and real-time flood fighting. In partnership with the Global Disaster Information Network,* the Task Force established the basis for a virtual database and a decision support system. It will take some time to complete this promising initiative. These efforts will remain as a legacy to aid flood fighters and planners with the latest computer models and information base for effective planning and real-time decision making during flood crises.

Because of the shortfall in funding, the Task Force has had to conclude its work before it could explore all issues in detail and complete its legacy projects. The work accomplished, and the work that still needs to be done on data networking and modeling, are discussed in this report.

Many people in the basin seek institutional changes to deal with flooding and other water issues. The Task Force advocates a two-tier institutional approach. Organizations established within the basin by governments, or perhaps the IJC, would work with grass-roots organizations to ensure that flood-related issues receive the continuing attention they require and to assume responsibility for carrying out the vision that the Task Force sees for preparing the Red River basin for the next major flood.

* *The Global Disaster Information Network is an interagency initiative within the U.S. government to integrate information relevant to disasters from all sources and to make the information available rapidly and reliably to whoever can take advantage of it to reduce loss of life and damage.*

2

Red River Flooding in History

When, in its 1997 report, *Red River Flooding: Short-Term Measures*, the Task Force warned that a flood of the magnitude of the 1997 flood could happen in any year, it concluded that “flood preparedness must be part of the culture of the Red River valley.”[3] Since then, the Task Force has conducted investigations to gain a better appreciation of the frequency and size of major floods. Flood preparedness must begin with an informed understanding of the scale and frequency of flooding that can occur.

Several methods help in extrapolating the early flood history of the Red River. The first is the historical record. The peak calculated natural flow* at the Forks, the junction of the Red and Assiniboine Rivers in Winnipeg, was 163,000 cubic feet per second (cfs) or 4,616 cubic metres per second (cms) during the 1997 flood, including 16,000 cfs (453 cms) from the Assiniboine River. The flow during the 1826 flood, the largest on record, is estimated to have been 225,000 cfs (6,371 cms); in the 1852 flood, 165,000 cfs (4,672 cms). From records kept by the Hudson’s Bay Company and other sources, Rannie documented descriptions of the Red and the Assiniboine floods.[4] He concluded that the Assiniboine contributed 30,000 cfs (850 cms) or more to the Red River flood peaks during the 1826 and 1852 floods. Without the Assiniboine, the flow would have been approximately 195,000 cfs (5,522 cms) in 1826 and 135,000 cfs (3,823 cms) in 1852. On this basis, it can be concluded that the 1997 flow on the Red River near Winnipeg was larger than that of 1852 but still substantially smaller than the 1826 flood.

Going beyond the written historical record, sediment deposits at the Forks in Winnipeg and evidence of European settlement can be correlated to nineteenth century floods.[5] These tenuous correlations do not indicate the magnitude of a flood with any precision, but they are instructive. Once it is understood how to relate major sediment deposits to floods, floods farther back in time can be inferred. By applying radiocarbon techniques to date bison bones and other organic materials in sediment layers, it is possible to obtain convincing evidence of flood episodes for over a thousand years, particularly in the 14th century.

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* *In this report, the term “natural flow” means the flow that would have occurred had Winnipeg’s flood control structures (Shellmouth Reservoir, Portage Diversion, and Floodway) not been in operation. It is the flow that would have occurred over the current landscape, not the flow that would have occurred prior to landscape modifications by settlers.*

The change from the drier Sub-Boreal Climatic Episode to the moister Sub-Atlantic Climatic Episode around 2900 years ago is marked by evidence of substantial floods at The Forks. The Neo-Atlantic Climatic Episode (ending circa A.D. 1200) was characterized by a warmer, drier climate and only two floods are noted in that portion of the stratigraphic profile, which encompasses more than two hundred years. With the shift to the Pacific Climatic Episode (A.D. 1200 to A.D. 1550), a cooler, moister regimen occurs in the Red River region and five floods are recorded at The Forks within a seventy year period (A.D. 1270 to A.D. 1340).
S. Kroker, 1999 Flood sediments and archaeological strata

Canadian and American scientists are continuing to look for further geological evidence of flooding in the basin. The work should lead to a better understanding of the magnitude and frequency of floods and the geologic processes that influence floods and flood risk. Thirty sites in the valley have been identified in which sediments may reveal flood history. Radiocarbon dating of charcoal found within the deposits indicates 1,200 years of depositional history related to flooding.[6] Scientists are analyzing core samples from three sites, first to identify known historical events, such as the floods of 1997, 1852, and 1826, then to determine earlier flood events.

Analysis of tree rings in samples dating to the mid-1600s may also indicate floods before European settlement.[7] To that end, researchers have established a Red River tree-ring network, extending from Emerson to Winnipeg, with 160 samples from living bur oaks, historical buildings and logs found in sediment deposits. Anomalies in the tree rings have already identified the 1826 flood, and it is expected that this examination will be able to reconstruct earlier climatic and hydrologic events as well.

In other research sponsored by the Task Force, but not yet completed, sediment is being analyzed for biological indicators of previous flooding.[8] Investigators are also looking at two off-channel lakes, normally separated from the Red River but inundated in the 1997 flood, for “diatom signatures.” Diatoms are distinctive microscopic algae found in sediments. When found in river sediments deposited in lakes, they differ from those in normal lake sediments. Diatom signatures could indicate flooding in geological time.

Residents of the Red River basin should prepare for floods larger than 1997. The question is, How much larger?

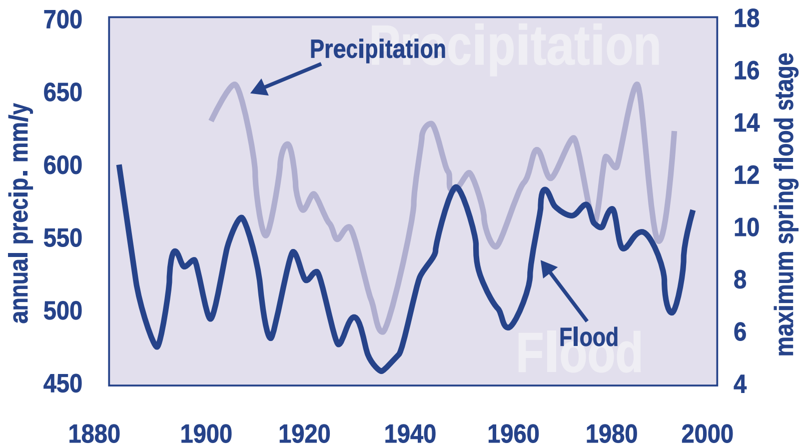
Periods of flooding are often associated with climatic change. Several investigators of post-glacial climate patterns of the Great Plains agree on the climate episodes of the last 2,500 years. The Red River seems to flood more when stronger westerly airflows bring increased precipitation. Possible changes resulting from human activity further complicate the study of climate patterns. A growing scientific consensus sees the increase in atmospheric carbon dioxide in the twentieth century, for example, as contributing to the 0.5°C rise in average global temperatures (0.9°F). While warming could lead to increased precipitation, it is not possible to draw any definitive conclusions as to whether these changes will increase or decrease the number of major floods in the Red River basin.

Climate change aside, the Task Force is convinced that residents of the Red River basin should prepare for floods larger than 1997. The question is, How much larger?

Manitoba hydrometeorologists have tried to answer the question. They have analyzed the conditions preceding large floods, reviewed the historical record, simulated a series of large floods, and determined the meteorological conditions that could produce such floods.

Figure 1

Precipitation and Flooding on the Red River: 1880 to 1998



Five factors determine the size of Red River spring flooding: autumn soil moisture, winter precipitation, rate of spring snowmelt, spring rain, and timing of the south-to-north progression of the melt and rain. Warkentin used these parameters to generate for the Task Force a series of 2,000 simulated floods at Winnipeg.[9] Of these, some 34 natural floods were greater than that of 1997, a figure that accords well with the historical record. Six floods were larger than that of 1826, the largest being about 300,000 cubic feet per second (8,495 cms). Statistical analysis of these generated peaks shows that the 1997 flood was about a 90-year event at Winnipeg; the 1826 flood was about a 300-year event; and the very large flood, a 1,000-year event.* The 1826 flood was not documented in the U.S. portion of the basin and is not therefore the flood of record south of the border.

The analysis described in this section is imprecise and speculative. The evidence, however, is convincing that a flood of the magnitude of 1997 will happen again, as will a flood as large or larger than that of 1826, the most extensive in Canadian history.

Conclusion 1: ***Analysis of the geological record, historic floods of the nineteenth century, statistics, and the hydrometeorological factors that cause floods in the Red River basin indicate that floods of the same size as in 1997, or even greater, can be expected in the future.***

* *This work confirms a study (The Risk of Going Under, 1998) following the 1997 flood by Professor Cas Booy of the University of Manitoba. His statistical analysis of Red River flood peaks, taking into account clustering of peaks, concluded that the probability was high that the 1997 flood would be exceeded in the next 50 years.*

3

Flow Management

The 1997 flood was rare, although it is certain to be equaled or exceeded at some time. Reducing the damage from floods of this magnitude requires improving flood protection measures in the basin, modifying the flow regime to reduce peak flows, or a combination of the two.

The Commission and Task Force heard from a number of residents and experts who strongly believe that the 1997 flood peak would have been reduced if a substantial portion of the runoff had been stored or delayed. If their ideas are feasible, the impact of future floods can be reduced with efforts directed at projects that store or delay peak runoff. There are various proposals for creating more reservoirs, restoring wetlands, and using micro-storage. Others see land drainage as a contributing factor to flooding and seek land drainage limitations.

The Task Force examined these flow management issues as they relate to floods at least as large as that of 1997. The Task Force did not study the effects of flow management on the smaller Red River floods or tributary floods that tend to affect agricultural lands in the spring and summer.

Flood Storage

Record-breaking snowfall during the winter of 1996–1997, capped by a major blizzard in early April 1997, contributed 8 to 10 inches (20 to 25 cm) of water equivalent to the Red River basin for the 1997 flood. That is equivalent to 21 million acre-feet of water in the basin upstream of the Assiniboine River junction at the Forks in Winnipeg (excluding the non-contributing Devils Lake basin). Of that amount, 9 million acre-feet ran off during the spring, while 12 million acre-feet remained on the land, slowly dissipating through evapo-transpiration, infiltration, and release to streams after the flood. Table 1 shows 1997 flood volumes at several main stem locations, according to U.S. Geological Survey, Environment Canada, and Manitoba Conservation figures.

Five dams (Baldhill, Homme, White Rock, Red Lake, and Orwell) account for over 1.0 million acre-feet of flood-control storage. (Because of its headwaters location, Red Lake reservoir's full flood control storage potential is rarely realized.) In 1997 according to the U.S. Army Corps of Engineers, the five reservoirs prevented damages of over $61 million.

Table 1

Flood Volumes at Wahpeton, Fargo, Halstad, Grand Forks, Drayton, Emerson, and Winnipeg

Gage Location	1997 Flood Volume (acre-feet)	Drainage Area (square-miles)	Peak Discharge (cfs)*
Wahpeton	780,000	4,000	12,700
Fargo	1,450,000	6,800	27,800
Halstad	3,400,000	18,000	69,900
Grand Forks	4,900,000	26,000	111,000
Drayton	5,700,000	31,000	124,000
Emerson	6,300,000	36,000	129,000
Winnipeg	9,000,000	45,000	163,000**

* 1 cubic foot per second (cfs) is equivalent to 0.0283 cubic metres per second (cms).
** Calculated natural flow at the Forks (see footnote on page 11)

There are another 280 retention projects, with total storage capacity of almost 0.7 million acre-feet (see Appendix 4).

Of the many dams that can store floodwaters temporarily, most benefit downstream agricultural areas, not communities. The areas below these dams are generally agricultural or undeveloped wildlife areas.

While it is evident that holding back a portion of the peak flow can reduce damage so that existing flood protection works do not fail, the issue is whether there is enough potential storage available at an economically justifiable cost to significantly reduce the damage from rare floods. Several additional storage sites (Table 2) have been identified in past studies. Some of these reservoirs were not built because of economic, social, environmental, or other concerns. These concerns still exist.

Table 2

Sites Where Additional Flood Storage May Be Technically Feasible

Location of Reservoir	Acre-Feet
Wild Rice, MN	44,000
Huot area on Red Lake River, MN	240,000
Bald Hill on Sheyenne, ND	100,000
Maple River, ND	60,000
Upstream of Lake Traverse, MN & SD	75,000
Downstream of Lake Traverse	65,000
Pembina River, ND	110,000
TOTAL	**694,000**

Only a small amount of additional storage is under active development in the basin. For the most part, the figures in Table 2 should be considered as theoretical.

Flood Peak Reduction

The UNET and MIKE 11 unsteady flow hydraulic models developed by the Task Force were used to evaluate additional largely hypothetical storage (see Chapter 11 for a discussion of these models). Some of the storage included the theoretical reservoirs listed in Table 2; in other cases quantities of water were simply removed at key locations. In one UNET scenario, the 1997 tributary flood hydrographs were modified to reflect optimum operation of these reservoirs. Reductions in flood peaks were then calculated for Wahpeton, Fargo, Grand Forks, and Drayton (Table 3). Under these optimal theoretical conditions, water levels are reduced by about a foot at all locations but by over two feet at Grand Forks (0.61 m).

Table 3

Impact of Storage Projects on the 1997 Flood Levels in the United States

	Additional Storage (Acre-Feet)	Water Levels (feet above sea level)		Difference from 1997
		1997	*Modeled Value*	
Wahpeton	140,000	962.1	961.0	-1.1
Fargo	300,000	901.0	900.1	-0.9
Grand Forks	584,000	833.7	831.3	-2.4
Drayton	584,000	800.6	799.6	-1.0

Similarly, a project undertaken by the Minnesota Department of Natural Resources[10] used a hydrologic model to compute the storage required to reduce the 1997 peak flow at Grand Forks to that of the 1979 flood, that is, from 111,000 cfs (3,143 cms) to 89,000 cfs (2,520 cms). The model used the 1997 daily flow data for April and May. The water was routed through simulated reservoirs of various sizes by trial and error until the predicted peak stage was reduced to 49.0 feet (14.9 m) from the actual 54.2 feet (16.5 m). This reduction required approximately 1.3 million acre-feet of flood storage.

The MIKE 11 model also examined peak reduction scenarios for the Canadian portion of the basin.[11] The simulations removed 100,000, 200,000, and 400,000 acre-feet from the 1997 inflow hydrograph at Grand Forks to test the theoretical effect on downstream water levels. Another storage simulation removed 800,000 acre-feet from the 1997 hydrograph between Grand Forks and Emerson, 75,000 acre-feet of that total from the Pembina River. The model removed the water at optimal times, with no consideration given to possible storage location. In practice, it is unlikely that a storage reservoir could be operated to remove water at optimal times during large floods.

For the 400,000 acre-foot storage removal scenario, the peak water level at Emerson fell to 792.3 feet (241.5 metres) above mean sea level, 0.5 feet (0.15 metres) less than 1997 modeled levels. A summary of the results for all the scenarios is presented in Table 4.

Table 4 indicates that up to 800,000 acre-feet upstream storage reduces 1997 flood levels along most of the main stem of the river in Canada by a little over a foot (0.305 metres). The simulation also confirmed that, for floods of 1997 magnitude, Pembina storage has no effect on Red River levels at Emerson. Upstream storage, however, does have a much greater effect at the Red River Floodway inlet at Winnipeg, where the 25-mile (40 km) wide “Red Sea” narrows to a width of less than one mile (1.6 km). Water levels in this area are sensitive to reductions in streamflow, and storage of 800,000 acre-feet in the upper basin could reduce levels by almost five feet (1.52 metres). Lower water levels at the Floodway inlet could reduce risk to Winnipeg itself. One possible storage site upstream of Winnipeg is discussed in Chapter 5.

Table 4

Impact of Storage Projects on Flood Levels in Canada

	1997	Storage (Acre Feet)				Storage (Acre Feet)			
		100,000	200,000	400,000	800,000*	100,000	200,000	400,000	800,000*
		Modeled Values				*Difference from 1997*			
Location	**Water Levels (feet above sea level)**								
Emerson	792.8	792.7	792.6	792.3	791.6	-0.1	-0.2	-0.5	-1.2
Morris	783.2	783.1	783.0	782.7	782.1	-0.1	-0.2	-0.5	-1.1
Ste. Agathe	776.2	775.9	775.8	775.5	774.8	-0.3	-0.4	-0.7	-1.4
Floodway Inlet	771.5	770.1	769.0	767.7	766.7	-1.4	-2.5	-3.8	-4.8

* For the 800,000 acre-foot simulation, the volume was removed between Grand Forks and Emerson. For the others, the water was removed at Grand Forks.

Conclusion 2: ***It would be difficult if not impossible to develop enough economically and environmentally acceptable large reservoir storage to reduce substantially the flood peaks for major floods.***

Micro-storage

From the air, the network of section line roadways in the Red River basin looks like a waffle or an ice-cube tray. The visible lines that are the road surfaces represent areas generally higher than the adjacent lands. Culverts restrict the flow of water from these areas, thus providing some unmanaged short-term storage (see Figure 2). There have been proposals to increase flood storage by using the roadways and adjacent land as a series of small low-head reservoirs, which can then be controlled by gates on road culverts.[12]

Other options include a passive system in which road culverts would not be gated but would be undersized to retard runoff. Both the active and passive approaches envisage thousands of micro-storage sites scattered throughout the basin rather than the flood storage reservoirs discussed earlier.

The principle behind micro-storage is that floodwaters can be stored during periods of peak flow and then released. A critical point is that the water stored has to reduce the peak on the Red River, not necessarily on the tributary where the micro-storage is located. Any storage will reduce flow volume, but effective reduction of peak flows requires accurate and detailed forecasts and a sophisticated control system.

One drawback to this type of storage is that controlling local flows would delay the runoff and thus increase the duration of flooding on some lands. This local flooding could be reduced with a detailed plan for separately operating the gates that control water levels in each impoundment.

Figure 2 (a)

19 April 1997 RADARSAT Image

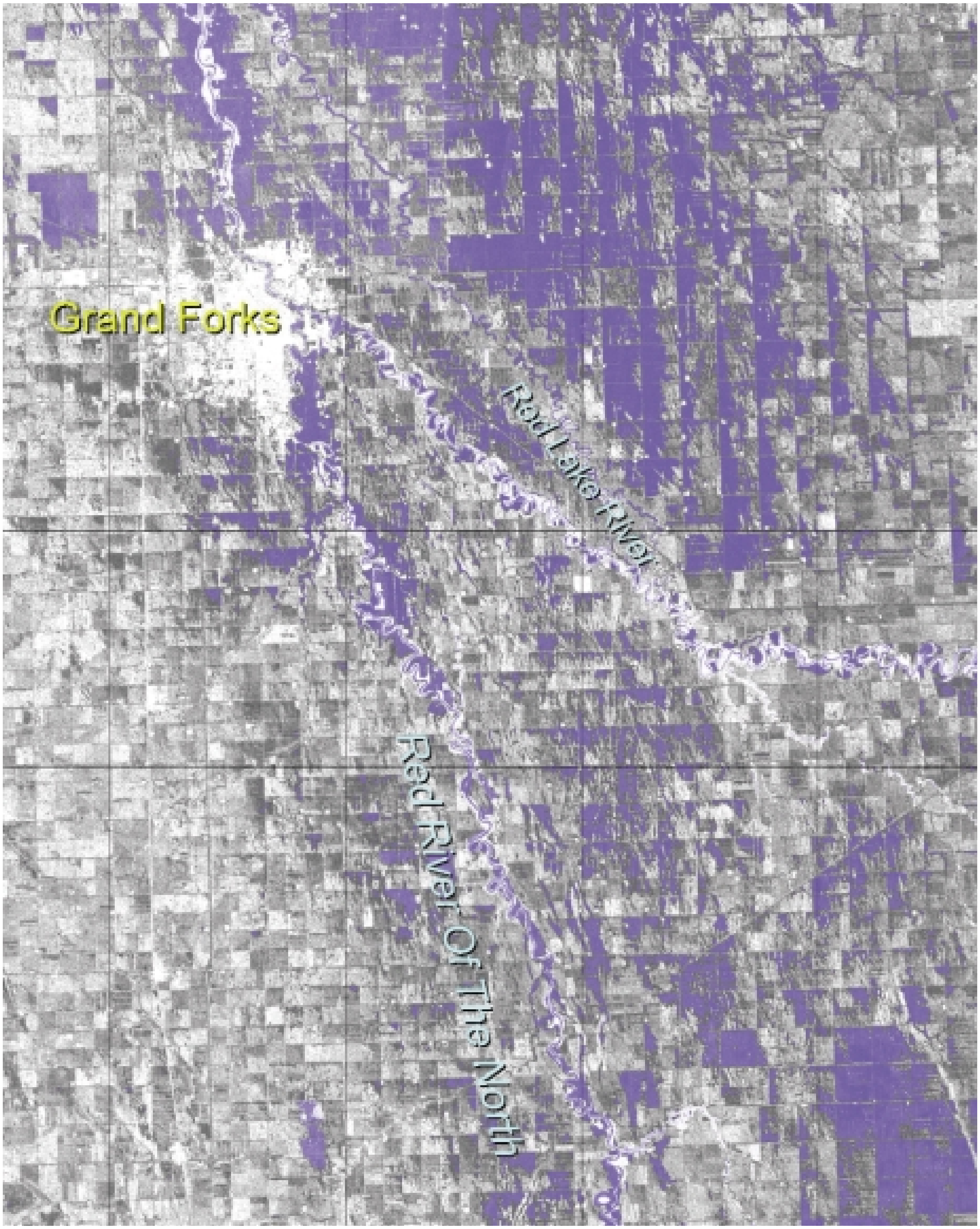
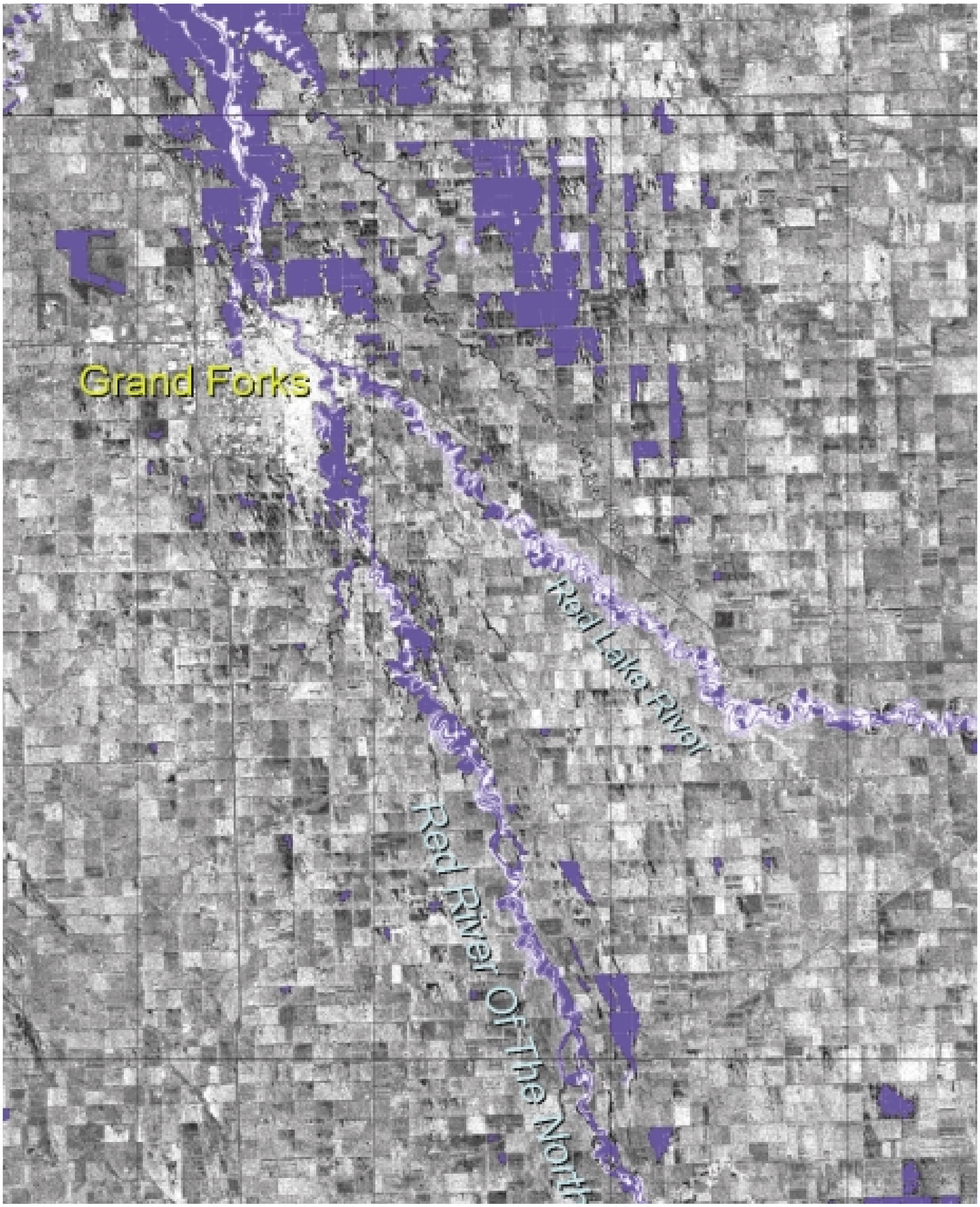


Figure 2 (b)

24 April 1997 RADARSAT Image



> *Achieving the desired flood control effect would require the commitment of well over 700 square miles (1,800 km^2) to micro-storage.*

Reducing the 1997 flood peak to 49.0 feet (14.9 m) from the actual 54.2 feet (16.5 m) at Grand Forks would have required approximately an additional 1.3 million acre-feet of storage, according to the Minnesota study mentioned earlier. If water could be stored to an average depth of three feet (1 m), that 1.3 million acre-feet storage could be contained on approximately 400,000 acres of land (160,000 hectares), or about 700 square miles (1,800 km^2), all upstream of the point where the flood peak would be reduced. The farther away the distributed storage is from the center needing protection, the more inefficient it becomes. Because of that and because local runoff conditions vary from year to year, achieving the desired flood control effect would require the commitment of well over 700 square miles (1,800 km^2) to micro-storage.

During large floods, small impoundments tend to fill and spill, thereby delaying the movement of water downstream. This delay affects the timing of the tributary peaks, something that may or may not have a positive effect on the Red River peaks in any given year. To be absolutely certain that micro-storage would not have a negative effect on Red River peaks, water would have to be retained on the land until it was clear that the Red River peak was subsiding, a period of two or three weeks.

Micro-storage would therefore require many infrastructure changes—for example, roads would have to be raised and leveled, and culverts would have to be replaced or gated. To reduce erosion damage to roads, overflow sections would have to be constructed by hardening a section of road. It would also be necessary to design a remotely operated gate that would be ice-proof, rodent-proof, bullet proof, and trash-proof. Buildings on the land used for micro-storage would have to be floodproofed.

Assuming an additional road elevation of about 1.5 feet (0.5 m), current construction costs, and no hardening, the approximate cost of implementing micro-storage would be at least $250,000 a square mile ($96,500 per km^2), provided no major changes would be needed. Other capital costs, and annual operation and maintenance, would be additional. Micro-storage therefore is not inexpensive storage.

In addition, landowners would likely have to be compensated for delayed or foregone planting. Based on recent experience, payments for such storage could range from $20 to $80 per acre per year (roughly $12,000 to $50,000 a square mile) ($50 to $200 per hectare or $5,000 to $20,000 per km^2), depending on the value of the crops. This payment could be required annually, regardless of whether or not the land is flooded. The payment could also perhaps be made as a lump sum flood easement. Determining storage cost payments is critical to establishing the feasibility of any micro-storage proposal.

A detailed plan for separately operating the gates that control water levels in each impoundment could reduce local agricultural flooding resulting from micro-storage. Such control capability would also reduce the possibility of aggravating downstream flooding on the main stem through inappropriate gate operation. Active operation of micro-storage would require an elaborate supervisory control and data acquisition system working in conjunction with a fine-resolution distributed hydrologic model.

The distributed hydrologic model, which would include detailed topography of the flatter portions of the basin, would be used to forecast inflows from various sub-basins and predict the requirements for micro-storage. The control system would open and close individual culvert gates to reduce the peaks on the Red while minimizing local flooding. As the number of storage sites increases, it becomes more difficult to model the system and ensure compliance with optimal operation. The control system would have to operate under one authority immune from local disruption so that the flood control benefits would not be negated.

The operating rules should also account for use of the system in dry years. Such use may benefit agricultural production at the risk of jeopardizing downstream water supplies.

Conclusion 3: *Large-scale micro-storage has some potential to reduce flood peaks on the Red River but is likely to be impracticable and costly. There are many obstacles to its effective and efficient implementation.*

The role of wetlands in the prairie ecosystem is an issue of major importance.

Wetlands

Wetlands influence both water quantity and quality, serving to alter flow regimes and water chemistry. They contribute to groundwater supplies and can modify the effects of local floods and droughts. They also benefit wildlife and serve as valued habitat in regional and even continental ecosystems, for example as resting places for migratory waterfowl. The role of wetlands in the prairie ecosystem is an issue of major importance, which the Task Force was not able to explore. Task Force focus was narrower, the potential for wetlands to reduce the peaks of large Red River floods.

For the purposes of this report, wetlands are defined as shallow depressions in the land that retain water on the surface for longer than a few days. The Task Force looked at wetlands from the point of view of their ability to reduce the flood peaks of large Red River floods.

The early settlers of the Red River basin saw wetlands as a nuisance and an impediment to agricultural productivity. To support them, government programs funded wetland drainage. When roads were built, they had ditches, which drained individual fields and entire wetlands. Government programs also funded the construction of farm impoundments, conservation dams, and flood control storage.

One study undertaken for the Task Force reconstructed the pre-agricultural landscape of the Canadian portion of the basin. Based on surveys in the 1870s, lands were categorized as prairie, woodland, scrub, and wetlands and displayed in a geographic information system.[13] Wetlands comprised 12 percent of that landscape compared to 3 percent in 1995. Reliable figures on wetland drainage for the basin are not available, but it seems clear that the vast majority of Red River wetlands were modified by human activity during the twentieth century.

The Task Force looked at wetlands from the point of view of their ability to reduce the flood peaks of large Red River floods.

Wetlands may retain floodwaters, reducing peak flows or total flood volumes or both. However, the extent to which restoring wetlands can help alleviate floods is controversial. Since little research has been done on this subject in the Red River basin, the Task Force undertook two studies on wetland storage to quantify the potential reduction in flows on tributaries during major floods like the 1997 flood. The work was conducted in the Wild Rice River basin in Minnesota, the Maple River basin in North Dakota, and the Rat River basin in Manitoba.[14]

The studies used a digital elevation model of the three watersheds to define the potential wetland storage volume available, and calibrated a hydrologic model for the current conditions in the basins. Increases in potential wetland storage under a number of scenarios up to a four-fold increase were then applied to the hydrologic model, and the resulting flow conditions were compared to the existing situation. In all three cases, the calculated effect of additional wetland storage on the 1997 peak flow of the tributary was insignificant.

These results are not surprising. In 1997, there was an exceptional amount of snow and water on the land before the 1997 runoff—the highest amount of the century. Virtually every part of the basin contributed to the flow and relatively little additional storage was available.

There are a number of uncertainties associated with these hydrologic studies, including the accuracy of the digital elevation models. A more detailed model may provide better estimates of potential wetland storage. Different storage scenarios might also be used, but the scenarios tested did include large increases in wetland area. Based on the present results, the Task Force believes that it is unlikely that more sophisticated hydrologic modeling would change the general findings concerning effects on large floods.

The influence of wetlands in reducing peak flows for smaller or local floods is another issue. Hydrologic analyses, similar to those conducted for this study, may show that additional wetland storage could lower peak flows during smaller and local floods. This may be particularly relevant to reducing agricultural flooding from summer rains.

The Task Force studies examined the economics of increasing wetland storage.[15] Land can be purchased directly or as a storage easement. Benefit-cost analysis of wetland storage showed that the costs outweighed the benefits to flood control. Environmental and other benefits and costs were not included in the analysis.

Wetland restoration should be evaluated for local benefits and costs, rather than for any basin-wide benefit related to major floods.

The overall findings for the basins studied indicate that the flood control effects of wetland restoration should be evaluated for local benefits and costs, rather than for any basin-wide benefit related to major floods. Overall, benefits are more likely to be associated with ecosystem restoration and wildlife habitat than with control of major floods.

Conclusion 4: ***Wetland storage may be a valued component of the prairie ecosystem but it plays an insignificant hydrologic role in reducing peaks of large floods on the main stem of the Red River.***

Conclusion 5: ***There may be many good environmental and other reasons to restore wetlands, but wetland restoration is an economically inefficient method of reducing flood damages for infrequent large floods, like the Red River flood of 1997.***

Recommendation 1: ***Wetland restoration projects for flood control should be evaluated on the basis of their local benefits and costs rather than imputing a basin-wide benefit.***

Drainage

Drainage of wetlands and agricultural and urban uses of land are often cited as factors contributing to the record 1997 flood. Wetlands and land use can have significant effects on how much water runs off into streams and rivers, and how soon, particularly when climatic conditions are near average or "normal". However, record or near-record winter precipitation over thousands of square miles and the resulting runoff volume in 1997 caused depressions in the land to fill and spill. Wetland drainage and land-use practices likely contributed little to the record flooding.

While drainage has reduced the natural storage capacity within the basin, other offsetting factors increase storage. These include the 1.7 million acre-feet of storage in reservoirs, other retention structures, and the storage effect of the gridded network of roads on detaining water during large floods.

Artificial drainage can be classified into four types, which sometimes operate in combination with each other:

- **Wetland drainage**: Areas of standing water are drained through outlet ditches—there is almost no tile drainage in the basin.

- **Road ditch drainage**: Water drains from the road system and adjacent lands by road ditches.
- **General field, or sheetwater drainage**: Surface water (not water in wetlands) is removed from fields by either ditching or land planing (leveling)—tile drainage is not used for general field drainage in the basin.
- **Water table drainage**: Surface drains lower water tables enough to facilitate farming or other uses of lands with naturally high water tables.

The impact of artificial drainage on flood flows depends primarily on the hydrology of the watershed and cannot be generalized.

Wetland and road ditch drainage account for about 90 percent of drainage volume. Drainage starts with privately constructed drainage (such as ditches or land leveling), that lead to public drains (which are funded in large part by taxes levied on benefiting properties) or road ditches, which enter natural watercourses.

Drainage influences runoff by changing the volume or the timing of flows. Artificial drainage may increase the absolute volume of water entering natural watercourses by adding formerly non-contributing areas to the drainage system. The downstream effect of a change in runoff volume, however, depends on timing of flood peaks.

Artificial drainage moves water more quickly from where it accumulates (either as rainfall or as snowmelt) to a natural watercourse. The change in timing of when water enters a natural watercourse may increase peak flows, cause no change, or decrease the peak flows. During the 1997 flood, tributary peaks tended to coincide with peaks on the main stem, thus exacerbating an already serious situation. The 1997 flood volume at Winnipeg was similar to that of the 1950 flood, but the peak was substantially higher.

The impact of artificial drainage on flood flows depends primarily on the hydrology of the watershed and cannot be generalized. Small-basin studies of drainage show the effects of drainage on peak flows and volumes. Extrapolating those effects to the entire basin is difficult, as peak timing is a major consideration. Removing water quickly from the land may sometimes provide a benefit; in other cases, it may mean that local peaks coincide with main-stem peaks. Drainage is an issue that requires further study.

Effects of Distributed Storage and Drainage on Peak Water Levels

In summary, additional tributary storage would generally achieve modest reductions in water levels for the quantity of water stored, whether in reservoirs, on fields, or in restored wetlands. Its effectiveness would also depend on the timing of release. As well, drainage projects may or may not increase main-stem water levels, depending on the flood in question.

Additional tributary storage would generally achieve modest reductions in water levels for the quantity of water stored.

The analytical challenge is to consider how a series of projects distributed throughout the basin can affect water levels downstream on the Red River itself. This analysis can be accomplished using the distributed hydrologic models discussed in Chapter 11, combined with the Task Force's UNET and MIKE 11 hydraulic models. Some steps have been taken to implement partially distributed hydrologic models on some tributaries, and further work will undoubtedly be accomplished in the future as data needs are met and as funding permits.

These models will increase our understanding of how the basin functions and will provide new insights. They will not, however, reveal any specific storage solution to large floods on the Red River. They are more likely to help identify measures for reducing the impact from smaller tributary floods, such as constructing small impoundments, changing tillage practices, or returning land to permanent vegetative cover.

Another factor that confounds the use of distributed storage to reduce flood peaks along the main stem is the difficulty in managing such storage. Decision-support tools exist to manage operations at multiple reservoirs and predict the downstream effects. However, as the number of impoundments increases, the complexity of the system increases even more rapidly. Actively managing a system having, in effect, hundreds of small reservoirs is fraught with problems and the results are uncertain.

The operation of a distributed reservoir system would likely be too uncertain for urban centers at risk from large Red River floods. The choice is between management of a flood at the point of origin or the relatively more certain prospect of relying on local measures, both structural and non-structural.

Effects of Urban Levees on Flooding

Concerns were raised about the effects on downstream water levels of constructing new levees for Grand Forks and East Grand Forks. Would the risk to downstream communities be increased by the reduction in off-channel storage?

The UNET hydraulic model used to examine effects of upstream storage was adapted to analyze this issue. The model kept urban areas dry until the levees overtopped at the level of the 1997 flood. The storage represented by the flooded cities was simulated at or just preceding the flood peak to provide near-maximum effect on reducing discharges and flood stages downstream. Smaller floods do not overtop the levees. Floods larger than 1997 would overtop the levees sooner and use the available storage well before the peak arrived. Only if the levees were overtopped a few days later than actually occurred would the model show a higher stage increase downstream.

The Grand Forks and East Grand Forks storage areas were filled with water during the 1997 flood calibration modeling. The maximum volume of water stored within these areas at the peak of the flood was 15,000 acre-feet. This quantity is insignificant compared to the large volume of water in the Red River during the 1997 flood. The results on downstream water levels are shown in Table 5.

Table 5

Modeled Stage Increases With no Levees Overtopping

Location	River Mile	Stage Increase above 1997 Flood (Feet)
Letellier, Manitoba	141.17	0.00
Pembina, North Dakota	158.00	0.02
USGS gaging station at Drayton, North Dakota	206.70	0.04
Minnesota Highway 1 at Oslo, Minnesota	271.20	0.04

Ice Jams

River ice can cause property damage, erode stream banks, disrupt transportation and hydropower operations, and make flood forecasting difficult. As of 1999, the U.S. Army's Cold Regions Research and Engineering Laboratory (CRREL) National Ice Jam Database lists 397 events in North Dakota in which ice, particularly ice jams, affected river stages and a further 488 events in Minnesota. Rannie[16] has catalogued similar data from the Canadian portions of the basin. There has been no effort to produce a basin-wide list of ice jams.

Tributaries with significant channel gradients and confined channels are prone to ice jams. Examples include the Sheyenne River from Valley City to upstream of Kindred, North Dakota; the Pembina River above Walhalla, North Dakota; and the Red Lake River from Thief River Falls to Crookston, Minnesota. Ice jams in these reaches can cause rapid and sometimes severe stage fluctuations. Assiniboine River jams can affect operation of the Portage Diversion, part of the flood protection system for Winnipeg. The Winnipeg Flood Protection study, described in Chapter 5, examined this problem.

Main stem conditions differ from those of tributaries in that there is usually a broad, wide floodplain and mild stream gradients. During the initial break-up, river levels can fluctuate greatly as ice jams form, release, and re-form further downstream. Once the river starts to overflow its banks, however, the width available for floodwaters increases dramatically and the ice jam potential is reduced. Generally, the ice dissipates before the peak flood stage.

In 1996, a major ice jam resulted in flooding in portions of Selkirk, Manitoba. As the 1997 flood approached, thousands of holes were drilled in the ice near Selkirk to weaken the surface. No ice jam flooding took place, but the evidence is inconclusive whether that outcome is attributable to drilling.

Getting the Water Moving Earlier

The Task Force heard the theory that peak flows could be reduced if ice were removed from the river channel prior to runoff. This was often phrased as "getting the water moving earlier."

Aside from the potential for creating ice jams by creating an enormous quantity of ice chunks in the river, such a strategy would be ineffective. The quantity of water flowing in the river in one day near the peak can equal one month's flow before breakup.

Ice Control Using Air-cushioned Vehicles

Under certain conditions, air-cushioned vehicles, such as hovercraft, can create a standing wave capable of breaking up to three-foot thick ice. Generally the ice surface must be free of ice ridges and the vehicle must work from an ice-free open water area. Air-cushioned vehicles are not effective at clearing broken ice. On the St. Lawrence River, ice breakers clear the ice broken by air-cushioned vehicles. The air-cushioned vehicles used on the St. Lawrence weigh 120 tons.

A number of structural and non-structural ice management techniques can prevent or reduce the frequency of ice jams. Structural measures are expensive and therefore not cost-effective for Red River conditions. An exception might be channel modifications in communities having a persistent problem at one location. Similarly, ice conditions in the Red River basin generally cannot be controlled by ice suppression techniques, such as bubblers and thermal or flow regime modification.

Two potentially feasible ice-control procedures have been used in the basin. They involve either surface treatment to hasten melt or ice cutting to control break-up. Dark substances applied to the ice surface absorb solar radiation and increase melting. For the greatest ultimate benefit, the substances must be applied well before break-up, but that means the dust could be covered by new snow. The substances used in dusting should be chemically benign. A related technique to hasten melt is to remove snow from the ice surface, as the underlying ice cover will absorb more solar radiation than a snow cover.

Ice cutting is generally considered a technically and economically feasible method of ice control, especially for smaller events. Ice cover can be weakened in locations subject to frequent ice jams through drilling, sawing, or splitting. Caution must still be exercised, however, as there may be potential for problems with disposal of the broken slabs. If they move downstream and lodge, they may cause further problems.

Ice dusting with chemically benign substances and ice cutting appear to have potential as feasible, non-structural, ice management strategies in the Red River basin. Structural measures could be justifiable at locations where ice jams cause frequent and serious damage to property and infrastructure. In all cases, adoption of a mitigative strategy should be based on thorough study of local conditions, and care should be taken to protect downstream interests.

Recommendation 2: ***Future ice jam information from the entire basin should be incorporated into the CRREL Ice Jam Database so that ice problems in the basin can be analyzed further. Where feasible, historic ice jams from the Canadian portion of the basin should be entered.***

4

Communities at Risk

General

Residents and governments at all levels in the Red River Basin recognize the need for flood protection and have been active in taking measures to safeguard business, homes, properties and communities. See, for example, the list of 280 reservoir retention projects in Appendix 4 and the list of local protection measures in Appendix 3. Although the number of projects indicates a strong commitment to safeguard homes, investments, and communities, flood mitigation activities in the basin go well beyond those listed in these tables. Measures also include relocation of homes and businesses out of the floodplain, construction of agricultural levees and ring dikes around rural homes, agricultural practices to prevent rapid runoff, restoration of wetlands, preparation and updating of evacuation plans, and other non-structural flood damage reduction projects. (See Chapter 6 for a more general discussion of floodplain regulation and other policies in place to promote flood mitigation and community resiliency.)

United States Army Corps of Engineers

Pembina, ND

Much more should be done to prepare for floods of a similar magnitude or larger than occurred in 1997. One cannot entirely prevent damage from floods in the basin, but the actions that can be taken need to be evaluated and appropriate resources allocated when proposed improvements are cost-effective.

Local Protection Projects

Many communities protect themselves from floods by retaining runoff before it gets to the floodplain or by removing structures from harm's way. Although these measures are typical and effective, many communities have found levees to be the only economically justifiable and socially acceptable protection measure. Urban levees are appropriate provided they are evaluated systemically, are set back at a reasonable distance from the river, and take account of natural functions of the

Many communities have found levees to be the only economically justifiable and socially acceptable protection measure.

floodplain. If the structural improvements are not engineered to withstand the forces of flooding, the levees are not high enough, or they can not be raised in an emergency, local systems may give residents a false sense of security. In some instances, not all sources of flooding may have been considered, such as "backdoor" flooding, inadequately plugged sewer systems, unknown seepage paths under a levee, inadequate closures at streets and railroads, and interior drainage. Individual community projects must also be evaluated systemically to determine negative consequences outside the community.

Some risk remains even when permanent levees provide a high level of flood protection. Dike elevation design is based on floods of a certain height or frequency. Costs weighed against the damages prevented usually determine the flood frequency to defend against. The new levees in Grand Forks, for example, are designed for a 210-year flood. A greater flood that overtopped the levee would place all people and property of that community in jeopardy, especially if residents were unprepared. The lower the level of protective structures, the more frequently the community is at risk. As part of flood protection preparedness, communities need contingency plans to prepare for the potential overtopping of their levees.

The projects listed in Appendix 3 show that many communities in the United States had temporary levees in place in 1997. Many communities have upgraded their levees since then, some in compliance with federal design standards. These communities qualify for the U.S. Non-Federal Flood Control Works Inspection Program (FCWIP), which encourages construction of non-federal levees to minimum standards. Under the FCWIP, the federal government compensates participating communities for 80 percent of the cost of rehabilitating their flood control works in the event of major flood damage. The state and local governments cover the remaining 20 percent of the cost.

Approximately 70 percent of the communities in the U.S. portion of the basin, do not meet minimal federal standards and are not certified for the FCWIP.

Communities with levees built to federal standards and designed to protect against 100-year floods, including a freeboard allowance, can request certification from FEMA to remove the protected area from the 100-year floodplain. However, levees in approximately 70 percent of the communities in the U.S. portion of the basin, as listed in Appendix 3, do not meet minimal federal standards and are not certified for the FCWIP. While not necessarily inadequate, these levees may have been built under emergency conditions, often in less than ideal weather, quickly, or without engineering. They may or may not be adequate but they are now being relied upon as the only line of protection against floods.

Inclusion in the FCWIP ensures that qualified engineers will inspect the levees on a biannual basis and assist communities in the rehabilitation of flood-control structures damaged by floods. The inspection is at no cost to the community.

Recommendation 3: ***Communities in the United States portion of the Red River basin should ensure that community-built flood damage reduction projects are certified by FEMA for 100-year or greater protection, or should participate in the Non-Federal Flood Control Works Inspection Program.***

In Manitoba, $130 million in federal-provincial funds were made available after the 1997 flood for floodproofing. Funds are available for construction of community ring dikes to provide protection to 1997 flood levels. Projects have been undertaken at Ste. Agathe. Feasibility and design work is essentially complete on seventeen additional community diking projects, totaling an estimated $40 million. Construction is scheduled to begin in the summer of 2000 and to be completed by March 31, 2003. The projects include Rosenort, Niverville, Gretna, Aubigny, St. Pierre-Jolys, Lowe Farm, Riverside, Emerson, Rosenfeld, and Dominion City.

Large Population Centers

Winnipeg (population 670,000) survived the 1997 flood, suffering comparatively less damage than some other cities in the basin. However, its flood defenses were stretched to the limit and may prove inadequate for the next flood of similar size or larger. The next chapter examines in detail the risks faced by Winnipeg and alternative measures to reduce those risks. The situation in other basin cities is discussed below.

Fargo/Moorhead (population over 100,000): The record-setting flood crest elevation occurred in 1997 at 39.62 feet (12 m) (elevation 901.42 feet above mean sea level) (274.75 m). A permanent flood control project completed in Fargo in 1961 included four channel cutoffs and a 3,500-foot (1067 m) levee. The design height of the permanent levees in Fargo was to a stage of 41.3 feet (12.6 m); however, with settling, the actual protection is to a 40.0-foot (12.2 m) stage. The West Fargo diversion of the Sheyenne River Flood Control Project, completed in 1993, prevented cross flows from the Sheyenne River from flooding Fargo and West Fargo. Moorhead has no permanent federal flood control project. Both communities avoided major flooding in 1997 by either raising existing levees or building temporary barriers. Since the 1997 flood, both communities have implemented mitigation measures, including the acquisition of almost 100 floodplain homes, raising and stabilizing existing levees, installing permanent pump stations, and improving storm sewer lift stations and the sanitary sewer system.

The City of Fargo is also investigating the feasibility of providing permanent protection to areas on the south side of the city. The height of the permanent flood control projects was exceeded during the 1997 event, and flood barriers built since the flood have not been certified. The current review of the hydrology of the Red River being conducted by the U.S. Army Corps of Engineers and FEMA may alter the 100-year flood level and require revision of FEMA's flood insurance maps for Fargo and Moorhead. The routing of flows representing an 1826 event shows that a flood stage at Fargo/Moorhead would have been 4.6 feet (1.4 m) higher than occurred in 1997*

Grand Forks/East Grand Forks (population 60,000): The maximum stage reached in 1997 was 54.35 feet (16.56 m)(elevation 833.35 feet (254 m) above mean sea level. Temporary levees had been built to stages 52.0–52.5 feet (15.8-16 m) when they were overtopped. Damages from the flood to the cities of Grand Forks and East Grand Forks were estimated to be $3.6 billion[17]. Since the flood, these communities have been working with the U.S. Army Corps of Engineers to develop a plan for setback levees and floodwalls. The proposed $350.3 million project will be constructed between 2000 and 2006 to provide permanent protection for an event having a 210-year frequency of occurrence. The elevation of this barrier would be 838.5 feet (255.6 m) above mean sea level at the primary gage, which is 5.15 feet (1.57 m) higher than the level of the 1997 flood. Since the flood, 571 homes have been acquired in Grand Forks in addition to approximately 520 commercial and residential properties in East Grand Forks. Until the permanent barrier is completed, both communities have taken interim measures, including the raising and stabilizing of temporary levees and improving storm and sanitary sewer systems. With assistance from Housing and Urban Development (HUD), the City of East Grand Forks has also completed a section of removable flood wall in the downtown area. The 1826 flood levels at Grand Forks/East Grand Forks would reach a stage 3.6 feet (1.1 m) above that of the 1997 event, or 1.5 feet (0.46 m below the top of the proposed permanent levee.

Wahpeton/Breckenridge (population 12, 000): In Wahpeton, heroic effort and good fortune contained the 1997 floodwaters, which came within inches of overtopping the emergency levees. During the summer and fall of 1997, the city began construction of permanent levees on its own, but a shortage of funds and the desire to have a federally certified flood protection system ended the project before completion. The project was designed for the 1997 flood plus three feet (0.9 m) of freeboard. In Breckenridge, even heroic effort could not prevent approximately $20-25 million of flood damages in 1997. Flooding in Breckenridge is complicated by the fact that damage can occur from either the Red River or the Otter Tail River. At the request of Wahpeton and Breckenridge, the U.S. Army Corps of Engineers began a cost-shared flood reduction feasibility study in June 1999. Preliminary screening of alternatives has now been completed for both cities, and feasible multi-featured flood reduction projects have been identified. Detailed optimization and designs will be completed in July 2000. The federal project is estimated to cost $7 million for Wahpeton and approximately $17 million for Breckenridge.
At Wahpeton/Breckenridge, the routing of the 1826 flood results in a stage at 1.9 feet (0.58m) above the 1997 stage.

* *Data on the 1826 flood are limited mostly to Canadian sources, but the U.S. Army Corps of Engineers UNET model has used the information available to simulate a flood of the estimated magnitude of the 1826 flood as it might affect Fargo/Moorhead, Grand Forks/East Grand Forks, and Wahpeton/Breckenridge.*

Selkirk (population 10,000): The City of Selkirk is the northernmost city on the Red River. The Selkirk Golf and Country Club, the Selkirk waterfront, and a number of storm water outfalls are vulnerable to large floods or from backwater flooding from major ice jams. These areas suffered flooding in 1995, 1996, and 1997. The Selkirk Golf and Country Club is now protected with a permanent dike to a 160-year level of protection plus two feet (0.6 m) of freeboard. The Marine Museum, located adjacent to the river, is also protected to the 160-year level plus freeboard, as is Selkirk Park, located nearby. The city and the Province of Manitoba are currently discussing the design and cost-sharing of protection measures for the storm water outfalls.

Small Communities Where Levees Cannot Be Justified

Many projects in small communities do not meet criteria for federal funding.

In the United States, unless a protection project is tied to emergency measures, many projects in small communities do not meet criteria for federal funding. For example, the U.S. Army Corps of Engineers conducted a reconnaissance study to determine federal interest in permanent flood protection for Minto, North Dakota, a town of 600 residents on the Forest River about 30 miles north-northwest of Grand Forks, where 12 homes were flooded in 1997. Only emergency community sandbagging and dike construction prevented more extensive damage. The Corps concluded, however, that the benefit-cost ratio for permanent flood protection was only 0.43, considerably less than the required 1.0 normally required. Without federal interest in this work, flood damage reduction measures will have to rely on state or local initiatives.

Rural Homes and Farmsteads

Like communities in the United States that cannot meet federal economic criteria for assistance with flood protection, homes and farmsteads in rural areas are often ineligible for U.S. federal funding. Flood protection typically includes constructing individual ring levees, raising structures, or relocating out of the floodplain. Some homeowners have taken their own protection initiatives; those who have not remain susceptible to flooding.

In Manitoba, the federal-provincial program provides assistance for rural residents to raise or floodproof their homes. Under this program, $44.3 million is available for moving, raising or diking individual homes and properties. In 1998, the maximum government contribution for the federal-provincial program increased from $30,000 to $60,000. More than 2,500 homeowners, farms, and businesses are expected to benefit from the increased funding.

Agricultural Land

Although farmers cannot cultivate flooded land, it is not generally economical (at least under U.S. federal funding criteria) to protect agricultural land against spring floods in the Red River Basin. Spring snowmelt (as in 1997) is the source of most large floods in the basin. Such floods cause less economic damage than do the rainfall floods during the

Roads rail lines … can have unintended effects by retaining or redirecting flood waters.

growing season that can destroy crops. Recognizing the dependence of the region upon the farm economy, many locally funded agricultural levees have been built. They are typically built to a relatively low frequency level of protection (2- to 10-year flood frequency).

There has been little oversight of the impacts resulting from constructing these agricultural levees. The floodway* now being developed in connection with the update of the Red River profile in the United States will be available as a guide for future use of the floodplain.

Transportation Corridors (Roads, Railroads, Bridges)

Major floods can disrupt transportation. In 1997, the primary north-south highway corridor (Interstate 29 and Provincial Trunk Highway 75) was closed, as was the main east-west corridor (U.S. 2). No bridges were open over the Red River between Fargo and Winnipeg, a distance of over 200 miles. Primary railroad lines were under water, requiring the re-routing of rail traffic. Roads and railroads will continue to get flooded in events like the 1997 flood. Road and rail lines are often raised to reduce the risk of their being flooded. In the flat terrain of the Red River Basin, such construction can have unintended effects by retaining or redirecting flood waters. The raising of any road or rail line must anticipate possible hydraulic impacts.

* *In the United States, the "floodway" is defined as the channel of a river or watercourse, and adjacent areas. These areas must be reserved in order to discharge a 100-year flood without cumulatively increasing the water surface elevation more than one foot.*

5

Winnipeg at Risk

In 1997, the fate of Grand Forks was very much in the minds of Winnipeg residents as they and emergency management teams, including the military, worked to defend against the rising “Red Sea” to the south. Their efforts included the incredible feat of extending the West Dike by 24 kilometers (14.9 miles) and raising it, all within six days.

Winnipeg, the largest city in the Red River basin, had in place a substantial flood defense infrastructure constructed by the federal and provincial governments between 1962 and 1972. The permanent measures erected during those years included the Shellmouth Reservoir, Portage Diversion, and the Red River Floodway. The primary diking system within the city was constructed following the disastrous 1950 flood. In 1997, all these measures, coupled with enormous human effort and good fortune, succeeded in saving the city from the fate of Grand Forks. But Winnipeg had a close call. In a future flood of the magnitude of 1997 or larger, the city may not be so fortunate. A flood equal to the flood of record in 1826 could lead to the evacuation of at least 300,000 people and cause damages of as much as $5.8 billion.

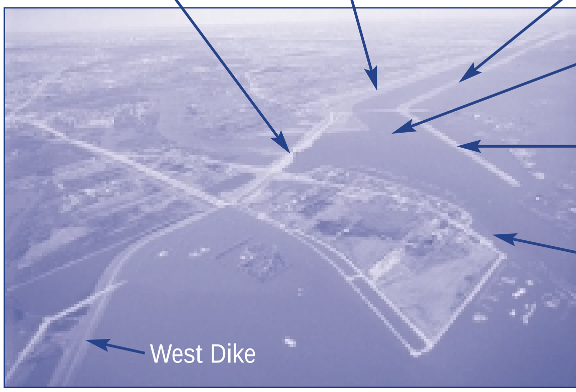
Winnipeg had a close call. In a future flood of the magnitude of 1997 or larger, the city may not be so fortunate.

Winnipeg faces a number of threats from large floods. Of particular concern are:

- possible overwhelming of the design capacities of the overall flood protection system;
- capacity limits of the flood protection infrastructure when flood stages approach or exceed those experienced in 1997;
- wind and wave conditions at the West Dike of the Red River Floodway; and
- lack of comprehensive emergency plans for extreme floods.

To assess the vulnerability of Winnipeg, the Task Force investigated flood risks in collaboration with the Province of Manitoba and the City of Winnipeg. A Winnipeg engineering firm was contracted to do the study.[18] The work included:

- identifying the capacities and vulnerabilities of Winnipeg’s flood protection system;
- examining new structural measures or operational changes to increase protection; and
- conducting pre-feasibility engineering of selected measures.



Floodway Entrance

Vulnerabilities

The study identified 57 ways in which Winnipeg is vulnerable to large floods. Many are generic, so the number of potential individual failures is much larger. For example, failure of Floodway bridges is one vulnerability, but it includes 13 bridges. The consequence of a failure also varies—failure of a pumping station is clearly less significant than a breach of the West Dike.

There are eight categories of vulnerability. The study identifies and describes the inadequacies within each, along with the consequence of failure, the level of concern, additional work required to further define the vulnerability, and the priority for further study. High priority areas where the consequences of failure are severe were studied extensively, while some low priority areas were simply identified. A panel of experts provided advice on identifying vulnerabilities and possible mitigation measures.

1. **Overall Flood Protection System.** These vulnerabilities include limitations on the overall capacity of the flood control system, inadequate detailed emergency preparedness and response plans, floodplain development that limits flexibility and may affect public safety, and flood monitoring concerns.

2. **Red River Floodway Inlet Structure.** If the embankments near the inlet structure erode or fail, floodwaters could bypass the inlet. The control system could fail in ways that would make it impossible to control gates—for example, fire in the inlet structure. Other issues include damage from ice, debris, or sabotage, and the need for clarity and understanding of the operating rules.

3. **Red River Floodway Channel.** Bridge failures could restrict the Floodway capacity. The embankments could fail. A failure of the Seine River Syphon could breach the West Embankment of the Floodway and allow an uncontrolled flow of up to 15,000 cfs (425 cms) to enter the city from the Seine River. Many services, such as water and electricity, are vulnerable under certain circumstances as they cross the Floodway channel, but that risk appears low.

4. **West Floodway Embankment.** If any portion of the first three miles (4.8 km) of the West Embankment (between the Floodway itself and the city) is breached, an uncontrolled flow of water would enter the south or east side of Winnipeg.

5. **West Dike.** Failure of the West Dike (the long dike extending from the Floodway Inlet Structure toward the town of Brunkild) through wind action, overtopping, or other causes would lead to uncontrolled flows into south Winnipeg by way of the La Salle River.

6. **Flood Protection Infrastructure within Winnipeg.** The city itself is subject to a number of internal vulnerabilities. These relate to the primary and secondary diking systems and to the flood-pumping stations and floodgate chambers. When river levels are high, floodwater can enter the city through the storm water or sanitary sewer system. There is no guarantee that the many temporary measures taken during the 1997 flood would be as successful again, even for a flood of the same magnitude.

7. **Portage Diversion.** The major threat is that the break-up of ice jams upstream of the diversion reservoir could cause a surge of ice and water and damage the system. Failure of the system for any reason could reduce the flow diverted to Lake Manitoba and hence increase flows toward Winnipeg.

8. **Shellmouth Dam.** The gates could fail, or the dam could breach or fail from erosion. While a Shellmouth dam failure would have severe consequences immediately downstream, the effect on flood protection levels in Winnipeg would be relatively minor.

Ultimate Capacity of the System

The study found that the flood protection system has a reliable capacity through Winnipeg of 71,000 cfs (2,010 cms). In 1997, the flow was 80,000 cfs (2,265 cms). This judgment was based on a safe water level in the city. Calculations of the shortfall in reliable capacity of the channel through Winnipeg are offset by increases in Floodway capacity. The Floodway could operate reliably beyond its 60,000 cfs (1,700 cms) design capacity to handle 73,000 cfs (2,067 cms). Consequently, water levels upstream of the Floodway inlet would rise above natural levels. Finally, the Portage Diversion and Shellmouth Dam can reliably meet their respective design capacities of 25,000 cfs (708 cms) and 7,000 cfs (198 cms).

Theoretically, the ultimate reliable capacity of the system is 176,000 cfs (4,984 cms), somewhat higher than the design capacity of 169,000 cfs (4,785 cms) or the 1997 flood rate of 163,000 cfs (4,616 cms). More refined analysis of complex wind effects on the “Red Sea” may alter that figure. Providing this level of protection would raise water levels at the inlet structure above natural levels. Moreover, extreme floods on the Red River rarely coincide with extreme events on the Assiniboine. In 1997, for example, the maximum flood control capability of the Portage Diversion was not needed.

The flow through Winnipeg in 1997 exceeded the reliable system capacity.

The flow through Winnipeg in 1997 exceeded the reliable system capacity (see Table 6). The city was fortunate, but it cannot realistically expect such a favorable outcome every time. On reviewing the vulnerabilities of the flood protection system in Winnipeg and its reliable capacity, the Task Force finds:

Conclusion 6: *Under flow conditions similar to those experienced in 1997, the risk of a failure of Winnipeg's flood protection infrastructure is high.*

Table 6

Capacities of Winnipeg Flood Protection System in Cubic Feet Per Second (cfs)*

Component	Design capacity	1997	Reliable capacity
Shellmouth Reservoir	7,000	4,000	7,000
Portage Diversion	25,000	11,900	25,000
Floodway	60,000	67,100	73,000
River Channel	77,000	80,000	71,000
Totals	**169,000**	**163,000**	**Up to 176,000**

* 1 cubic foot per second (cfs) is equivalent to 0.0283 cubic metres per second (cms)

Flood Damage Estimates

PFRA

The consultants used Geographic Information System methodology along with U.S. Army Corps of Engineers and Canadian guidelines to estimate flood damages for various floods up to a 1-in-1000-year flood.[19] They considered several direct and indirect sources of damage, mainly damage to residential and other buildings, damage to infrastructure, temporary relocation costs, and flood-fighting and emergency response costs. The 1997 flood cost of $67 million in Winnipeg was used as the base case.

Damage estimates were based on a Digital Elevation Model (DEM) that defines the topography of the land and water surface elevations associated with various floods, plus depth-damage curves for various types of structures. The depth of inundation—the difference between the water surface and the land surface—was applied to the depth-damage curve to produce a building damage estimate. Other damages were calculated by examining damages in Grand Forks in 1997 and projecting those damages to the Winnipeg situation. The results are summarized in Table 7.

Table 7

Estimated Flood Damages for City of Winnipeg ($ millions)*

Type of Damage	1:90 Year (1997) (163,000 cfs) *No Flooding*	*With Flooding*	1:290 Year (1826) (225,000 cfs)	1:500 Year (250,000 cfs)	1:1000 Year (295,000 cfs)
Residential (structures/contents)	9	200	2200	4,070	8,280
Commercial (structures/contents)	0	110	700	2,360	4,560
Temporary relocation costs	-	250	820	950	1,080
City infrastructure impacts	17	160	1460	2,200	2,710
Flood fighting / emergency response	41	41	490	730	900
Additional transportation costs	0	0	100	150	200
Totals	**67**	**761**	**5,770**	**10,460**	**17,730**

* 1 cubic foot per second is equivalent to 0.0283 cubic metres per second

Flood Protection Levels

What level of flood should be planned for—the 1997 flood, the 1826 flood of record, or some theoretical event, such as a 500-year or 1000-year flood? The 1997 flood would have produced a natural flow through Winnipeg of 163,000 cfs (4,616 cms). The 1826 flood is considered to have had a peak flow of 225,000 cfs (6,371 cms), approximately equivalent to a 1:300 flood. A large flood that could reasonably be expected to occur, calculated by combining hydrometeorological variables that are extreme but not individually unprecedented, was about 300,000 cfs (8495 cms).[20] This coincides closely with the 1000-year flood.

In the Netherlands, flood protection along major rivers is designed for a 1:1,250-year event.

Some jurisdictions base flood protection on such rare events when the risk of flooding will have enormous consequences. In the Netherlands for example, flood protection along major rivers is designed for a 1:1,250-year event, and 1:10,000 for coastal storm surges. The flood frequency of design floods depends on location, but the standard in most jurisdictions is a rare event, with return periods up to several hundred years. In Canada, for example, British Columbia uses the 1:200 flood and Saskatchewan uses the 1:500 flood.

A 1:100-year flood has a one percent probability of occurring each year. This annual probability can be converted mathematically to calculate the probability of recurrence over specific periods. For example, there is a 22 percent probability that a 1:100 year flood will occur in the course of 25 years, the length of a typical residential mortgage. The same flood has a 39 percent probability of occurring over a 50-year period. On the same basis, the current reliable capacity of the Winnipeg flood protection works has a 37 percent probability of being exceeded at least once in the next 50 years.

Given the concentration of Manitoba's population in Winnipeg and the importance of the city to the provincial economy, higher levels of flood protection are desirable. As a minimum, it is reasonable to provide protection against a known event, such as the flood of 1826.

Recommendation 4: *The design flood used as the standard for flood protection works for Winnipeg should be the highest that can be economically justified or, at a minimum, the flood of record, the 1826 flood.*

Mitigation Measures: Structural

To overcome the vulnerabilities, more than one hundred mitigation options were identified. These options addressed many vulnerabilities besides lack of hydraulic capacity.[21] Structural options related to improving hydraulic capacity include:

- expanding the Red River Floodway;
- twinning the Floodway;
- raising Floodway bridges;
- modifying the east embankment of the Floodway;
- raising primary dikes;
- raising the West Dike and west embankment of the Floodway;
- constructing a Ste. Agathe Detention Structure;
- improving the river channel downstream of Winnipeg;
- implementing a pump scheme at the Floodway inlet; and
- diverting the eastern tributaries of the Red River.

Other Ideas

The study considered two public proposals for increasing the discharge capacity of the Floodway Channel; remove the outlet structure and lower the inlet weir crest level.

Analysis shows that removing the outlet structure could produce a minor increase in flow capacity of 2,000 cfs (56.6 cms) but at the potential cost of significant erosion. Removal cannot be justified.

Lowering the inlet weir crest level by 7 feet (2.13 m) to the level of the Floodway channel would increase the discharge capacity by 50 cfs (1.4 cms). This benefit is insignificant and not worth the complications arising from early entry of ice into the Floodway channel.

Assessment of these projects was based on the degree to which they improve the ultimate capacity of the flood protection system, their approximate costs, and their potential benefits. Any proposed project must be socially and environmentally acceptable as well as technically feasible and cost-effective. The last three projects listed were eliminated from detailed consideration as economically unattractive and technically limited; the channel improvements and eastern tributary projects were environmentally unacceptable. The remaining projects have been subject to pre-feasibility engineering studies.[22] The findings of these studies will be adjusted as acceptable projects advance to the design stage.

Red River Floodway Expansion. The design capacity of the Red River Floodway is 60,000 cfs (1,700 cms) flowing from the inlet at an elevation of 770.25 ft. (234.7 m} With the present bridges, the channel is capable of a flow of up to 92,000 cfs (2,605 cms) at 778 feet. (237.1 m) This level, however, cannot accommodate wind effects on the Red Sea or minimize the risk of overtopping of the West Dike. As indicated, the present reliable ultimate capacity is 73,000 cfs (2,067 cms) at 774 ft. (235.9 m) Increases in discharge capacity above 73,000 cfs could be achieved by expanding the discharge capacity of the Red River Floodway channel. Fourteen options involving various combinations of width and depth increases have been studied.

For pre-feasibility studies, it is neither necessary nor appropriate to optimize channel design. For economic comparisons, however, various options were studied to identify a channel configuration reasonably close to optimum.

To accommodate increased flows for an expanded Floodway, the outlet structure would require modification. The inlet structure would not change but its operating rules would need review and modification. Many of the structures that cross the Floodway would have to be altered. These include road and rail crossings, hydro lines, gas pipelines, and hydraulic structures adjacent to the Floodway channel.

The consultant's economic analysis shows that the optimum net benefit is achieved by increasing the Floodway by approximately 75,000 cfs (2,100 cms). This would increase the ultimate reliable capacity for protection of Winnipeg from 176,000 cfs (4,984 cms) to approximately 250,000 cfs (7,079 cms). The optimum channel configuration increases both depth and width. This would increase flood protection for Winnipeg from the existing approximately 1-in-100-year level to a 1-in-500-year level. Larger increases in floodway capacity are probably not feasible, as the backwater from the north would extend into the city significantly above the height of the primary dikes. Even this expansion would require permanently raising the Primary Dikes on the north side of Winnipeg by about 3.5 feet (1.07 m). The West Dike would also be raised as part of the project.

This would increase flood protection for Winnipeg from the existing approximately 1-in-100-year level to a 1-in-500-year level.

Expanding the Floodway is a major project, as large as the original construction, and would take several years to complete.

Red River Floodway Twinning. An analysis similar to that of floodway widening was conducted for twinning the Floodway. The analysis indicated that, while technically feasible, it would cost as much as 30 percent more than Floodway expansion.

Raise Floodway Bridges. The 13 bridges over the Red River Floodway were designed in the mid-1960s for the 60,000 cfs (1,700 cms) design flow of the Floodway. The varying heights of bridge girders above the channel are largely determined by the elevations of the road and rail approaches that existed at the time. As the Floodway flow reaches approximately 70,000 cfs (1,982 cms) (corresponding to a water level of 772 feet (235 m) at the Floodway inlet), some girders start obstructing the flow.

Eight of the Floodway bridges obstruct flows higher than the design capacity. At a water level corresponding to 778 feet (237 m) at the Floodway inlet, the bridge decks impede flow and reduce potential capacity by up to 11,000 cfs (311 cms). This reduction does not include other potential effects due to displacement of the decks or ice or debris jamming against the bridge and backing up water.

Three scenarios to raise bridges were examined:

- Raise all the bridges that obstruct high flows; or
- Raise the six bridges at the upstream end of the Floodway; or
- Raise only the St. Mary's and PTH 59 South road bridges and the CPR Emerson line rail bridge.

The first two options, at a water level of 774 feet (236 m), allow a 4,000 cfs (113 cms) increase in flow, the latter a 3,000 cfs (85 cms) increase. Raising the West Dike and allowing the water level to rise to 778 feet (237 m) would provide a benefit of up to 11,000 cfs (311 cms) in the first scenario and 6,000 to 8,000 cfs (170 to 226.5 cms) under the latter two.

High-flow conditions require emergency measures to protect the bridges vulnerable to submersion. Hydraulic loading caused by submersion can shift and in some cases push bridge decks off their piers, creating unpredictable backwater effects. It is proposed to ballast the bridges or lock down the bridge decks to prevent shifting.

Bridge modifications would be part of any Floodway expansion project.

Modify East Embankment of Floodway. The east embankment of the Floodway and the Turnbull Drive dike constrain the flow in the approach to the Floodway inlet. Reducing the length of the embankment protruding into the river or excavating a portion to allow flow directly into the Floodway downstream of St. Mary's Road could lower water levels upstream of the constriction by up to half a foot (0.15 m). The cost would be modest. Preliminary economic analysis showed a relatively high benefit-cost ratio but a relatively small improvement to hydraulic capacity, in the order of 2,000 cfs (56.6 cms). Detailed analysis now under way will determine whether the project poses an additional risk to the flood protection system. If the project proves technically feasible, it could be an economic short-term measure to improve Floodway performance or be incorporated into future Floodway expansion.

Winnipeg Infrastructure Improvements. Approximately 75 miles (120 km) of primary dikes, supplemented by largely temporary secondary dikes, hold the Red River at bay within the boundaries of Winnipeg. Some of the primary diking system, however, is lower than the flood protection level specified by legislation enacted in 1980, which is equivalent to 27.8 feet (8.47 m) at James Avenue. The reliable top elevation is actually 26.5 feet (8.08 m), the level to which they were constructed in the 1950s. An examination of the feasibility of raising the dikes six feet (1.8 m) above the flood protection level to allow increased water levels in the city showed that the proposal had little merit. The cost of raising the primary dikes is high relative to the benefits gained. For the most part, the dikes form part of the city's road network. Modifications would also be needed to bridges, underpasses, and the internal drainage system.

These complexities could mean that a more modest increase in dike height may be feasible in some areas. Once the measures for protecting Winnipeg from future floods have been determined, this can be examined in more detail.

The primary diking system is penetrated in many places to provide sewer and land drainage to areas protected by relatively insecure secondary dikes or no dikes at all. In addition, numerous ungated sewers, channels, and streams flow by gravity to the river. These are temporarily plugged during floods, but such plugs are prone to failure. Moreover, rain during a flood could trap water behind dikes. Resolving these problems and reducing risk to the city requires significant modifications to sewer and land drainage systems. These modifications are costly and should be optimized and undertaken once the overall plan for Winnipeg flood protection is determined.

Projects that provide benefits under conditions of high river levels have been treated as a single protection measure, which essentially provides flood protection benefits to the city from a level of 20.5 feet (6.25 m) at James Avenue to 25.8 feet (7.86 m). This reduces the risk of failure of parts of the system and could correspond to an increase in reliable capacity of up to 20,000 cfs (566 cms) in Winnipeg. For the benefit-cost analyses, these measures have been subdivided into two levels of protection:

- Projects providing protection up to 23.0 feet (7.01 m)
- Projects providing protection between 23.0 feet. and 25.8 feet (7.01 and 7.86 m)

This allows an evaluation of the merits of increasing the reliable flood protection capacity to 25.8 feet (7.86 m) in two distinct increments, with costs representing each level. Once the appropriate flood protection level for Winnipeg has been agreed upon, the appropriate protection against high river levels and required modifications to the internal drainage system can be determined.

Raise West Floodway Embankment and West Dike. The vulnerability analysis concluded that the freeboard allowance of two feet (0.6 m) on the West Dike is too low. Six feet (1.8 m) of freeboard when the Red Sea is at 774 feet (236 m) at the Floodway inlet is more appropriate. When flood waters reach 778 feet, (237 m) the study estimated that eight feet (2.4 m) of freeboard is needed. These freeboard estimates could change after further study. Based on current knowledge, a scheme for raising the west floodway embankment and West Dike by three to six feet (0.9 to 1.8 m) was devised.

The Ste. Agathe Detention Structure would protect Winnipeg up to the 1000-year flood.

The pre-feasibility study used six feet (1.8 m) of additional dike height because water levels greater than 778 feet (237 m) at the Floodway inlet would require costly modifications to the Floodway inlet control structure. Raising the west dike is an essential step in any program to improve flood protection. This could raise water levels upstream of the inlet to be above the natural level and, hence, affect upstream residents. Wind set-up on the "Red Sea" is currently being analyzed. The study will determine the required freeboard and the amount by which the dike must be raised. Raising the West Dike would also provide a short-term benefit to Winnipeg flood protection. Revisions to the Floodway operation rules would also have to be considered.

Ste. Agathe Detention Structure. This is a 25-mile-long (40 km) earth dike across the valley south of Ste. Agathe, connected to a raised west dike and a control structure on the Red River capable of passing flows equal to the 1997 flood without undue restriction. When the flow becomes greater than the present capacity of the Winnipeg flood protection system (approximately at the 1997 flood magnitude), gates on the river would detain water temporarily on lands upstream.

The Ste. Agathe Detention Structure would protect Winnipeg up to the 1000-year flood. It would also reduce flood damages for the residents located between the project and the Red River Floodway inlet. The structure would operate only for floods above the 1997 level. The retention of flow would increase water levels south of Ste. Agathe. Water levels at Morris could increase by about one and a half feet (0.5 m) and six feet (1.8 m), respectively, for the 1826 flood and 1000-year flood. Increased water levels would diminish upstream, likely becoming zero at the international boundary.

It should be a condition for proceeding that the project must increase the level of flood protection for communities and individuals upstream of Ste. Agathe and compensate those who may be affected. A combination of measures would likely be needed.

The structure would have environmental consequences, in particular obstruction to navigation and fish passage. As a result, boat lift and fish passage facilities would be incorporated into the design of the river control structure to reduce these effects. In addition, culverts would be installed in the dike to allow the Rat and Marsh rivers to follow their usual course during normal times. During floods, the peak flows would be diverted by a constructed diversion channel to the Red River.

The Ste. Agathe Detention Structure would be a major project requiring several years to develop. It would provide Winnipeg and areas south of the city to Ste. Agathe with greater flood protection than an expanded Floodway, and at a lower cost.

Table 8

Comparison of Ste. Agathe and Floodway Projects

Project	Protection Level (cfs)*	Present Values ($ millions)			Risk of Exceeding Capacity in Next 50 Years (%)
		Cost	*Benefits*	*Net Benefits*	
Raise West/East Dikes + Modify Bridges + Expand Floodway	250,000	770	1,500	730	10
Ste. Agathe Structure + Improvements in City of Winnipeg flood Protection Infrastructure	300,000 +	475	1,900	1,425	5 (for capacity to 300,000 cfs)

* 1 cubic foot per second is equivalent to 0.0283 cubic metres per second

Selection of Best Options. The Task Force analysis indicates that the preferred projects to protect Winnipeg against very large floods are:

- expanding the Red River Floodway, or
- constructing the Ste. Agathe Detention Structure.

The Ste. Agathe project is much less costly to construct but has greater social and environmental implications. Table 8 compares these two large projects.

Floodway expansion would require more improvements to the internal drainage system than the Ste. Agathe Detention Structure, and that cost differential is not reflected in these costs. The figures for the Ste. Agathe project include the present value of estimated average of future damages in upstream areas, but do not include the cost of flood easements.

Smaller projects, individually or in combination, would increase the current level of protection, but could not economically protect against the 1826 flood. These smaller projects include raising the West Dike and west Floodway embankment, modifying the Floodway's east embankment, and raising some of the upstream bridges on the Floodway. After the decision on project selection, the city's infrastructure would need to be modified. Table 9 summarizes the preferred options, their effects on reducing risk, and their costs and benefits.

These projects have undoubted environmental consequences and would have to be constructed subject to and in accordance with the environmental laws of Canada and Manitoba. Expanding the Floodway, constructing the Ste. Agathe Detention Structure, and raising the West Dike would require a detailed review that could best be accomplished under a cooperative federal-provincial process.

Since the Ste. Agathe project would raise upstream water levels, this project would need to demonstrate the effects, if any, on water levels at the international boundary.

Since the Ste. Agathe project would raise upstream water levels, this project would need to demonstrate the effects, if any, on water levels at the international boundary. Construction and operation of projects that increase water levels at the boundary require an IJC Order of Approval or an international agreement. In any case, appropriate notification and consultation with the U.S. and state governments must be pursued if this project is to be selected.

Table 9

Summary of Preferred Options for Increased Security of Flood Protection

Measures to Achieve Protection	Flood Protection Effectiveness (cfs)*	Present Values (millions $)			Risk of Exceeding Capacity in Next 50 Years (%)
		Cost	*Benefits*	*Net Benefits*	
0 Existing system	176,000	-	-	-	37
1 Modify east embankment at Floodway entrance	to 178,000	2.5	68	65	34
2 1 + Raise West Dike and west embankment	to 194,000	50	475	425	24
3 2 + modify 6 bridges over Floodway	to 200,000	165	590	425	22
4 3 + Improve flood protection Infrastructure in Winnipeg	to 209,000	240	640	400	20

* 1 cubic foot per second is equivalent to 0.0283 cubic metres per second

Public safety requires immediate attention by the city, province, and federal governments to design and implement measures to further protect Winnipeg.

Coordinated Action

Public safety requires action to reduce risk as quickly as possible. This will necessitate immediate attention by the city, province, and federal governments to design and implement measures to further protect Winnipeg.

The Task Force recommends a two-step approach. The first would be to secure Winnipeg against a flood of the size of 1997, but assuming adverse weather conditions and subject to potential failures. In 1997, Winnipeg benefited from unusually favorable weather after the early April blizzard—light winds, no rain. Rushed temporary measures did not fail. The city cannot always expect to be so fortunate.

Recommendation 5: *Based on results from hydraulic model studies, modify the east embankment of the Floodway to improve the performance of the Floodway entrance to lower upstream water levels and increase capacity.*

Recommendation 6: ***The west dike should be raised to allow a water level elevation of 778 feet at the Floodway inlet structure with appropriate freeboard.***

Recommendation 7: ***The primary diking system should be raised where economically feasible to the elevation specified in existing legislation.***

In addition to these measures, a major project is needed to increase flood protection for Winnipeg. Both the Ste. Agathe Detention Structure and Floodway expansion can achieve a high level of protection at reasonable cost, although the Ste. Agathe structure is much less expensive and can provide a greater degree of protection. To some extent both projects would raise upstream water levels over natural levels for floods larger than 1997. These large projects will require extensive public and environmental review to determine their acceptability.

Recommendation 8: ***The City of Winnipeg, the Province, and the federal government should cooperatively finance detailed feasibility studies of the two major projects that would protect Winnipeg against very large floods.***

Recommendation 9: ***The three jurisdictions should work towards a Winnipeg Protection Agreement to finance the development of a long-term protection plan that would include construction of the Ste. Agathe Detention Structure or Floodway expansion.***

Recommendation 10: ***Modifications to the sewer and land drainage systems should be optimized and undertaken once the overall plan for Winnipeg flood protection is determined.***

Mitigation Measures: Non-structural

Some important protective measures are non-structural. Of immediate concern is Winnipeg's emergency preparedness. The response in 1997 was heroic, but more planning needs to be undertaken to prepare for extreme events. Manitoba jurisdictions are required to have detailed Emergency Preparedness and Response Plans (EPRP). The EPRPs lay out in detail the best response to all foreseeable failures. The plans include notification charts, inundation maps to guide emergency evacuation, and other information to improve responses in an emergency. For Winnipeg, the flooding component of the plan should include:

- emergency evacuation of large portions of Winnipeg;
- emergency response to breaches in flood-retaining structures;
- emergency construction of approximately 50 miles (80 km) of temporary dikes; and

- operation of flood control works when unprecedented conditions require engineering decisions that are difficult to make without methodical pre-planning.

The current effort by the city to assemble and document emergency procedures needs to be expanded and coordinated with the Province of Manitoba and the federal government.

> **Recommendation 11:** ***The City of Winnipeg should give immediate high priority to the preparation of a detailed emergency preparedness and response manual.***

Other prudent measures that should be undertaken include correcting sewer cross-connections, improving the land drainage system, data acquisition and modeling, and combined and separate sewer operations.

Improvements to the flood protection system will necessitate a further examination of the rules for operating flood control structures. If the Floodway is to be expanded, it would be feasible and perhaps necessary to maintain water levels below the state of nature during medium-sized floods, such as those of 1979 or 1996 and above natural levels for large floods. Construction of the Ste. Agathe Detention Structure would require a completely new set of operating rules for it and the Floodway. Those rules should form the basis for protecting or compensating upstream residents.

> **Recommendation 12:** ***Operating rules for new flood control measures should be designed to accommodate all flow regimes, even those beyond design capacity. The public should be consulted on any proposed new operating rules.***

6

Flood Preparedness and Resiliency

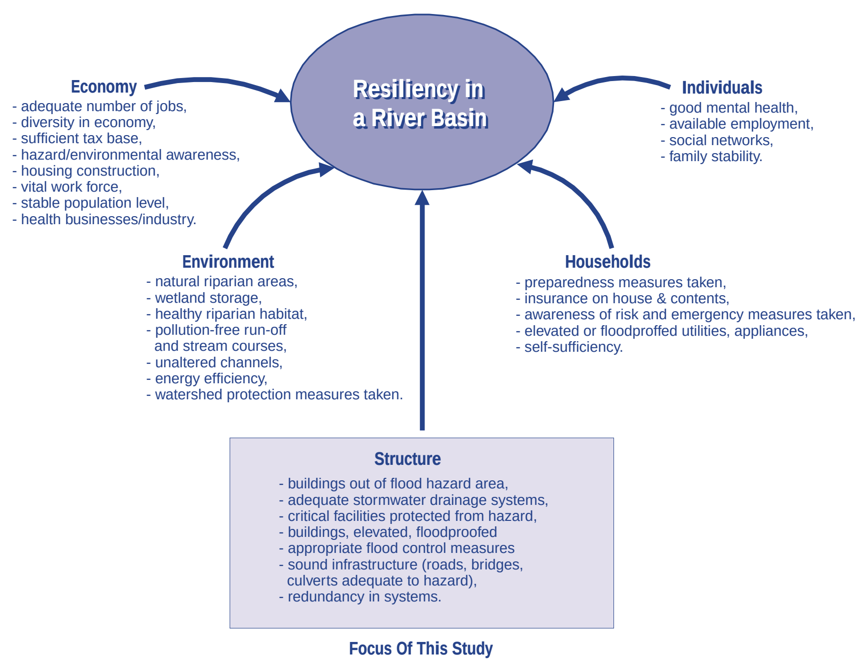
Residents of the Red River basin must prepare for flooding. They must defend against flooding where possible and become resilient to the effects of flooding where they cannot avoid it. Resilience is the ability to bounce back or adapt quickly to the consequences of an extreme natural event, such as a flood. Many activities, techniques, and measures that reduce the effects of future floods promote flood resilience. They include accurate and timely warnings, flood control measures, the designation of flood-prone areas as open space, flood insurance, flood-resistant construction, and storm-water management.

The previous chapters reviewed a number of structural measures that are being taken in the Red River basin or that can be taken to defend against flooding. However, many communities and residents will still remain at high risk from major floods. To supplement structural measures, communities will have to implement other measures to keep the impact of flooding low and to give residents the ability to adapt quickly to the consequences of a flood.

Figure 3 highlights many of the elements of a resilient basin. For example, in a flood-resilient basin, riparian areas are in natural or restored condition, with no paved channels. There is little threat of flood-induced pollution. Flood-resilient infrastructure and housing reduce the risk to buildings. Residents understand the risks, are adequately insured, and know what to do when a flood threatens. Business is sufficiently diversified so that the local economy is not disrupted or destroyed.

Figure 3

Elements and Components of Resiliency in a River Basin



This chapter examines some possible measures to promote better floodplain management and community resilience, including floodplain definition, building standards, education, flood insurance, use of expertise, monitoring, and assistance. It concludes with a brief review of some research on the social ramifications of flooding and points to areas for further research.

Canada and the United States differ in their approach to flood preparedness and community resiliency. The United States has a framework for dealing with the issues through the National Flood Insurance Program (NFIP) and the National Mitigation Strategy. While an event like the 1997 flood reveals that this approach still has shortcomings and gaps, it does link flood insurance to mapping, building standards, community action, and financial incentives to adopt appropriate mitigation measures. The Canadian approach is less integrated. Canadian flood preparedness and community resiliency efforts deal with many of the same elements, but there is currently no common program or framework tying them together. Results tend to be event-driven, ad hoc, with little programming emphasis on individual responsibility for mitigation initiatives.

Definitions

FLOODPLAIN - Any land area susceptible to inundation by floodwaters from any source.

100-YEAR FLOOD - A flood having a one percent chance of being equalled or exceeded in magnitude in any given year—not a flood occurring once every 100 years.

100-YEAR FLOODPLAIN - The area adjoining a river, stream, or watercourse covered by water during a 100-year flood.

FLOODWAY - The channel of a river or watercourse, and adjacent areas. In the U.S., these areas must be reserved in order to discharge a 100-year flood without cumulatively increasing the water surface elevation more than one foot.

FLOOD FRINGE - That portion of the floodplain outside the floodway that is inundated by flood waters in which encroachment is permissible.

ENCROACHMENT - Any obstruction in the floodplain that hinders the natural passage of flood waters.

SURCHARGE - An increase in flood elevation due to obstruction of the floodplain that reduces its conveyance capacity.

Floodplain Management

For communities and residents to take responsibility for flood preparation, they need to understand where the water will flow in floods of various magnitudes and how often they will be at risk. Basic to this understanding is floodplain mapping. In general terms, the floodplain is that portion of a river basin covered by water during a flood. Regulatory measures, however, require a more precise standard. To administer the U.S. National Flood Insurance Program, the Federal Emergency Management Agency (FEMA) uses the 100-year flood—that is, a flood with a one percent chance of being equaled or exceeded in any given year. Manitoba uses the floodplain of the 1997 flood.

The choice of a particular flood—a 100-year rather than 150-, 250-, or 500-year flood—is arbitrary. People living just outside a 100-year designated floodplain are not significantly safer than those living within its precise boundaries.

The area demarcated by a particular standard should be redefined when new statistical, hydrological, hydraulic, or historical information yields more accurate maps. The Task Force and others have developed new data, tools, and techniques to improve floodplain definition in the Red River basin.

A well-informed public should have knowledge of three related flood risk areas:

- the floodway, where hazards are high and occupancy and use must be severely limited;
- the regulatory floodplain, where occupancy and use are allowed, provided certain floodplain management requirements are met; and
- the lower-risk floodplain, where regulations may not be required but certain occupancy and use considerations are recommended.

Floodway: In general, the floodway* is where flood water flows swifter or deeper and poses a threat to life and property—typically the river channel, tributary channels and major overland flow areas. Obstructions in the floodway should not significantly affect upstream properties; according to U.S. legislation, they should have zero impact. FEMA defines the regulatory floodway as the channel of a river or other watercourse and the adjacent land areas that must be reserved to discharge a 100-year flood without cumulatively increasing the water surface elevation more than one foot. Floodways in the U.S. portion of the Red River basin have been defined for urban areas. In Manitoba, the most flood-prone communities have ring dikes or are now constructing them. Neither country has identified floodways in rural areas or urban expansion areas. In general, floodways in the Red River basin should be hydraulically defined and building or encroachment on the floodway should be severely restricted.

Regulatory Floodplain: Structures in a regulatory floodplain are at risk of flooding, but generally from lesser water depths and lower velocities than would occur in a floodway where there might be a threat to life and risks to property. Elevated and floodproofed[23] structures in a regulatory floodplain are likely to survive a major flood. Parts of the floodplain are often evacuated during a flood. For regulatory purposes, standard practice in the U.S. portion of the basin defines a floodplain in terms of the one-percent, or 100-year flood.

The area of the defined floodplain may change with new information, especially following major floods, and with the development of new flood control structures, dikes, or other infrastructure. A systematic program to ensure application of new information to floodplain definition is essential. In the United States, FEMA is required within every five years to assess the need to revise and update all floodplain areas and flood risk zones identified under the NFIP.

In Manitoba, the Department of Conservation defines its designated flood area (DFA) as the 100-year flood or a specific event, whichever is greater. As the standard for regulations in other provincial departments is the 100-year flood, this inconsistency may lead to confusion. Analysis of the 1997 flood shows that it is a 1:90 year flood at Winnipeg but greater than a 100-year flood from Ste. Agathe to the international boundary.

* *The use of the term floodway should not be confused with the Red River Floodway, which is a 47.3 kilometre (29 mile) channel constructed to divert Red River floodwaters around Winnipeg.*

Recommendation 13: ***In the U.S. portion of the Red River basin, the 100-year floodplain should continue to be defined in light of the best available information and the revised flood elevations should be used as the basis for floodplain regulations.***

Recommendation 14: ***In Manitoba, either the flood of record or the one-percent flood should be used for Red River basin regulations.***

Lower Risk Floodplain: Areas outside the regulatory floodplain flood much less frequently. Despite less frequent flooding, hospitals, fire stations, police stations, water treatment plants and other critical facilities may still need to be protected where economically feasible and where essential in flooding emergencies. The United States federal government uses the 500-year standard of protection for any "critical action" using federal funds.[24] A "critical action" is an action for which even a slight risk of flooding is too great. The Red River spreads so much during major floods that, for the most part, large increases in flood volume raise water levels relatively little. Except immediately south of Winnipeg, the difference in elevation between a 100-year flood and a much larger, rarer flood is small. In certain circumstances, dikes to protect against larger floods may cost little more than for a 100-year flood. The 500-year floodplain is delineated (as B-Zone) on the NFIP flood insurance rate maps (FIRMs).

Recommendation 15: ***The 500-year flood (0.2 percent flood) should be defined throughout the Red River basin and used to inform the public of the potential risks of flooding from rare events, including the need to buy flood insurance in the United States, and as the basis of regulations for siting and floodproofing critical facilities.***

In the United States, areas protected by levees meeting NFIP criteria are considered out of the 100-year floodplain. NFIP levee criteria include a three foot freeboard requirement above the 100-year flood elevation. Protected areas for such levees are generally identified as an area of lesser risk (Zone B or Zone X on flood insurance rate maps). The river side of the levee is generally a floodway and is shown with cross-hatching. Dikes, flood channels, and other measures to prevent damages against, for example, a 100-year flood, may only postpone damage until a larger flood occurs. The flood defenses enable more development than if the area had remained unprotected. As a consequence,

U.S. Critical Facilities

Hazardous Materials Production, Storage and Waste Facilities
- Superfund sites
- Landfills
- Hazardous waste facilities
- Petrochemicals and major pipelines

Essential Utilities
- Municipal and industrial National Pollutant Discharge Elimination System sites
- Water treatment plants
- Major water supply intakes
- Water well field
- Sewage treatment plants
- Power plants
- Major power utility substation
- Communications equipment and related antennas

Essential Services
- Hospitals
- Group homes for the mobility impaired
- Schools
- Major Airports
- Post offices
- State or federal bridges
- Prisons

Emergency Services
- Fire Department
- Police stations
- Military bases
- Major computer centers

property damage will be greater if the works fail in larger floods. Protection has limits, and people remain at risk—the risks are less but damages could be catastrophic. Consideration should be given to floodproofing behind dikes to protect against possible overtopping or a breach.

Building Standards

Much of the flood damage in 1997 was the result of the dominant housing style—one- or two-story homes on full basement foundations, with basements used as living space. Housing appropriate to the floodplain would foster long-term resilience. But what is appropriate? The NFIP prohibits construction of residential buildings with basements in the 100-year floodplain. All new or substantially improved buildings must have the lowest floor including basement elevated to or above the 100-year flood elevation. Dry floodproofing of residential buildings is prohibited. The lowest floor including basement of a commercial and non-residential buildings must be elevated or dry floodproofed to or above the 100-year flood elevation. However, NFIP community exception criteria allow floodproofed residential basements in certain areas. Exceptions are granted to communities likely to experience specific flood risks (water depths and velocities), if the community adopts specific design and construction requirements for floodproofed residential basements. Several communities in the basin have this FEMA exception.

Both Minnesota and North Dakota base their building codes on the Uniform Building Code, which will become part of a new U.S. national model code, the International Building Code. Minnesota includes floodproofing standards in its code while North Dakota does not. Cities and counties in both states may adopt the state building code and take responsibility for subsequent enforcement. Few jurisdictions in the Red River basin have adopted the state code.

> **Recommendation 16:** ***Both North Dakota and Minnesota should consider adopting the new International Building Code that includes requirements for design and construction in flood hazard areas.***

Canada has a national model building code that provinces may adopt in whole or in part. However, there are no National Building Code requirements for structures on floodplains. The apparent justification is that people should not build on floodplains. Such a view is inappropriate for Manitoba, where approximately 70 percent of the people live on the floodplain. In the United States, FEMA has been working with the American Society of Civil Engineers on a national standard (ASCE 24) for building design in flood hazard areas.

> **Recommendation 17:** ***The National Building Code of Canada should specify design and construction standards for buildings in flood hazard areas such as the Red River basin. Floodplain construction requirements should be incorporated into the Manitoba code when available.***

Education

Public awareness activities should emphasize the flood risk associated with any floodplain location or any location structurally protected from floods.

Flood protection standards and works can give a misleading sense of security. Many people seem to believe that the measures in place—standards, flood protection measures, and buildings constructed above the base flood elevation or outside the mapped special flood hazard area—give them adequate or even complete protection. Public awareness activities should emphasize the flood risk associated with any floodplain location or any location structurally protected from floods.

Flood protection standards protect against an identifiable degree of risk—for example, the 100-year flood. However, individuals and localities are still subject to residual flood risk. Nearly 25 percent of flood insurance claims in the United States are from outside the 100-year floodplain. Individuals and localities need to account for that residual risk by building communities resilient to flooding.

IFMI aims for a transboundary consensus on actions to improve disaster resilience.

In the United States, FEMA's Project Impact is a major initiative that encourages communities to protect themselves from the effects of natural disaster by taking action to reduce disruption and cost. The three principles of the initiative are: preventive actions at the local level; private sector participation; and long-term investment in prevention measures. In the Red River basin FEMA has initiated a pilot of a new concept for Project Impact, The International Flood Mitigation Initiative (IFMI). The initiative aims for a transboundary consensus on actions to improve disaster resilience. The Province of Manitoba is also contributing to IFMI. The effort has been characterized by a number of public meetings and working sessions involving a broad cross-section of individuals from both the public and private sectors.

Recommendation 18: ***Federal, state, provincial, and local governments in the Red River Basin, in conjunction with the private sector, should continue to develop, refine, and implement effective strategies to improve the disaster resiliency in basin communities. Efforts should be made to increase public awareness of flood risks throughout the basin.***

Enforcement

Building codes, zoning and other regulatory measures are only as effective as their enforcement. Enforcement effectiveness usually mirrors resources, training, public understanding and commitment, and related political will. In some cases, one or all of these elements are lacking.

Recommendation 19: ***State, provincial and other appropriate authorities should review the effectiveness of and compliance with the floodplain management regulations in the basin and take steps as needed to improve enforcement.***

Floodplain Acquisition

Buyouts of flood-damaged buildings reduce future flood losses and help build resilience, but only if the vacated land remains permanently as open space. In the United States, programs and funding should continue for voluntary buyouts of structures subject to repetitive flood damage or at great flood risk. This policy is effective, and many observers advocate its expansion.

Current FEMA policy prohibits the construction of levees, floodwalls, and other flood control projects on land that was acquired as a result of the Hazard Mitigation Grant Program (HMGP) 25. FEMA is in the process of developing a Memorandum of Agreement with the U.S. Army Corps of Engineers that addresses the construction of flood control projects on this acquired land. Coordination and consultation procedures and the issue of limited exceptions to the above policy are being discussed in the development of this agreement. The FEMA-Corps discussions, however, do not deal with state and other non-federal projects, and should be expanded to include non-federal agencies and projects.

In East Grand Forks, Minnesota the existing emergency levee is located nearly at the top of the channel bank of the Red River. The proposed U.S. Army Corps of Engineers project for the city, if built, would relocate the levees up to 1000 feet (304 m) landward to the limits of the existing 100-year flood plain. Additionally, the area between the river bank and the new levee would be cleared of structures (approximately 700) and maintained as open space. The alignment of the setback levees may use some HMGP acquired lands. FEMA and the USACE are in the process of reviewing this particular project to determine the appropriate action in consideration of the FEMA policy on the use of HMGP acquired property.

Recommendation 20: ***While the restriction of reuse of acquired properties is prudent as applied to residential, commercial or other non-flood damage mitigation purposes, FEMA should revise its interpretation of "structures" under the Hazard Mitigation Grant Program regulations to exempt water level control devices, dikes, levees, flood walls and any other feature that would mitigate future flood losses.***

Recommendation 21: ***The Canadian federal government should include in the Disaster Financial Assistance Arrangements provisions to allow for the permanent removal of structures in areas subject to repeated flooding.***

Mitigation Approach

Following a major flood, funding is often provided for actions that correct and mitigate the damage experienced. This time of crisis presents an opportunity in which community will and resources are available for worthwhile mitigation initiatives. However, after a major flood, governments must act quickly and there is little time to coordinate projects. To avoid piecemeal implementation and confusion, emergency and floodplain managers need to work out beforehand what should be done in the post-flood period. Action taken at one site, or for one purpose, should not hinder another. Basin or local mitigation plans that spell out the overall strategy are helpful. Mitigation activities need to be coordinated among funding entities, as well as among federal, state, provincial and local jurisdictions.

United States National Mitigation Strategy

The National Mitigation Strategy encompasses all U.S. state and federal agencies, as well as the emergency management community and the public. It has two components. By the year 2010, it aims to:

(1) substantially increase public awareness of natural hazard risk, so that the public will demand safer communities in which to live and work; and

(2) significantly reduce the risk of loss of life, injury, and economic, natural, and cultural resources that result from natural hazards.

The foundation of the Strategy involves strengthening partnerships and creating them where none exist in order to empower all Americans to fulfill their responsibility for building safer communities. These partnerships are essential to the five major elements of the Strategy:

1. Hazard identification and risk assessment;
2. Applied research and technology transfer;
3. Public awareness, training, and education;
4. Incentives and resources;
5. Leadership and coordination.

The Strategy sets forth a series of objectives by which to measure success in achieving the national mitigation goal and offers the basis for establishing priorities for the use of limited resources in fulfilling the major elements. Most important in this regard is the Mitigation Action Plan, or MAP, which highlights actions Americans and their governments must take to successfully launch the National Mitigation Strategy.

Recommendation 22: ***FEMA and Emergency Preparedness Canada should develop an integrated approach to mitigation initiatives at all political levels based on a comprehensive mitigation strategy for the entire basin. In the United States, the strategy should be integrated within the National Mitigation Strategy.***

Despite implementation problems within the Red River basin, the United States has a national mitigation strategy (see box) and an approach for dealing with flood mitigation. Through the combined use of insurance, incentives, and land use and building standards, the National Flood Insurance Program promotes numerous mitigation initiatives. Canada has no strategy to guide or fund mitigation measures supported by the federal government or partnership with the provinces.

The Canadian approach emphasizes flood-fighting preparedness, response, and recovery. For example, the $130 million in federal and provincial funds available for flood protection and flood proofing supports the construction and raising of ring dikes around basin communities until 2002 and helps homeowners, farmers, and businesses finance the floodproofing of their establishments. As important as mitigation might be, however, there is no coordinated approach to integrate structural and non-structural mitigation measures.

That may change. Emergency Preparedness Canada, in cooperation with the Insurance Bureau of Canada's Institute for Catastrophic Loss Reduction, has proposed a National Mitigation Policy. Further consideration should be given to this proposal and to introducing a variety of mechanisms (such as funding programs and technical assistance) to support mitigation programs at the local level. The federal government should have policies that encourage the development and funding of mitigation strategies with provincial and local partners.

Recommendation 23: *The Canadian federal government should establish a national flood mitigation strategy, or a broader disaster mitigation strategy, and support it with comprehensive mitigation programs.*

In its proposal, *A National Mitigation Strategy*, the Insurance Bureau of Canada recommends:

- establishment of a natural disaster protection fund, into which governments invest $100 million to $150 million a year to reduce the costs of future suffering and disaster recovery;
- expansion of the governments' response and recovery program by 15 percent to invest in mechanisms to prevent the recurrence of extreme events; and
- the creation, by insurers, governments, and others, of a new organization to promote prevention, mitigation and preparedness.

Flood Insurance

Flood insurance can be a positive public force for promoting flood preparedness and resiliency. It helps individuals assume responsibility for living in flood-prone areas and permits government funds to be directed to mitigation and other measures more sustainable than recovery assistance. In the United States, communities and states play an important role. To participate in the National Flood Insurance Program, a community must agree to adopt and enforce floodplain management requirements. If these conditions have not been met, federally backed flood insurance cannot be purchased. All new and substantially improved construction is then actuarially rated.

In Canada, standard residential property insurance policies do not cover flood damage. The flood insurance issue requires examination. Because the subscription base is smaller than in the United States, conditions may differ in Canada. The 1,300 flood-prone

U.S. National Flood Insurance Program

The National Flood Insurance Program (NFIP), established by the National Flood Insurance Act of 1968, makes federally-backed flood insurance available in states and communities that agree to adopt and enforce floodplain management measures that meet or exceed minimum federal criteria. In 1973, the Act was broadened to require the purchase of flood insurance as a prerequisite for obtaining any form of federal or federally related financial assistance, such as mortgage loans from federally-insured lending institutions. More than 18,400 communities now participate in the program, and the NFIP has mapped floodplains in over 20,000 communities. The 1994 National Flood Insurance Reform Act strengthened the NFIP by providing for mitigation insurance and establishing a grant program for state and community flood mitigation planning and projects.

The 1968 Act also requires the President to develop a Unified National Program for Floodplain Management. A 1994 update includes a set of national goals for floodplain management. Executive Order 11988 (Guidelines for Floodplain Management), issued in 1977, requires federal agencies to undertake a planning process prior to taking actions that affect floodplains. The Midwest floods of 1993 resulted in a further evolution in federal flood policy. Now there is a new emphasis on the acquisition or relocation of flood-damaged properties using funding from a number of federal programs and from state and local governments and the private sector. These floods also led to a reexamination of federal floodplain management policies and programs by the Administration.

communities in the country are concentrated mostly in the Great Lakes–St. Lawrence Basin, whereas the estimated 19,000 flood-prone communities in the United States are dispersed more widely. Since the end of Canada's federal-provincial Flood Damage Reduction Program in 1993, there has also been a lack of current floodplain information and the means to produce it. However, options could be examined to determine if a viable flood insurance program—one that learns from the United States experience—is possible in Canada.

In the United States, purchase and renewal rates are low where property owners are not required to have flood insurance. The purchase rates are much higher within the 100-year regulatory floodplain, where the National Flood Insurance Reform Act of 1994 requires property owners to purchase flood insurance before they may obtain loans involving federal funding or federally insured mortgages. Lending institutions face a financial penalty if they fail to require the purchase of such insurance. Many of the homes flooded in the Red River basin in 1997 were outside the 100-year floodplain and therefore were not required to have insurance.

In a sample of homeowners in Grand Forks, 94 percent knew about flood insurance, but only 20 percent had it at the time of the flood. Of those who did not have insurance, about 40 percent had inquired about flood insurance but had decided not to purchase it. Those who did not purchase insurance said they believed the National Weather Service crest predictions; they thought the dikes and flood control devices would provide adequate protection, or they thought that a flood would not damage their home.[26]

The incentive to participate in the NFIP is weakened if, during an emergency, compensation is given irrespective of insurance coverage.

Disincentives that discourage people from buying or renewing flood insurance policies in the Red River basin should be re-examined. For example, the short qualification period of 30 days before insurance comes into effect enables residents to predict the spring flood risk and to purchase only when the risk is high. Furthermore, after large floods, such as the one that occurred in 1997, the President may declare an emergency and make compensation available to insured and uninsured alike. The incentive to participate in the NFIP is weakened if, during an emergency, compensation is given irrespective of insurance coverage.

It should be noted that flood insurance can help residents recover from floods that are not declared emergencies, and that disaster assistance funds alone do not fully cover losses. Disaster assistance comes in the form of either an Individual Family Grant, with a maximum benefit of $13,000, or a low interest Small Business Administration loan, which must be repaid. There are no guarantees that properties will be bought out. Funding for a buyout project is initiated at the local level and requires state or local matching funds.

Within the NFIP, an incentive for good floodplain management is provided through the Community Rating System. The better a community's floodplain management, the more favorable the individual's NFIP insurance premiums. In addition, FEMA is currently working to close some of the gaps between its disaster assistance and flood insurance programs.

More emphasis needs to be placed on developing mechanisms to increase the participation and retention rate for the program and for FEMA to make the whole program actuarially sound.

> **Recommendation 24:** ***In the U. S. portion of the Red River basin, FEMA should expand current efforts to market the sale and retention of flood insurance both within and outside the 100-year floodplain. Innovative marketing should be considered to attract and retain policy holders, including increasing the waiting period from 30 days to 60 days before flood insurance comes into effect.***

Expertise and Information Sharing

Information about recovery and rebuilding techniques specific to the Red River basin should be shared between the United States and Canada as a matter of routine. One vehicle for doing this would be the formation of technical assistance teams comprising experts on clean-up techniques, molds, the draining and reconstruction of basements, and the design and building of ring dikes. These teams could serve as consultants to localities, give workshops for homeowners, and perform other similar services after a flood. A useful mechanism being developed by the Task Force and the Global Disaster Information Network is a basin-wide database of technical and other information related to recovery, mitigation, and flood resilience, accompanied by lists of sources of additional information. This database could be made widely accessible through public libraries or the Internet.

> **Recommendation 25:** ***Recovery, rebuilding, and mitigation expertise and information should be widely shared across the border in advance of flooding.***

Resilience Monitoring

Snow cover, water levels, soil moisture, and other indicators of potential flood risk are routinely measured in the basin, but indices of resilience, such as the extent of occupancy of the floodplain, number of insured households, sales tax revenues, and health of riparian ecosystems, are not. This lack of information handicaps efforts to build flood-resilient communities. Monitoring such factors would not only help identify problems and deficiencies in individual and community resilience, but it would also help establish a baseline against which progress can be measured. Resilience is not static, and monitoring would need to be done routinely to capture the ebbs and flows in the basin's status.

Recommendation 26: ***Measures of flood resilience should be developed, and a system should be established to monitor resilience in the Red River basin.***

The Human Effects of Flooding

The 1997 flood has inspired considerable research that can lead to the reduction of the human effects of flooding and to increased flood resiliency of the population.

The effects of flooding on the human population is an indicator of resiliency. While the Task Force was unable to examine these issues in depth, it recognizes that the 1997 flood has inspired considerable research that can lead to the reduction of the human effects of flooding and to increased flood resiliency of the population. The Task Force commissioned a review of the available research[27] from which the following preliminary findings are drawn:

- The widespread disruption of households after the flood may have affected women more than men. Women tended to shoulder more of the responsibility for domestic arrangements and duties, and these were made much more difficult when undertaken in temporary, often unsuitable, housing arrangements.

- Women with home-based businesses, especially day care, suffered from the disruption of those businesses as well as of their homes, first by the evacuation and then by the flood damage to housing.

- In the early months after the flood, businesses owned or managed by women in Grand Forks were twice as likely to remain closed as were others.

- Women in the United States were at increased risk of domestic violence after the flood; protection orders increased significantly, as did counseling calls to crisis centers. The Grand Forks shelter closed, leaving a gap in safe housing. Shelters were closed or relocated, and some women were forced by the flood to re-establish contact with or even return to violent partners.

- Stereotypical gender patterns became more prominent after the flood, to the detriment of women. Women's domestic and kin work intensified when living conditions were disrupted, but both men and women tended to discount women's extra behind-the-scenes work before, during, and after evacuation.

- Most women interviewed in Grand Forks reported a sense of accomplishment, confidence, and competence as a result of having had to assume multiple roles (additional domestic duties because of flood and the related evacuation; a paid job or profession; or volunteer relief, emergency response, or other activities).

- The stress to residents in the flooded and evacuated areas of Manitoba was increased by their inability to access timely, relevant flood-warning, evacuation, and recovery information from governments.

United States Army Corps of Engineers

- The flood tested marital relationships. Among Greater Grand Forks couples, for example, marriages that were strong before the flood emerged stronger in its aftermath; weak pre-flood relationships were further weakened. The relationships of couples with moderate levels of flood damage fared somewhat more poorly than the relationships of couples with little damage or total damage.

- Domestic violence in Grand Forks increased after the flood. People with lower social support, the elderly, and those with a prior history of violence were most affected.

- The flood seriously hindered domestic violence programs in the Red River Valley. As much as one year afterward, programs reported increased demands for service but fewer organizational resources (personnel, facilities, and money) than before the flood. In addition, the programs were largely unprepared to protect battered women and their children during and immediately after the flood, when housing was disrupted.

- Racial and cultural bias was evident in some aspects of recovery in the United States. Migrant families lost access to low-cost housing and other supplies, but were offered little recovery assistance. Some Hispanic women reported that volunteers in some relief projects effectively restricted aid to non-Hispanic residents.

- A majority (65 percent) of social practitioners dealing with juveniles, the family, mental health, and gerontology in Greater Grand Forks said that their clients were unsettled by the flood. Those with the fewest economic and personal resources beforehand were most upset. Financial and housing problems caused clients more anxiety and depression, and increases were reported in family violence and alcohol abuse, and in acting out by youths.

- Clients of social service agencies in Grand Forks generally reported receiving more and better attention after the flood from individual professionals and organizations. They noted the expanded efforts of some entities (such as the Salvation Army, churches, and church groups) and the appearance of new sources of assistance (such as the Federal Emergency Management Agency and the Red Cross).

More research is needed before the immediate and long-term social effects of the Red River flood can be fully understood.

Many issues have not yet been studied, and more research is needed before the immediate and long-term social effects of the Red River flood can be fully understood. Some of the areas where research may be helpful include the general area of basin-wide flood resilience, effects of temporary or permanent relocation, effects of the flood on quality of life, effects on children and minorities, implications for community and social identity, effect on farmers and farming communities, schools and the educational system, housing and other structure types that fared well or poorly in the flood, market and non-market losses, and positive results of the flooding.

It would be useful, and relatively simple, to conduct follow-up studies on some of the findings already identified. For example, a certain number of years after the flood, how many people carry flood insurance? For what reasons? Have the reasons changed from those reported by Pynn and Ljung?[28]

7

Flooding in the Lower Pembina River Basin

Flooding on the lower Pembina River has led to uncoordinated unilateral flood protection efforts that have caused harm to residents on both sides of the border. Unilateral dike and road building has been the source of transboundary disputes and tension in the Pembina Basin for more than 50 years. Federal, state, provincial, and local governments have carried out a number of efforts and studies to find solutions to the problems of transboundary flood management, but none have succeeded. Following the 1997 flood, residents of the basin resolved to renew efforts to find solutions to the problems. They have asked the International Joint Commission to aid in this effort.

Unilateral dike building has been the source of transboundary disputes and tension in the Pembina Basin for more than 50 years.

The Commission and the Task Force see an opportunity to help resolve the problems by working to develop a common understanding of the physical facts of the situation. The Task Force has undertaken detailed mapping of the lower basin and has created a computer model that can be used in consultation with local groups, to test alternative ideas about flooding and flood protection. The Task Force also initiated development of Internet-based information and analytical links to facilitate transboundary cooperation and issue resolution. Agreement has not yet been reached on specific actions to ameliorate transboundary damages, but some of the critical information and analytical tools are now in place.

Pembina Basin

The Pembina River basin straddles the United States–Canada boundary for 130 miles from the Turtle Mountain near Boissevain, Manitoba, to the Red River at Pembina, North Dakota. The watershed is about 3,950 square miles in area (10,230 km^2), divided nearly equally between Manitoba and North Dakota. The river flows in a generally easterly direction through Manitoba before turning southeast, crossing the international boundary about 15 miles (24 km) northwest of Walhalla, North Dakota, between the communities of Maida, North Dakota, and Kaleida, Manitoba. From there the river continues on its way through North Dakota to the Red River.

The current population of the basin is approximately 65,000, with about 40,000 in Manitoba and 25,000 in North Dakota. Agriculture and associated processing and service industries dominate the economy of the basin.

The Pembina Escarpment separates the watershed. The area west of the escarpment is an undulating glacial moraine upland of potholes, ridges, and knolls. In this area the Pembina River flows through a deep, incised valley. The entire Manitoba portion of the Pembina River watershed lies above the Pembina Escarpment.

Near Walhalla, the river emerges from the uplands and flows onto the broad flat plain of the Red River Valley. Relief along the escarpment in the Walhalla area drops abruptly from an elevation of approximately 1,500 feet above sea level (457 m) by 500 to 600 feet (152 to 183 m) to the plain below. Over the next 15 miles (24 km) downstream from the escarpment, the valley containing the Pembina gradually disappears. From a point near Leroy, North Dakota, through the town of Neche and on to its confluence with the Red River at the city of Pembina—a distance of approximately 20 miles (32 km)—the river is at the same level as the surrounding plain, or slightly higher, confined by natural levees built up over centuries of flooding, or by man-made levees constructed in an attempt to control flooding.[29]

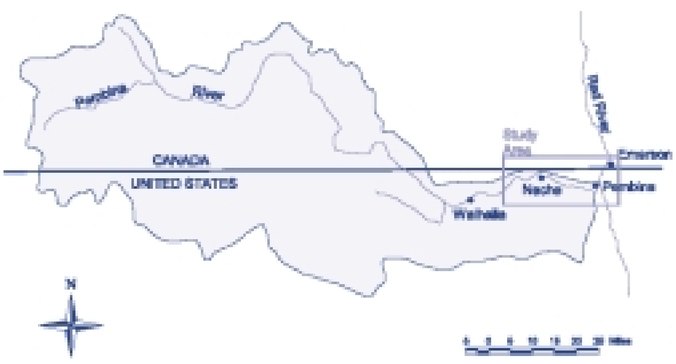
The Problem

Spring floods are a natural and common occurrence along the entire length of the Pembina River. But the most significant and devastating flooding occurs along the 35-mile (56.4 km) reach between the Pembina Escarpment at Walhalla and the Red River.

Since the river in the vicinity of Neche is at, or slightly above, the elevation of the land around it, flood flows breaking out of the main stem of the Pembina River under natural conditions move away from the river and overland into the Tongue River watershed to the south, or north toward Canada and eastward to the Red. The natural levees along the river impede the return of floodwater to the channel, and it does not return unless forced to do so by impediments such as roads.[30]

Figure 4

Pembina River Basin



Historical accounts mention major floods in 1882, 1897, 1904, and 1916. Since 1940, several other significant floods have occurred on the Pembina River downstream of the escarpment, including those of 1950, 1974, 1979, 1996, and 1997. Until the flood of the century in 1997 (at 14,300 cfs or 405 cms), the 1950 flood was the largest on record, at

10,700 cfs (303 cms). Based on statistical analysis of the flood peaks, the 100-year flood is deemed to be 18,000 cfs (510 cms).

Table 10

Major Floods on the Pembina Since 1950

Date	Peak Flow at Neche
Apr 27, 1997	14,300 cfs*
Apr 20, 1950	10,700
Apr 28, 1974	10,300
Apr 20, 1970	9,600
Apr 20, 1979	9,500
Apr 23, 1995	8,500
Apr 16, 1998	7,620
Apr 18, 1996	7,500
Apr 21, 1969	7,360
Apr 12, 1971	7,350
Apr 27, 1970	7,070

Note: Channel capacity at Neche is approximately 6,000 cfs.
* 1 cubic foot per second is equivalent to 0.0283 cubic metres per second

A Historical Perspective

For more than 50 years, efforts to solve the problem of flooding along the Pembina River have ranged from local, unilateral efforts to a number of attempts at international cooperation in fighting a common problem. In many cases, groups of local people have taken the matter into their own hands. These unilateral actions on both sides of the border have created tension between landowners and governments on either side.

As early as the 1940s, there were reports of Manitoba farmers and municipalities building a road-dike along the international boundary, creating an obstruction to cross-border flows. While there were culverts through the road-dike, they were not large or numerous enough to handle more than a minimum flow. When North Dakota farmers in Pembina County suffered damage and crop production losses in 1944 as a result of overland flooding, they reasoned that the blockage to the movement of the floodwaters into Canada had been the cause.

As early as the 1940s, there were reports of Manitoba farmers and municipalities building a road-dike along the international boundary, creating an obstruction to cross-border flows.

For their part, Canadian farmers expressed concern over a large land drainage project being planned in North Dakota. They asked for a complete survey of the proposed project and an accurate estimate of additional waters to be drained into Manitoba.

Following the 1950 flood, American farmers in the Neche area began to build dikes along the river to protect their land. After each major flood (in 1966 and 1969, for example) these dikes were extended or raised in preparation for the next flood. The Canadian action along the boundary in the 1950s and 1960s responded to increased overland flows from the south, which Canadians believed was aggravated in large part by the construction of these levees.

In an attempt to manage runoff reaching the international boundary from several drainage channels in North Dakota, Manitoba and North Dakota reached a tentative agreement in 1956 to construct the Rhineland Drain, also known as the International Boundary Drain. The drain runs parallel to the international boundary, just inside the Canadian border from a point about one mile (1.6 km) west of Gretna, Manitoba to the Aux Marais River crossing—a distance of about eight miles (12.9 km). The Aux Marais watershed extends a short distance into North Dakota in the area east of Gretna, Manitoba. From there it flows northeast through Manitoba to join the Red River near Letellier.

For three years after the drain was completed in the spring of 1959, negotiations continued over the installation of culverts and field inlets into the drain. In 1964, concerned over the possibility of additional flooding south of the border, the North Dakota State Water Commission and the county boards expressed an interest in extending the Rhineland Drain eastward along the boundary to the Red River. The proposal, however, was not feasible because of the depth of cuts required through the terrain. An alternative approach sought to redirect water eastward to the Red River using natural channels as much as possible. This option also floundered when the North Dakota State Highway Department indicated it had no obligation to construct or maintain a structure to accommodate the drain through Interstate 29. Local interests on the downstream end of the proposed project also expressed strong opposition to the project, and it was abandoned.

In October 1968, North Dakota expressed a further interest in improving drainage in the United States, with the hope of increasing the Aux Marais channel capacity to help accommodate additional flows. Manitoba expressed a willingness to increase the capacity of the Aux Marais River, but only if it could manage the amount of floodwater runoff entering Manitoba from North Dakota.

During the 1970s, the border issue began to intensify.

The 1970s were a decade of significant floods, in 1970, 1971, 1974, and 1979. During this period, the border issue began to intensify. Believing that construction activities along the international boundary violated the 1909 Boundary Waters Treaty, North Dakotans asked the International Joint Commission to review the problem. The IJC suggested that the problem should be referred to the Souris–Red River Engineering Board. In March 1970, the Governor of North Dakota asked the U.S. Secretary of State to involve the IJC.

On May 4, 1970, the U.S. State Department requested that the Canadians “secure the removal or reconstruction of the (boundary levee) in order that the normal flow of flood waters across the boundary may be restored,” in compliance with the 1909 Treaty.

During the April 1971 flood, there were unsubstantiated reports that Canadian farmers were patrolling their road-dike to prevent sabotage. Once again, the Governor of North Dakota asked the IJC to take action to relieve the problem. The IJC replied that it had no authority to prevent or halt any violation of the Boundary Waters Treaty without a request from governments.

Following each major flood in the 1970s, diking activities flourished on both sides of the border. The dikes along the Pembina River in North Dakota were extended and raised. Canadian farmers continued to extend and raise the road-dike along the international boundary. As the road system in the area was developed and improved over the years, roads also became a significant factor in altering natural overland flows.

Following each major flood in the 1970s, diking activities flourished on both sides of the border.

Between 1979 and 1990, an extended period of low flows and drought conditions helped ease the controversy surrounding water issues. However, the Red River valley was hit with another major flood in the spring of 1996, which breached the road-dike. North Dakota protested the efforts by local Manitobans to repair the breach, and the Manitoba government ordered that the repairs cease.

In April and May of 1997, record flooding occurred on the Pembina and Red rivers.

The 1997 flood is the largest on record for the lower Pembina River.

The 1997 Flood

The 1997 flood is the largest on record for the lower Pembina River. The Pembina experienced a double peak, a common, if not normal, occurrence. On April 22, a flow of 12,800 cfs (362 cms) was recorded at Neche as runoff from the lower portion of the basin passed. After dropping to 10,000 cfs (283 cms), the peak rose again three days later, this time to the record 14,300 cfs (405 cms), fed by runoff from upstream reaches of the river.

What was unusual (in addition to the size of the flood) was that the peaks on the Pembina and the Red coincided at their confluence. The peak runoff from local streams such as the Pembina is normally over by the time the peak on the Red River reaches the international boundary. The flows on the Red were in the order of ten times that of the Pembina. As a result, for a short distance from where it joins the Red River, the Pembina reversed its flow until it joined the overland flow from the Red and moved northward west of Interstate 29 and across the international boundary and into Manitoba.

Above Neche, most of the flow was contained within the river channel and associated levees, and by portions of the road network that acted as dikes in the area. Below Neche, the river broke out of its banks and moved south and north. To the south, County Road 55 contained the flow and redirected the flood waters back toward the river further downstream. From there, the flows continued overland until they met with overland flows from the rampaging Red River.

To the north, floodwater moved overland until it met the road-dike at the international boundary. Floodwater accumulated there until it spilled over a small height of land, known locally as Switzer Ridge, and then moved east to meet up with overland flows from the Red.

The eastern portion of the road-dike, just west of the Red River, was overtopped and failed in two locations. The failure, however, was more likely the result of combined overland flooding from the Red River and the Pembina, rather than of the Pembina itself. Following the flood, Canadians repaired the road-dike.

Along the international boundary from the Walhalla area to the Aux Marais River, six significant drainage ways cross into Manitoba from North Dakota.

Reservoir and Floodway Proposals

Along the international boundary from the Walhalla area to the Aux Marais River, six significant drainage ways cross into Manitoba from North Dakota. These are referred to by number; Crossing 1 is where Hyde Park coulee enters Manitoba, and Crossing 6 is the Aux Marais itself.

By 1973, discussions relating to the amount of water that should be allowed to pass into Canada along these drainage ways, and in particular through the Aux Marais, had been under way for nearly 20 years. That year, the Ad Hoc Canada–United States Water Resources Committee released a report containing a number of recommendations, among which were suggestions for installing additional culverts on the Aux Marais at the international boundary and at the five border crossings on the Walhalla–South Buffalo Lake watersheds. The committee also recommended that Aux Marais River and the Walhalla–South Branch of the Buffalo Lake System should be improved to accommodate flows equaled or exceeded once in eight years.

In addition, the committee developed a method of sharing the costs of the improvements and maintenance between Canada and the United States, based on the contributing drainage area for each channel lying within each country.

In October 1974, the Canada–United States Flood Control Review Committee was established to re-examine the recommendations and conclusions of the Ad Hoc Committee. In its terms of reference, the committee was instructed to assume, when preparing its recommendations regarding flow design or standard for drainage works, that the Pembilier Dam would be built, and to exclude from their consideration the presence of overflows from the Pembina River.

In its 1976 report, the Review Committee generally concurred with the earlier committee's recommendations. Only the recommendations describing the amount of flow crossing the border were revised, with more specific numbers and sizes of culverts to be installed.

In an inspection of the area in the spring of 1991, a technical committee of North Dakota officials and Manitoba Water Resources representatives determined that, in general, the actions recommended by the 1976 report (primarily in regard to the sizing and number of openings across the border) had not been applied. Manitoba, however, was in the process of upgrading the Aux Marais channel as recommended.

In 1996, a new International Technical Working Group examined the progress being made on the 1976 recommendations. The group determined that the Aux Marais system had been completed as recommended, with the exception of the emergency spillway. They also reached the consensus that waters reaching Crossings 1 to 5 further west were not affected by overflow from the Pembina, since they form part of the Walhalla–South Branch of the Buffalo Lake drainage systems. Accordingly, the Working Group agreed that the recommended openings in these border crossings could be installed, providing the cost-sharing agreement outlined in the 1976 report could be implemented.

The major stumbling block to a total solution seemed to be the failure to implement a flood control project on the Pembina River.

The major stumbling block to a total solution seemed to be the failure to implement a flood control project on the Pembina River. Canadian representatives insisted that no further changes should be made to the Aux Marais Crossing until provisions were made to handle additional flows from the Pembina River.

Nevertheless, the Pembilier Dam could still not be economically justified. The Working Group then considered the possibility of establishing an overflow channel, smaller than the one recommended earlier by the Corps, from the Aux Marais Crossing eastward about five miles (8 km) to join a natural channel to the Red River. The diversion would intercept excess flows on the Rhineland Drain at the Aux Marais Crossing and divert them along the south side of the border to the Red River. It was unclear whether local landowners and politicians would accept this proposal, and it has gone no further.

Early Studies

Prior to 1960, several studies were undertaken unilaterally in each country for the purpose of water management in the lower Pembina River basin. These studies revealed that no potential multi-purpose water management project could be justified economically unless both countries participated in the project.

In 1967 … the Commission recommended construction of two reservoirs to provide flood control, irrigation, and water supply to both the Manitoba and North Dakota portions of the Lower Pembina Basin.

In 1962, the governments of Canada and the United States requested the International Joint Commission to investigate and report on measures to develop the water resources of the Pembina River basin. In 1967, after considering recommendations made to it by the International Pembina River Engineering Board, the Commission recommended construction of two reservoirs to provide flood control, irrigation, and water supply to both the Manitoba and North Dakota portions of the Lower Pembina Basin.[31] The Pembilier Dam would be located immediately upstream of Walhalla and would provide 110,000 acre-feet of flood storage. The Pembina Dam would be constructed near Kaleida, Manitoba, and would be used entirely for irrigation and water supply.

In 1976, the Corps recommended the construction of a larger version of the Pembilier Dam.

Since implementation of the 1967 IJC proposal was being delayed, the U.S. Army Corps of Engineers initiated a study to examine the possibility of providing flood control and water supply by constructing a project within the U.S. portion of the basin alone.

In its 1976 report,[32] the Corps recommended the construction of a larger version of the Pembilier Dam than had been suggested in earlier studies. Of the total 147,000 acre-feet storage capacity, the reservoir would use 128,000 acre-feet exclusively for flood control. The report also said that the project would "relax social pressures surrounding the existing diking problems along the international border. These dikes were constructed to reduce the flow of Pembina River floodwaters to the Aux Marais basin in Manitoba."

During its further investigations in the late 1970s and early 1980s, the Corps also examined the feasibility of constructing a floodway to provide a certain degree of flood protection to the area downstream of Walhalla. One option—a 3,500 cfs (99 cms) diversion from three miles (4.8 km) east of Walhalla, north to the international boundary then east to the Red—was considered to be economically feasible and would provide a significant level of flood relief. However, it was not acceptable to the local people for a variety of reasons and, in the end, the report chose the Pembilier Dam and Reservoir as the most acceptable approach to flood control for the area. The study resulted in a Congressional authorization for a Phase 1 study to further investigate feasibility of the Pembilier Dam. The project was feasible at the time of authorization, but subsequent Phase 1 studies found the reservoir not feasible, primarily because of the decline in agricultural crop prices.

In the late 1970s and early 1980s, the Corps examined the feasibility of constructing a floodway.

Following a major flood in 1979, the interest in flood control in the valley grew stronger. In 1983, the Corps revisited its 1976 findings. The drainage area contributing to the project and the probable maximum flood were larger than calculated in 1976. Costs were higher and benefits lower. The study also examined a number of other flood control options and finally selected a 21-mile (33.8 km) long floodway from a point six miles

(9.7 km) west of Neche to the Red River as the most feasible plan. It had a positive benefit/cost ratio. This new proposal suggested locating the diversion point immediately upstream of Neche with a capacity of 2,000 cfs (57 cms).

Local objections to the plan were similar to those expressed in 1976. These included the loss of farmland to the channel, the relatively low level of flood protection being provided, inconvenience to farmers with land on either side of the channel, and the lack of water supply and recreational opportunities. Out of the 31 official responses received on the report, only eight supported the floodway plan and 19 supported the construction of the Pembilier Dam as the only acceptable solution to flooding in the area.

Under a 1980 Canada–Manitoba agreement for economic expansion and drought-proofing, the Prairie Farm Rehabilitation Administration (PFRA) conducted an extensive examination of options for supplying water to the area between the Pembina Escarpment and the Red River in Manitoba, an area referred to as the Assiniboine South–Hespeler Area. As part of the study, the feasibility of a dam on the Pembina River near Kaleida was considered. The relatively high cost of the project was a major drawback, and the Pembina Dam option was not pursued further by PFRA.

The most recent evaluation of reservoir construction on the Pembina for water supply and flood protection was conducted in 1999. The Lower Red River Valley Water Commission (Manitoba) contracted an engineering consulting firm, Acres International, to re-examine "sustainable water supply development and impacts of such development on flooding in the Red River basin." The Task Force provided half of the project funding.

Acres re-examined three projects discussed in previous reports—the Pembilier Dam and Reservoir, Pembina Dam combined with the Boundary Floodway, and the smaller Pembilier Dam and Floodway. A report indicating that costs exceed benefits has been prepared.

Current Activities

The Task Force believes that a solution to Pembina flooding issues requires—first of all —a common understanding of the facts of the situation. Technical information can help local groups and governments working to reach agreement on remedies to the transboundary flooding issues. The Task Force initiated a number of technical studies to aid in this effort. The work centered on three main initiatives—data acquisition and interpretation, model development, and decision support.

Technical information can help local groups and governments working to reach agreement on remedies to the transboundary flooding issues.

Data Acquisition and Interpretation. Accurate topographic data forms the basis for floodplain definition and floodplain management. To improve this information for the Red River Valley, the Task Force used a portion of the Lower Pembina basin to serve as a test area for preparation of a "seamless best available" Digital Elevation Model (DEM).

Three separate technologies were used to collect topographic data with the intent of fusing the data into one DEM. These were DGPS (differential global positioning system), Lidar (Light Detection And Ranging), and another, more experimental airborne technology, IFSAR (Inferometric Synthetic Aperture Radar). The U.S. Army Topographic Engineering Center managed the project.

In the fall of 1998, a DGPS survey of the centerline of paved and gravel roads and main levees was carried out. The data collected was processed to provide a complete set of elevations of these features to an accuracy of 2 to 4 inches (5 to 10 cm).

A 50,000-acre (20,234 hectare) section of the study area along the Pembina River from Neche to the Red River was flown in October 1998 using Lidar technology to acquire elevation readings accurate to 6 inches (15 cm). The data can be processed to produce a highly accurate "bare earth" DEM—that is, with buildings and trees removed in the processing.

IFSAR was also used to map the study area in October 1998. The aim of the system is to collect data for processing into a DEM at the rate of 40 square miles (104 km^2) a minute with 10-foot (3.05 m) vertical accuracy. By fusing the DGPS, Lidar, and IFSAR data, a more accurate IFSAR result may be possible. This analysis is still under way.

RADARSAT images of the study area were acquired for 12 days during the 1997 flood and four days during the 1996 flood. To assist future floodplain management and calibration of models, four RADARSAT images of the lower Pembina basin were produced. These images are coded for input into a GIS and the water features are classified. The satellite can obtain images in any weather, day or night, to a horizontal resolution of about 80 feet (24.4 m). The additional unprocessed data could be coded and classified as the need arises.

The U.S. Army Corps of Engineers recently analyzed flood frequencies for the Pembina River and found that there has been no significant change in the 100-year flood and the probable maximum flood as a result of the 1997 data.[33]

Model Development. The hydraulic models at the time of the 1997 Red River flood could not handle complex overland flows typical of a major flood in the valley. The Task Force sought a computer model capable of defining overland flows during a flood as well as one capable of being used for planning to determine the effects of new dikes or reservoirs.

The Task Force commissioned the development of two one-dimensional unsteady flow models aimed at achieving a water level accuracy of 6 inches (15 cm). A UNET model was implemented in the upper basin from Lake Traverse to Letellier, Manitoba, and a MIKE 11 model was applied to the lower basin from Grand Forks to Selkirk. The lower Pembina River basin is in the overlapping portion of the two models.

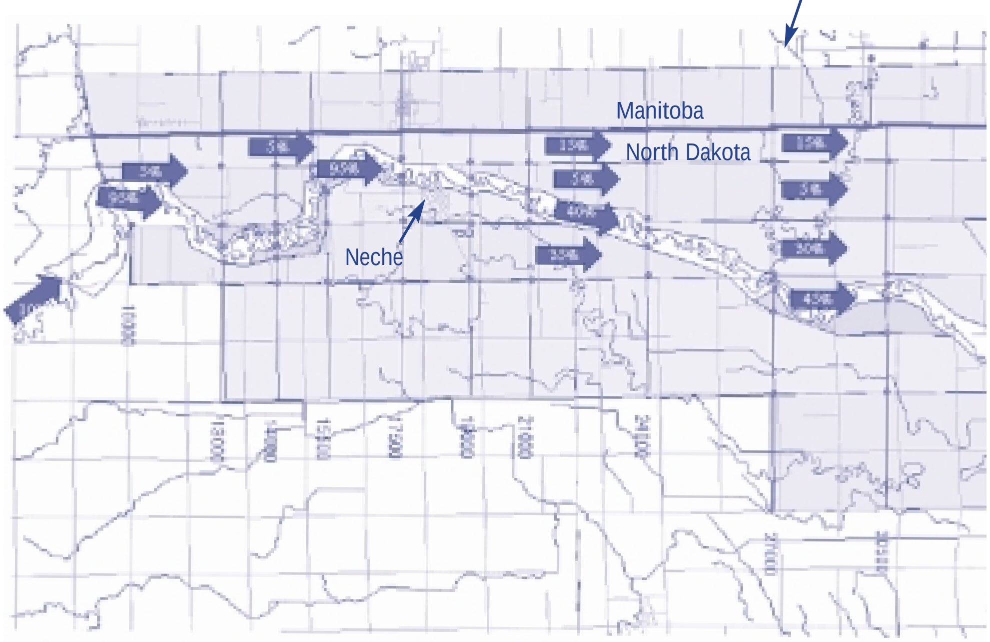
Storage (on the Pembina) was found to have no effect on water levels on the Red River at Emerson under 1997 conditions.

The models examined the effects of hypothetical upstream storage on lower basin water levels. Among the scenarios tested was the effect of storing 75,000 acre-feet of water at the optimum time in the Pembina basin. This storage was found to have no effect on water levels on the Red River at Emerson under 1997 conditions.

The Task Force added a detailed sub-model of the lower Pembina basin to the MIKE 11 model, which allowed examination of a variety of scenarios. The model was run for the Lower Pembina River for both 1996 and 1997 from a location about six miles (9.7 km) west of Neche to the confluence with the Red River at Pembina. A comprehensive discussion of the results of the modeling is presented in a separate report to the Task Force.[34] Findings can be summarized as follows:

Figure 5

1997 Peak Flow Distribution for Existing Conditions

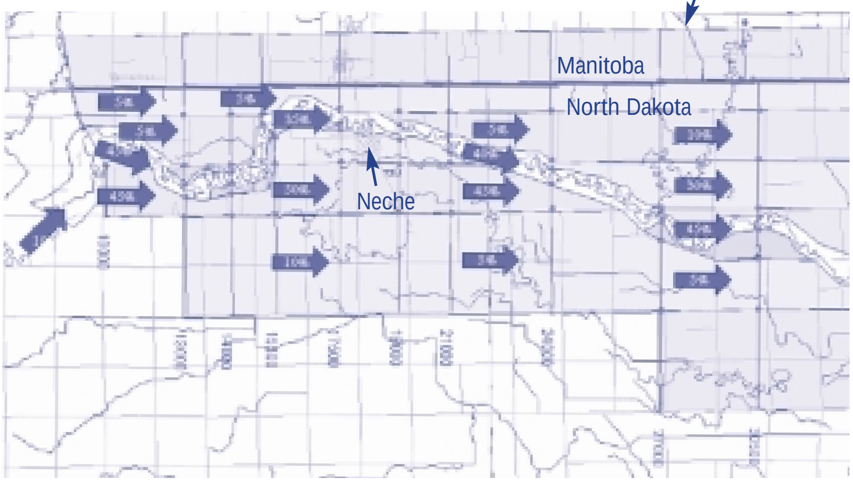


Under 1997 conditions, the flow on the Pembina River at Neche was 14,300 cfs (405 cms). This flow was contained within the channel, its associated dikes, and the adjacent road network until it broke out of the channel just east of Neche. About 15 percent of the flow (2,100 cfs or 59.5 m) moved northeastward from the breakout point to the international border, where it was impeded by the road-dike and by Switzer Ridge. A relatively small amount of the water passed through culverts in the road-dike and into the Aux Marais River. Most of the flow eventually crossed Switzer Ridge and continued along the U.S. side of the border and on to the Red River.

About 40 percent (5,700 cfs or 161 cms) moved away from the river to the south and east. This overland flow was confined by County Road 55 and forced to the east and eventually back across the river to the north side where it continued overland to the Red River. In effect, the road-dike along the international border on the north and county road 55 on the south acted as setback dikes, containing the flow between them.

Figure 6

1997 Flow Distribution Without Dikes



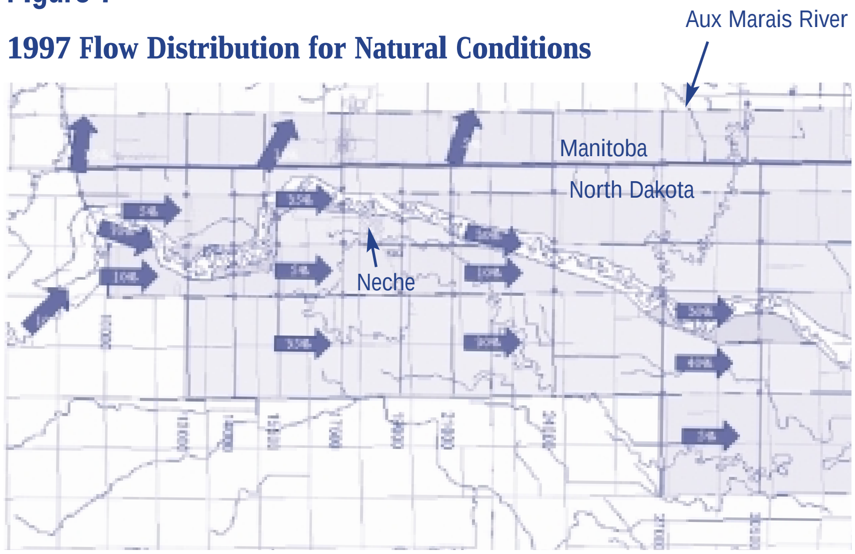
The modeling has shown that the capacity of the Pembina River channel downstream of Neche, with the existing dikes, is in the range of 5,100 to 6,400 cfs (144 to 181 cms).

Removing the system of dikes along the Lower Pembina River shows an entirely different overland flow pattern.. With no manmade levees in place, and under 1997 flows of 14,300 cfs (405 cms), the simulation revealed that the flow would have broken out of the channel west of Neche, instead of east. In addition, existing roads on the north side of the river would act as dikes locally and prevent Pembina River flows from reaching the international boundary. About 40 percent of the flow (5,700 cfs or 161 cms) would remain in the channel and the remaining amount would spill out on the south side of the river, flowing south and east, eventually meeting up with the river downstream and crossing it on its way overland to the Red. Again, County Road 55 acts as a setback dike on the south side of the river.

Under natural conditions—with no dikes along the river and no roads in place—flood flows would have left the river channel west of Neche. About 30 percent of the flow (4,300 cfs or 122 cms) would find its way north, 15 percent into the South Buffalo Drain in Manitoba via Hyde Park Coulee in North Dakota and another 15 percent further east. However, no floodwaters would flow along the international boundary east of Neche and no flow would enter the Aux Marais system.

Figure 7

1997 Flow Distribution for Natural Conditions



An additional 30 percent of the flow would escape to the south, past the present location of County Road 55. Only 30 to 40 percent of the total flow (4,300 to 5,700 cfs or 122 to 161 cms) would remain in the channel through Neche. This should be considered the natural capacity of the Lower Pembina River.

An engineered floodway of 2,000 cfs (56.6 cms) along the international boundary, as proposed by the U.S. Army Corps of Engineers in 1983, would have a minimal impact on flooding under conditions similar to those that occurred in 1997. The floodway would, however, provide benefits in lower flood years such as 1996.

Figure 8

1997 Flow Distribution with Boundary Floodway

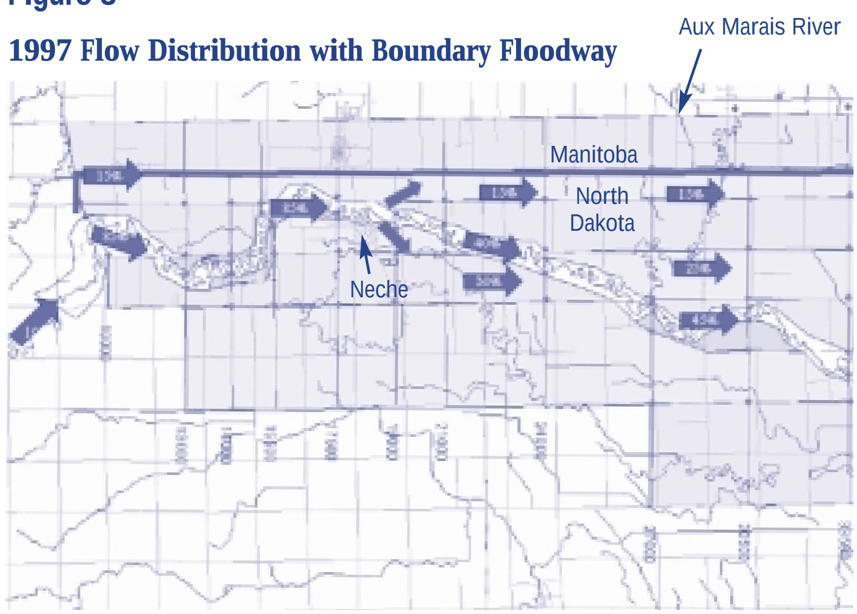
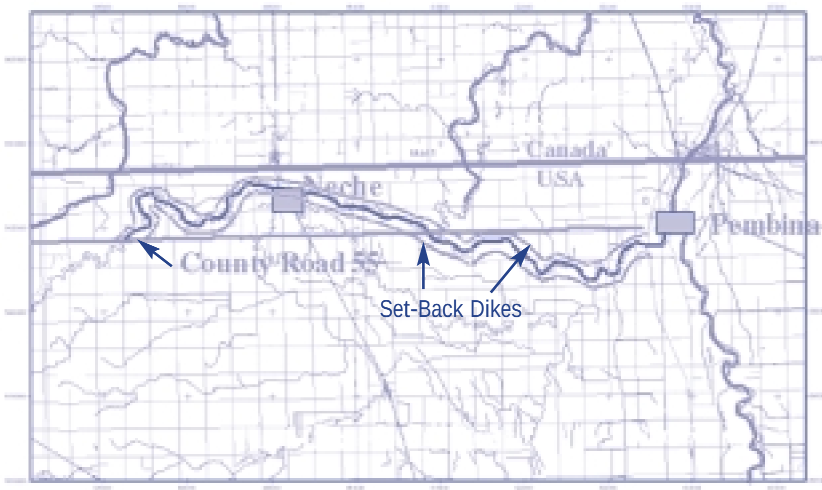


Figure 9

Set-Back Dikes



The model examined the feasibility of building a system of dikes set back from the river from a location upstream of Neche eastward to the Red River. The dikes would be set 2,700 feet (823 m) apart. Removing trees and shrubs from the channel between the dikes would increase its hydraulic efficiency but may not be environmentally acceptable. Allowing the natural vegetation to remain in the channel would decrease its hydraulic efficiency and require that the dikes be constructed two feet (0.61 m) higher than those for a “clean” channel.

Ideally, the dikes should be tied into a height of land on the upstream end and into an existing diking system on the downstream end. While it may be possible to tie the dikes into the sloping terrain at the upstream end, there is no logical tie-in at the downstream end, so they would terminate near where the Tongue River joins the Pembina. The land adjacent to the levees near the Red River would still be subject to overland flooding from the Red or Tongue Rivers.

The highway bridge across the Red River at Pembina and the railway bridge at Emerson in themselves have no impact on water levels in the area. However, the channel restrictions created in part by diking systems around the two communities may have a minimal impact on water surface profiles in the area.

Decision Support. One of the tasks initiated by the Task Force, in partnership with the Global Disaster Information Network, is the development of a virtual database for the Red River basin. The virtual database will provide a means of making data and information concerning mitigation measures, emergency response, and flood recovery available to governments, non-governmental organizations and the public.

The virtual database is a distributed database searchable over the Internet. Each contributing agency will continue to be responsible for maintaining and updating its own holdings and the related data documentation. Hundreds of relevant data sets held by dozens of agencies have been catalogued. Used in concert with a suite of models or model outputs and interactive tools, these data sets constitute a decision-support system. In effect the system would search for data, present or report data, export data to models and execute some models, and import and present results from models. Such a system must be developed in phases so that it can be tested and evaluated.

A prototype focusing on the Pembina basin is in the early stages of development. Specific flood management issues within the Pembina River basin addressed by the system will require the four following applications:

- Flood forecasting tools, including interpretation of official flood forecasts for both Canada and the U.S.
- Flood preparedness tools, to select appropriate structural and non-structural measures for reducing flood risk and flood damages, including hydrologic models to estimate runoff and hydraulic (or hydrodynamic) models to generate water elevation and flood-extent maps
- Optimization tools, including economic models to investigate possible modifications to flood control systems for minimizing economic loss
- Emergency management tools, including models to simulate, test and update emergency plans.

Grass Roots Involvement

Over the decades, a number of local interest groups have formed, only to fade away as the degree of concern over flooding issues in the Pembina area ebbed and flowed with the flood cycle. Today, there are a number of grassroots organizations, most notably the Red River Basin Board (RRBB) and the newly formed Pembina River Basin Advisory Board (PRBAB).

Today, there are a number of grassroots organizations…most notably the Red River Basin Board and the newly formed Pembina River Basin Advisory Board.

The RRBB has three special task forces, including the Pembina River Watershed Task Force. The purpose of this task force was to ensure that the work being done in the Pembina watershed was compatible with the objectives of the RRBB. The work of this task force has been placed in abeyance pending the outcome of the work of the Red River Basin Task Force, the PRBAB, and others.

Like the RRBB, the PRBAB was established in 1997. However, the PRBAB has the more narrow focus of attacking flooding problems and associated issues along the Pembina River. Membership includes representatives from counties, townships and municipalities, state and provincial governments, conservation districts, and water management organizations throughout the basin.

The PRBAB is currently working toward the development of a water management plan for the basin. The Board serves as a valuable forum for the public presentation and discussion of new information on water management as it becomes available. As an example, the results of the Task Force's computer modeling of flood flows along the Pembina have been shared with the Board at public meetings. Scenarios proposed at those meetings have been incorporated into the model.

Conclusion 7: ***There is general recognition in the region that flooding in the lower Pembina River basin has been profoundly affected by the construction of dikes and of roads that act as dikes on both sides of the boundary. Rectifying the transboundary flooding consequences of these structures will require action in both countries and there appears to be a general readiness to take such action.***

Recommendation 27: ***The International Technical Working Group, formed in 1996 but currently inactive, should be re-activated to examine the findings of the hydrodynamic model. Working with local interests, such as the Pembina River Basin Advisory Board, it should develop, implement, and fund a solution that is sustainable in the long term.***

Recommendation 28: ***Given the transboundary nature of the basin and the potential for federal involvement in funding and monitoring any agreement, federal agencies from both countries should be engaged in this process as well.***

Recommendation 29: ***Changes in the road network and diking system in the lower Pembina basin should be modeled by the hydrodynamic model prior to implementation of any plan to ensure that there are no unintended consequences.***

Recommendation 30: ***The virtual database and decision support system prototype that the Task Force has begun to develop for the Pembina basin should be continued by relevant agencies in Canada and the United States.***

8

Hydraulic Connection at Lake Traverse

The low continental divide between the Little Minnesota River in the Mississippi River basin and the Red River in the Hudson Bay basin historically has allowed the waters of the two systems to mix occasionally during periods of flood. Several early residents reported being able to take advantage of a much-shortened portage in the region of Browns Valley when water levels were high during spring floods.

Transfer of water from one basin to another has become a major environmental concern in recent years as the introduction of new species into a watershed can cause enormous damage. For example, over 100 non-native species have been either intentionally or accidentally introduced to the Great Lakes. A number of these, including the zebra mussel, have quickly expanded their range into the Mississippi basin but have not yet crossed the continental divide to the Hudson Bay basin.

The Commission heard concerns that flood waters in 1997 moved between the Little Minnesota River in the Mississippi basin and Lake Traverse in the Red River basin. This movement had the potential for transferring unwanted species from one basin to another. The Task Force examined the issue of the hydraulic connection between Lake Traverse and Big Stone Lake to determine:

The Commission heard concerns that flood waters in 1997 moved between the Little Minnesota River in the Mississippi basin and Lake Traverse in the Red River basin.

1. the probable frequency of inter-basin connection;
2. whether the flood control infrastructure at Lake Traverse affected the frequency of this inter-basin connection;
3. whether this infrastructure should be modified or operated in a different manner to prevent the future transfer of water at this site; and
4. whether other structural measures should be constructed to prevent the future transfer of water at this location.

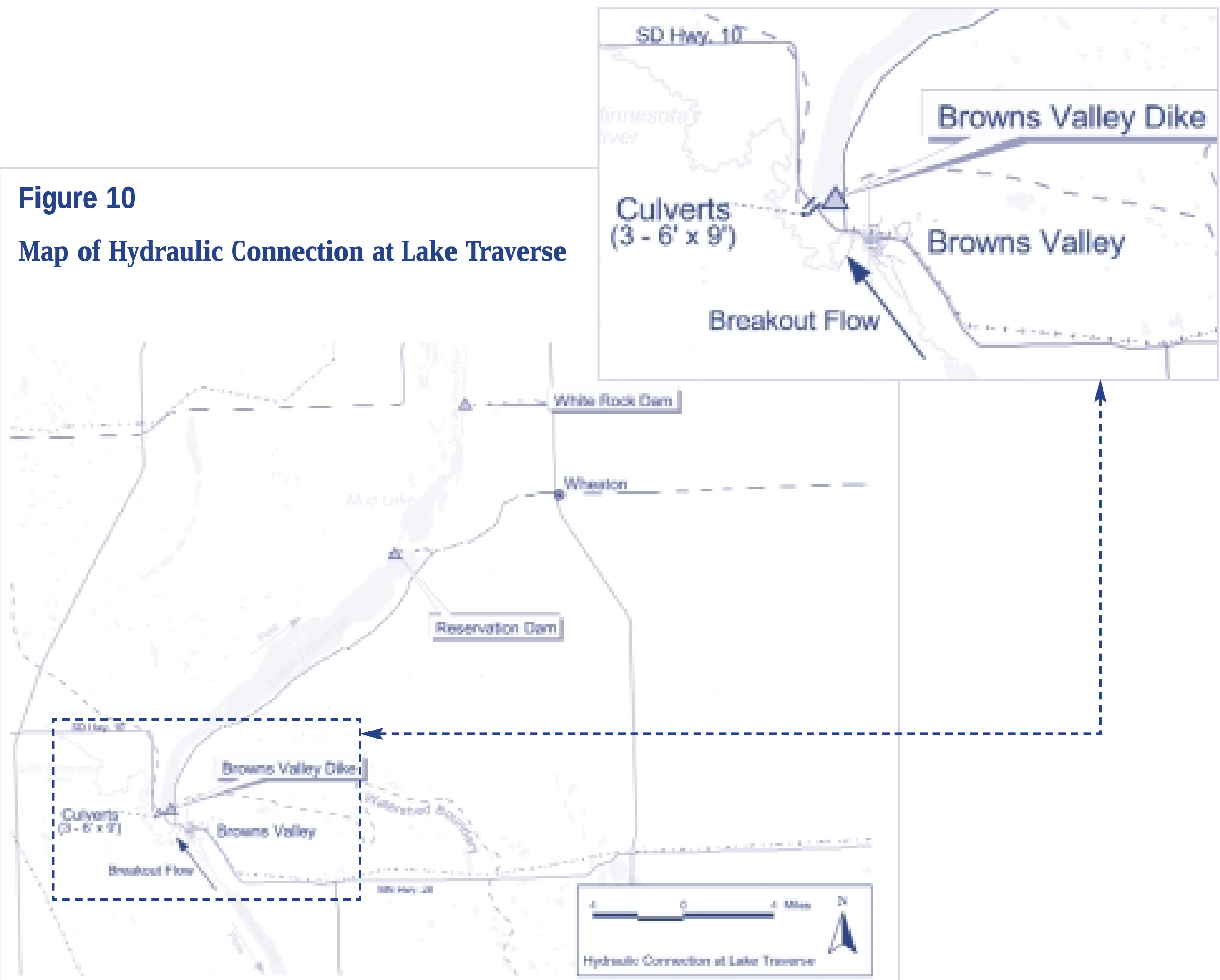
The Lake Traverse Flood Control Project was completed in 1941. It included the Reservation and White Rock dams at the outlet of Lake Traverse to the Bois de Sioux River (which flows into the Red River), and the Browns Valley Dike (forming part of South Dakota Highway 10) at the upstream end of Lake Traverse. The dike was designed to prevent high waters from backing into the city of Browns Valley or the Little Minnesota River. The Little Minnesota River flooded soon afterward, in the spring of 1943. Flood waters overtopped the left (north) bank of the Little Minnesota River, pooled upstream of the Browns Valley Dike, and eventually flooded parts of the city of Browns Valley. The dike was breached during the 1943 flood and remained breached until 1945, when culverts were inserted to allow possible overflows from the Little Minnesota River to escape northward to Lake Traverse.

The top elevation of the Browns Valley Dike is 987.0 feet (300.8 m), while the maximum regulated pool elevation in Lake Traverse is 982.0 feet (299.3 m). The invert or bottom elevation of the three open culverts (each one 6 feet (1.8m) high, 9 feet (2.7 m) wide, and 98.75 feet (30 m) long) is 974 feet (292.9m).

While studying this issue, the Task Force found that the continental divide at this location is formed by the left (north) bank of the Little Minnesota River rather than by the Browns Valley Dike. The minimum elevation of the north bank is approximately 983.9 feet (299.89 m).

Figure 10

Map of Hydraulic Connection at Lake Traverse



Construction of the flood control works in 1941 left the maximum regulated pool elevation of Lake Traverse at 982.0 feet (299.31 m). The highest water elevation recorded since 1941 was 982.21 feet (299.37 m), on April 16, 1997, while the lake was still covered with ice. Since the continental divide is at 983.9 feet (299.89 m), it is unlikely that water from Lake Traverse could have moved across it to the south and then entered the Little Minnesota River.

Before the flood control works were constructed, water levels in Lake Traverse would normally have been even lower than 982.0 feet (299.31 m), making it improbable that water flowed south across the continental divide at this point. The highest water level in Lake Traverse prior to 1941 was 977.3 feet (297.88 m), in the spring of 1916. Because construction of flood control works on Lake Traverse did not affect the elevation of the continental divide along the north bank of the Little Minnesota River, it is unlikely that these structures altered the frequency of inter-basin flows at this location.

The channel capacity of the Little Minnesota River in this reach is approximately 3,000 cfs (85 cms). Flow records indicate that channel capacity is exceeded during open river conditions (that is, when there are no ice jams), with a recurrence interval of between 1 in 10 years and 1 in 50 years (so that there is between a 10 percent and a 2 percent chance that the flow will be exceeded in any single year). However, the city of Browns Valley has a history of flooding related to ice jams, including the 1943 event, which led to the eventual breaching of the Browns Valley Dike. The artificially elevated stages resulting from ice jams likely increase the probability of the breakout flows. Once channel capacity is exceeded, excess flows can move either to the south to rejoin the Little Minnesota River (thus staying within the Mississippi basin) or across the continental divide to the north, into Lake Traverse within the Hudson Bay basin. During extremely large flood events, it is possible for excess flows to move both to the south and to the north.

Aerial photos suggest that the Hudson Bay and Mississippi basins were not hydraulically connected during the flood of 1997.

Flow records indicate that channel capacity was exceeded during the 1997 flood. However, aerial photographs taken during the fall of 1996 and compared with similar photographs taken during the spring of 1997 indicate that excess waters escaped from the south bank of the Little Minnesota River and remained within the Mississippi basin. This would suggest that the Hudson Bay and Mississippi basins were not hydraulically connected during the flood of 1997.

Long-time residents in the city of Browns Valley are familiar with the historical breakout flows from the Little Minnesota River that occurred during 1943 and again in 1993. Local residents observed northward flow through the culverts in the Browns Valley Dike during spring flooding in 1997. However, it is not known whether these flows originated from local runoff or breakout from the Little Minnesota River. Previous flood control studies for the city of Browns Valley in 1972 indicated that inter-basin flows could be eliminated, for

Eliminating this single pathway in the region of Browns Valley should only be considered as part of an overall, integrated approach to managing non-native species.

example, by removing the culverts through the Browns Valley Dike, but a diversion or additional flood protection levees and pumping facilities would need to be constructed. The approximate 1999 cost of these measures is $1.5 million. Other physical means may also be available to prevent future inter-basin flow at this location, but these require further investigation.

Hydraulic connections are only one of a number of mechanisms by which unwanted non-native species can migrate between adjacent basins. Eliminating this single pathway in the region of Browns Valley should only be considered as part of an overall, integrated approach to managing non-native species. Although the potential for exotic species to enter the Red River basin from the Little Minnesota River appears remote, it deserves attention because of the potentially severe consequences and the coordinated actions both federal governments are taking on the exotic species issue in some regions.

Recommendation 31: ***Engineering studies should be immediately undertaken to examine all means of eliminating the potential for the hydraulic inter-basin connection in the vicinity of Browns Valley. Governments should then implement the most feasible option. During the interim, the Little Minnesota River system should be closely monitored for undesirable species. If such species appear, immediate action should be taken to prevent their transfer to the Red River basin.***

Since benefits accrue basin-wide from coordinated actions taken to prevent the movement of non-native species between adjacent basins, local governments should not be held responsible for costs associated with monitoring or implementing corrective measures. While the U.S. Army Corps of Engineers will need to take the lead role in implementing this recommendation, cost-sharing options should be negotiated with Canada because of the basin-wide benefits.

Any additional increase in the maximum regulated pool elevation of Lake Traverse beyond the present 982.0 feet (299.31 m) would increase the probability that waters from the Red River basin could begin to cross the continental divide to the south and enter the Little Minnesota River.

Recommendation 32: ***Any modification to existing operating plans or physical structures associated with Lake Traverse that could increase pool elevation must be accompanied by features that eliminate the southward movement of water into the Little Minnesota River.***

Lake Winnipeg Water Quality

Water quality studies undertaken during the 1997 Red River flood identified several concerns that warranted further investigation. Follow-up studies conducted in 1998 and 1999 focussed on persistent toxic materials that may have been transported to Lake Winnipeg during the flood.[35] Additional work was also done on the potential damage to plant nutrients and on contaminants associated with suspended sediments carried to Lake Winnipeg during the 1997 flood.

In surface area, Lake Winnipeg is the world's tenth largest freshwater lake (23,750 km^2 or 9,173 square miles). It receives drainage from a catchment area of 977,800 km^2 (377,674 square miles), of which 116,500 km^2 (44,998 square miles) is the Red River basin. The Red River empties into Lake Winnipeg about 60 km (37 miles) north of Winnipeg. Lake Winnipeg provides recreational opportunities to thousands each year, has excellent beaches, and provides livelihood to about 850 licensed commercial fishers, their families, and employees. For many commercial fishers of First Nations origin, the Lake Winnipeg fishery provides the primary or sole source of income.

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Flood-Related Plant Nutrients

Large amounts of phosphorus and nitrogen were carried into Lake Winnipeg during the flood. Notwithstanding the amount deposited, it is not possible to tell how much this flood may have stimulated algal growth beyond normal, or whether there were more or fewer deposits than in other recent Red River floods, such as in 1979. The nitrogen load appears to follow the historical relationship with flow, while the phosphorus load may have increased by about 12 percent. This indicates either that the historical relationship did not accurately predict phosphorus loads for major floods or that changed land-use practices in recent years have contributed to greater relative losses of phosphorus.

Trace Elements

Trace elements associated with suspended sediments were monitored during the 1997 flood. Follow-up work in Lake Winnipeg during the winter of 1998 examined the concentration of trace elements in lake bottom sediments. Although 14 trace elements were analyzed, environmental quality guidelines published in 1999 by the Canadian Council of Ministers of the Environment (CCME) are available only for chromium, copper, zinc, mercury, cadmium, and arsenic. Many of the samples of cadmium, chromium, arsenic, and zinc exceeded the guidelines, but it is uncertain whether these concentrations have any biological effect. It cannot be determined with certainty whether the observed metal levels in the bottom sediments are due to the Red River flood or to previous or ongoing contributions, or whether the concentrations reflect the normal ranges in Lake Winnipeg.

Trace Organics

Water quality monitoring during the flood identified traces of fresh toxaphene in water and suspended sediments.

Toxaphene is a pesticide that was widely used in North America until it was generally banned in Canada and the United States in 1982, with some restricted uses allowed in the United States until 1990. During the flood of 1997, a small quantity of toxaphene is presumed to have been lost from a flooded agricultural warehouse near Grand Forks, North Dakota. Innovative analytical techniques were used to differentiate between normal background concentrations of aged toxaphene and concentrations of new or fresh toxaphene recently released to the environment. Water quality monitoring during the flood identified traces of fresh toxaphene in water and suspended sediments in samples collected from the Red River at the international border on May 5, 1997, (8.4 nanograms per litre (ng/l)) and near Winnipeg 15 days later (4.6 ng/l). Concentrations in water quickly returned to normal background levels of about 0.7 ng/l by the end of May. An estimated 46 kilograms (101 pounds) of new toxaphene was identified in Lake Winnipeg following the 1997 flood.

The implications for Lake Winnipeg wildlife consumers are not considered significant.

Toxaphene concentrates in the edible flesh of sport and commercial fish, and has health implications for wildlife and humans. CCME recently published a tissue residue guideline for toxaphene—6.3 nanograms per gram (ng/g) wet weight— to protect wildlife that may consume contaminated tissue. Toxaphene concentrations in the muscle tissue of various fish species collected during 1997, 1998, and 1999 from the Winnipeg Beach and Riverton regions of Lake Winnipeg were within the CCME guidelines, except for walleye collected in 1999 from the Winnipeg Beach area, which contained mean toxaphene concentrations of 8.05 ng/g. The implications for Lake Winnipeg wildlife consumers are not considered significant. The guideline represents an estimation of the safe concentration of toxaphene to protect avian fish eaters, divided by a factor of ten for uncertainty. The estimated safe concentration for the protection of mammalian predators is considerably higher, at 348 ng/g wet weight.

Ontario’s Ministry of Environment has developed fish consumption guidelines for toxaphene in edible muscle tissue. The concentrations in the muscle tissue of Lake Winnipeg fish are well below Ontario’s fish consumption guidelines.

The data on toxaphene in Lake Winnipeg fish is not well understood because there is a complex relationship between toxaphene concentrations in biological tissue and factors such as age, length, weight, lipid or fat content, differences between species of fish, and differences between locations within the south basin of Lake Winnipeg. Toxaphene concentrations seem to have increased in fish tissue since 1997. It is expected, however, that concentrations will begin to decline slowly within the next several years.

Toxaphene concentrations seem to have increased in fish tissue since 1997. It is expected, however, that concentrations will begin to decline slowly within the next several years.

Other trace organics, such as PCBs and DDT, were mobilized during the 1997 flood. Unlike toxaphene, however, only old or existing sources of materials were transported with the flood peak. It appears that PCBs and DDT, like toxaphene, generally increased in fish tissue following the 1997 flood. However, concentrations remain well below consumption guidelines developed by Health Canada for the protection of human health.

Although the flooded warehouse in the United States probably contributed to the new traces of toxaphene found in Lake Winnipeg, similar losses could have occurred within Canada, or from flooded on-farm storage in either country. North Dakota, Minnesota, and Manitoba have well-established voluntary programs in place to collect used pesticide containers and other household or on-farm hazardous wastes. However, there appears to be no systematic program in any jurisdiction to verify the efficacy of the voluntary programs or to eliminate the potential for the accidental release of banned hazardous chemicals through enhanced voluntary or mandatory measures.

> **Recommendation 33:** ***Governments should take immediate steps to ensure that all banned materials such as toxaphene are removed from storage areas in the Red River basin and that potentially hazardous materials are not stored in the 500-year floodplain. Reasonable quantities of such substances could be maintained in the floodplain for immediate use.***

> **Recommendation 34:** ***Governments should continue to monitor toxaphene in the Lake Winnipeg ecosystem until concentrations decline to pre-1997 levels.***

10

Data and Decision Support

Successful floodplain management and flood preparedness require reliable and accessible data. As part of its review of available information, the Task Force consulted data users in the Red River basin.[36] These users expressed a need for major improvements in the ways they could get data and in the means for disseminating it to the public, for more efficient data exchange between agencies involved in floodplain management, and for greater database integration within the basin. The Task Force itself faced obstacles in assembling the data it needed for an analysis of flood issues. In short, the fragmented and incomplete information available is a major obstacle to better flood planning and preparedness.

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The need for access to diverse data sources became apparent when the Task Force was developing some of its own models. In the process of meeting its data needs, the Task Force felt that it had an opportunity to help improve accessibility to the various flood-related data sources in the basin. Through its consultants, it assembled information about existing paper and electronic records and collected new data. Because the multi-jurisdictional, international setting of the Red River basin makes a central database impractical, the Task Force made use of existing communications and computing technology to begin development of a distributed virtual database. The information would be available electronically in an integrated form, but each of the underlying databases would continue to be maintained and operated by the relevant agencies.[37]

The ultimate goal is a distributed database that makes available for all users data on floodplain management and flood disaster activities, including the development of computer models. The integration of computer models with the virtual database has great potential for creating a powerful means to analyze flood-related problems in the basin. The concept of a binational information base for floodplain management sparked interest from the Global Disaster Information Network (GDIN), a program within the U.S. federal government. The goal of GDIN is to foster effective sharing of disaster-related information through the use of evolving information technologies. GDIN has been working in partnership with the Task Force throughout the study on the development of a database, networking, and decision-support system.

Global Disaster Information Network

GDIN is an interagency effort within the U.S. government to integrate information relevant to disasters and to make that information available rapidly and reliably to whoever can help reduce loss of life and damage.

The network will function via the Internet, U.S. federal intranets, and other communications media. It will be used to enhance training and communication among people with common interests and will be designed to broadcast and provide information on request.

The Red River Basin Disaster Information Network (RRBDIN) is a pilot project to test the GDIN concept and promote cross-border information sharing.

The primary responsibility for mitigating and responding to disasters lies with local residents. Design and operation of the Red River Basin Disaster Information Network, therefore, will strive to involve various stakeholder interests within the Red River Basin.

The GDIN initiative is working in partnership with the Task Force and is partially funding development of the virtual database and decision-support system initiative.

The Task Force and the GDIN have launched the Red River Basin Disaster Information Network (RRBDIN) to draw together data providers and users in a single online source to locate and use information on floodplain management issues in the basin. Ultimately the Task Force foresees integration of databases and models into a decision-support system (DSS) for managers and user groups throughout the basin.

Conclusion 8: ***Further improvement and maintenance of the Red River floodplain management database is required. Federal, state and provincial governments and local authorities must maintain a high level of involvement in further database development and in improving data accessibility.***

Hydrometeorological network augmentation

The most basic information for flood planning and preparedness is hydrologic and hydraulic data. Between the 1979 and 1997 floods there were considerable reductions in the stream gaging and meteorological networks used in flood forecasting as agencies underwent budget cuts. This was not acceptable and the Task Force's interim report made a number of recommendations concerning the state of the hydrometric and meteorological networks within the basin.

In Manitoba, the hydrometric network is being expanded, modernized and floodproofed. The work began in 1999 and is scheduled for completion in 2001.

Development of an improved meteorological network began in 1999, to overcome deficiencies in Environment Canada's climatological network and to meet increased demands for services both in the agriculture and water resource areas. By 2001, the network should provide information on precipitation, temperature, soil moisture, and other parameters for each township in the Canadian portion of the basin..

The hydrometric network in the United States, Minnesota, and North Dakota has been modernized or floodproofed since the 1997 flood.

Completion of the hydrometric and meteorological networks will largely satisfy data needs for flood forecasting and water management in general. Additional satellite data, airborne data, and weather radar data may also be needed. However, the various data sets from the expanded networks should provide the information needed for effective hydrologic modeling and forecasting in the near future.

Completion of the hydrometric and meteorological networks will largely satisfy data needs for flood forecasting and water management in general.

Recommendation 35: ***Hydrometric and meteorological data networks necessary for flood forecasting should be improved and maintained in a state of readiness to forecast future floods.***

Datum Standardization Issue

A frequently heard comment at the Red River Basin Information/Data Needs Assessment Workshops was that everyone needs to use the same gage reference system so that each entity can understand how any reported water elevation (stage) along the length of the Red River relates to its own situation.38 Changes in procedure that result in river-stage reporting as gage height (local datum) instead of elevation (standard datum) could cause numerous problems in implementation for both agencies and community groups.

The Task Force explored some of the basic issues in a report.[39] One of the findings related to the different vertical reference systems (datums) used in Canada and the United States. Because the channel slope in the border area is only 0.1 to 0.2 feet per mile (1.89 to 3.78 cm per km), the small difference between the Canadian and American reference systems of 0.15 feet (4.57 cm) could be significant for hydraulic models of the area. Adjustments should be made using commonly available conversion software.

Other types of differences that must be reconciled include the following:

- River stage data and forecasts are already reported as elevations in Canada, but in the United States this information is presented in terms of gage height.
- Most common maps used in the United States and Canada (such as flood insurance and topographic maps) use different datums and are not standardized to the most current and accurate datum.
- The U.S. government has affirmed NAVD88 as the official civilian vertical datum for surveying and mapping, but the Canadian government has not yet done so.

Recommendation 36: ***New geographically related data collection in the United States should be in accord with the North American Vertical Datum of 1988.***

Recommendation 37: ***For consistency and accuracy data used in models should take into account the differences in data at the border. Because datum conversions can affect data accuracy, any conversions between standards should be noted and reported along with the data.***

Recommendation 38: ***U.S. National Geodetic Survey and the Geodetic Survey of Canada should convene a forum of datum experts in the year 2000 to discuss Red River Basin datum issues and develop a long-term transition plan.***

The virtual database will be searchable via the Internet by such headings as data type, data holder or owner, and location.

Virtual Data Base

The Task Force has developed the Red River Basin Virtual Database (RRBVDB) so that Red River basin data managed by Canadian and U.S. agencies can be accessed more easily. The intent is to provide interested parties throughout the basin with information related to emergency response activities, planning activities to prevent and protect against floods, and flood-recovery activities. All interested governmental organizations, non-governmental organizations, and the public will have access to the information and can contribute additional data to the Virtual Database.

As the virtual database is distributed, individual databases remain housed in their home agencies. This makes it unnecessary for data providers to submit regular updates to a centralized data clearinghouse. Users will be able to locate required data quickly, find a description of the contents and limitations of the data, and retrieve data sets of interest. The virtual database will be searchable via the Internet by such headings as data type, data holder or owner, and location.

The Task Force completed the first stage of building a searchable database for the basin, which identified all information providers who could contribute flood-related information. Metadata (data about data) describing data sets by availability and usefulness for various types of analyses were then identified or prepared. Metadata provides a method for capturing and documenting long-term memory about data and must be a prerequisite for any data set catalogued in the RRBVDB.

The 99 agencies and organizations contacted in the United States, including 65 with some form of Internet capability, yielded 384 data sets.[40] Metadata already exist for many of these data sets, especially within federal and state agencies. Limited funding curtailed further development planned for U.S. metadata.

Canadian metadata were compiled from 34 agencies, in accord with the U.S. Federal Geographic Data Committee Content Standards for Digital Geospatial Metadata. The Task Force catalogued 121 data sets. Internet data services vary: 26 agencies have a corporate or departmental Web site, 5 are actively promoting data services over the Internet, and 3 currently use the Internet for e-mail and have browse access only.

In particular, the cost-recovery policies of some (Canadian) agencies, especially in federal departments, makes public dissemination of data too costly to be practical.

Many agencies plan to move from a passive and static web-based environment to a more interactive and dynamic environment when the information-sharing and application-use capabilities of the Internet become stronger. The next generation of Web sites will incorporate facilities in which products and services are offered to business partners, suppliers, contractors, and the public at large.

While there is support for the RRBVDB among the agencies with appropriate data sets for flood management in Manitoba, issues remain concerning public access to the data. Foremost is the security of the internal network. No agency is willing to risk the integrity of the original data sets by giving the public unlimited online access. Other issues arise from the conservative “data culture” in Canada. In particular, the cost-recovery policies of some agencies, especially in federal departments, makes public dissemination of data too costly to be practical.

These Canadian policies have hampered the work of the Task Force. The perceived need to recover the costs of data sharing stifles the public and private creativity needed to respond to the flood threat and ultimately puts public safety at risk. By increasing communication and coordination, an operational RRBVDB offers the opportunity to increase partnering efforts for sharing the costs of data development. Increased collaboration of this type would ultimately result in the greatest benefit to the public good in terms of lower costs and greater access to information.

Recommendation 39: ***All key data providers in Canada should make available at no cost and with no restriction the data sets necessary for the Red River floodplain management and emergency response, and regional or basin-wide modeling activities.***

Recommendation 40: ***Data providers should remain responsible for maintaining and replicating the data sets.***

Table 11

Key Data Providers*

Canada	United States
1. Manitoba Conservation Water Resources Branch.	1. U.S. Geological Survey 2. National Weather Service
2. Environment Canada	3. U.S. Environmental Protection Agency
3. Manitoba Emergency Management Organization	4. Minnesota Land Management Information Center
4. City of Winnipeg Water and Waste Department	5. North Dakota State Water Commission 6. Minnesota Department of Natural Resources
5. Manitoba Highways and Transportation	7. Minnesota Department of Transportation 8. North Dakota Department of Transportation

Task Force Data Collections

Time Series Flood Inundation: The 1997 flood is especially difficult to understand because of the complex weather conditions before and during the event, its long duration and multiple peaks, ice, and its unpredictable overland flow. To reconstruct the flood, evaluate the total area inundated, and help calibrate models, the Task Force analyzed RADARSAT imagery taken during the event. The RADARSAT satellite, which can image through clouds and rain, works equally well by night or day and can collect data at almost any point on the globe. RADARSAT produces monochrome images with resolution of up to 25 m (82 feet). Each image can encompass a spatial extent of approximately 100 by 100 km (62 by 62 miles), thus providing broad aerial coverage. The satellite takes less than two days to revisit sites at the latitude of the Red River basin.

The development of alternative flood protection works requires an estimate of the cost of damages from floods of a magnitude equal to or greater than the 1997 flood.

The Task Force obtained 26 RADARSAT images collected between April 4, 1997, and June 7, 1997. Images of the flood from south of Winnipeg to approximately 15 miles (9.3 km) south of Wahpeton and Breckenridge have been geocoded and mosaiced.

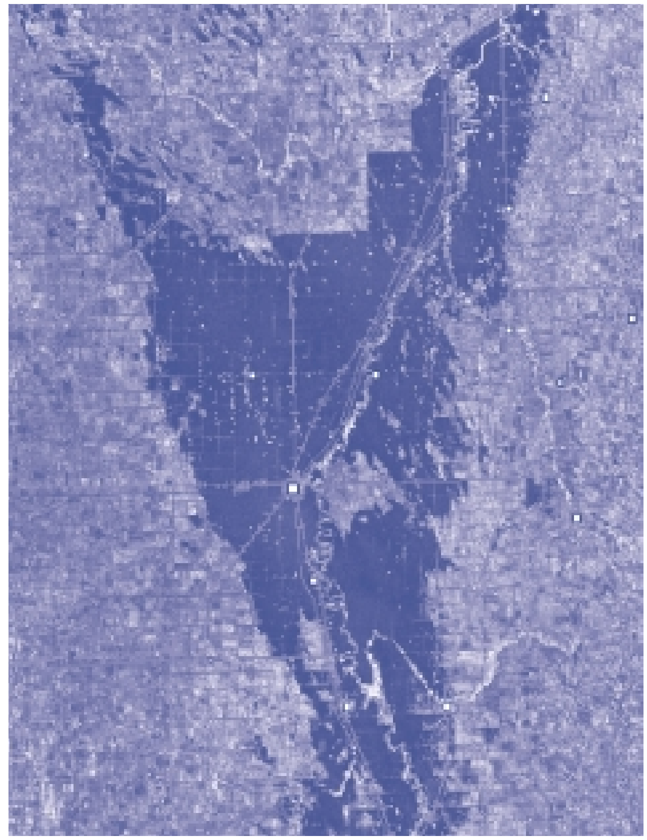
Stage-damage Curves: The development of alternative flood protection works requires an estimate of the cost of damages from floods of a magnitude equal to or greater than the 1997 flood. This means developing a model for stage-damage

* *A key finding from Task Force studies is that there are many important data providers. A data set is not necessarily less "key" just because it is not available for the whole basin. There is a danger in focusing exclusively on the major data providers and leaving out the smaller or regional ones, which need to be included. See Phase Four Technology Management Corp. (1998),* Red River Basin Virtual Database: Data Assessment Report (Canada) *(http://www.ijc.org/boards/rrb/CA_data1.pdf), and Rust Environment & Infrastructure (1999),* Red River Basin Virtual Database: Data Assessment Report *(U.S.A.)*

calculations, or stage-damage curves, which represent the flood damage likely at differing depths. Such modeling can also aid in decision making during emergencies and in the flood-recovery phase. The Corps of Engineers has updated U.S. stage-damage curves to reflect current economic data. In the 1997 flood, according to U.S. Department of Commerce estimates, the total damages in the U. S. portion of the Red River were approximately $4 billion, of which $3.6 billion was incurred in the immediate vicinity of Grand Forks and East Grand Forks.[41]

Figure 11

Southern Manitoba, May 1997



In Canada, the Task Force updated the depth-damage relationships for Winnipeg and the area south of the city.[42] The work proceeded in two phases. First, based on a sample of damage data (186 of some 5,000 damaged structures) provided by Manitoba Emergency Management Organization (MEMO), relationships of damage to depth of flooding were calculated. Damages were calculated as a percentage of market value of the structure. Stage-damage curves were calculated for different classes of structure and, as well, for agriculture and infrastructure damages.

Following that, the curves were used to create a number of map products using a geographic information system. The location and elevation of 60,000 buildings were incorporated into the GIS to enable visualization of damage under various scenarios. The resulting model can be used for planning and design of flood control measures and for flood recovery purposes following future floods. One specific calculation involved damage estimates for a flood of 1826 magnitude.

The location and elevation of 60,000 buildings were incorporated into the GIS to enable visualization of damage under various scenarios.

The Task Force consultants estimated that the total damages to Manitoba in a flood similar to that of 1997 would be $235.6 million for structural damages, $14.7 million for agricultural damages, $47.5 million for infrastructure damages, and an estimated $67.4 million damage to the city of Winnipeg. For a flood of 1826 magnitude, the damages would be $7.94 billion, $7.47 billion to the city of Winnipeg,* $336.8 million structural,

* *A more rigorous assessment of the City of Winnipeg damage was provided in the KGS study* Winnipeg at Risk, Part 3. *The estimate generated by this study is lower ($5.8 billion) since the depth-damage relationships were derived from a more conservative approach than the MEMO derived depth-damage curve.*

Analysis of future flood control measures, operation of existing flood control structures, and evaluation of different hydrologic scenarios depends on adequate topographic representation of the basin.

$66.5 million agricultural, and $65.6 million for infrastructure damages in the valley.

High-Resolution Digital Elevation Models: One of the main objectives of the Task Force was to coordinate and investigate requirements and capabilities for a detailed Digital Elevation Model (DEM) for the Red River basin.

Analysis of future flood control measures, operation of existing flood control structures, and evaluation of different hydrologic scenarios depends on adequate topographic representation of the basin.

Because of the costs of acquiring high-resolution elevation data, the Task Force was unable to develop a detailed basin-wide DEM. A variety of activities undertaken, however, do provide partial DEM data and lay the groundwork for further acquisition of high-resolution elevation data.

The U.S. Geological Survey and the Canadian Centre for Remote Sensing cooperated to create seamless "best available" digital elevation data. A DEM for the Canadian section of the Red River basin was generated from 1:30,000 aerial photographs and 1:60,000 digital ortho-photographs of the basin. The majority of the best available DEM for the U.S. portion of the basin has been developed from USGS 1:24,000 topographic maps.

Within a portion of the Pembina basin, the Task Force tested various techniques for obtaining digital elevation data, including Global Positioning System-based ground surveys and aerial survey systems such as Lidar (Light Detection And Ranging) and IFSAR (Interferometric Synthetic Aperture Radar). These three technologies were compared in terms of costs, data accuracy, and other DEM production considerations.

The Task Force found that airborne laser and radar mapping can be a fast, reliable, and cost-effective method of obtaining three-dimensional data for the creation of a DEM. These data can be accurate to within the range of 0.5 meters to ±15 centimeters (1.6 feet to ± 6 inches) depending on the technique used.

Further work toward compiling a basin-wide elevation model will require considerable resources, but it can be best accomplished through a coordinated effort that involves sharing of expertise, funds, and data. Opportunities for resource sharing should be coordinated using RRBDIN communication tools to the extent possible.

Drawing on the expertise of hydraulic and hydrologic modelers, the needs for a basin-wide variable resolution DEM were identified:

- detailed elevation of infrastructure within the floodplain, with vertical accuracy of 2 inches (5 cm), including roads, railways, main drains, and Red River tributaries;
- detailed elevation for specific urban locations, with vertical accuracy of 4 inches (10.6 cm);
- less detailed (3 feet or 1 m) elevation data, preferably for the entire 1826 flood high-water area and alternatively for the 1997 flood high-water area; and
- detailed DEM of ten areas, approximately 25 square miles (65 km^2) each, for quality control of DEM extrapolation techniques for the rest of the basin.

For the fairly new Lidar and IFSAR technologies, the contractors doing the collection often license the data sets. By restricting the sharing of this important data set, this practice is counter to the data-sharing philosophy of the RRBDIN. The Task Force required the contractor who collected Canadian data for the Task Force to provide the data sets free of any use or sharing constraints. This approach made the data freely available and did not result in added cost to the data collection effort.

The Task Force required the contractor who collected Canadian data for the Task Force to provide the data sets free of any use or sharing constraints.

Recommendation 41: ***Development of the digital elevation model for the Red River Basin should be completed by collaborative initiatives of the relevant agencies.****

The Red River Basin Disaster Information Network and Decision Support System

The Task Force and GDIN interests have initiated the Red River Basin Disaster Information Network (RRBDIN) as a means of providing decision-making tools for floodplain management, disaster relief, and mitigation. Because the system is Internet-based, necessary data will be readily available to users. Especially important is the ability of such a system to deliver information during an emergency. The RRBDIN is being developed to provide an interactive and iterative process of building basin-wide information resources and to improve communications and enhance cooperation.

The network consists of a growing community of RRBDIN members (individuals and organizations), who will use and help develop several tools incorporated into an Internet Web page (http://www.rrbdin1.org). The Web page is evolving as the members test and direct its contents. It includes communication tools, searchable lists of organizations and points of contact, a document library, policies and procedures, a searchable catalog of available databases, map presentation and search tools, analysis tools (hydrologic and hydraulic models), a bulletin board, and other information resources.

* *In Canada the relevant agencies could be Manitoba Conservation's Water Resources Branch and Agriculture Canada's Prairie Farm Rehabilitation Administration; in the U.S. the Federal Emergency Management Agency, the Corps of Engineers, and the states of Minnesota and North Dakota. For specific local or regional areas, affected counties, watershed districts, and municipalities should contribute as well.*

The RRBDIN is envisioned as a single online source where people can locate information and data relating to water management issues in the Red River basin. The types of interaction made possible by this technology should lead to stimulating and creative thinking, and ultimately a growing knowledge base to benefit all Red River basin stakeholders long after completion of this IJC study. It is hoped to involve the broadest range of interested individuals in an exchange of data, information, knowledge, and ideas through the free sharing of relevant databases and participation in various networking opportunities. The vision is for the RRBDIN to become a trusted and dependable resource for informed decision making that is built upon and maintained by a strong network of cooperating individuals, organizations, and agencies.

Development of an information network that ties together a broad range of Red River basin agencies and interests could improve basin flood management.

The Task Force believes that development of an information network that ties together a broad range of Red River basin agencies and interests could improve basin flood management. Existing information systems are designed for individual agency problems and requirements, which result in stand alone "islands of automation." Advances in information technologies enable greater sharing and processing vital information. A decision-support system (DSS) can connect these "islands" and allow decision-makers and others to ask floodplain management and preparedness questions and carry out automated analyses. The DSS brings together models and the virtual database.

The RRBDIN provides the framework from which the DSS is being developed. The DSS is being formed in several stages, beginning with a prototype for the Pembina sub-basin that uses a small number of databases. Following the testing of the prototype, an advanced prototype will be developed, and finally the fully functional DSS.

The DSS can be understood as a collection of scenarios, or stories, that define problems (for example, flood risk assessment, real-time status of ice or debris jams, and disaster emergency response). Each scenario describes the problem, shows how the user would interact with the DSS, and sets out the data, model, and output requirements (such as database table, map, or chart).[43]

The cross-border approach presents a unique opportunity in which to showcase a suite of technical and institutional challenges.

Interest in the effort continues to grow, as evidenced through discussions with the Open GIS Consortium and the National Science Foundation. Organizations such as these are interested in the concept for a variety of reasons. For instance, the Task Force work is providing the context in which to test and evaluate new modeling techniques, communication protocols, advanced sensing capabilities, fusion techniques and interoperability procedures. The cross-border approach presents a unique opportunity in which to showcase a suite of technical and institutional challenges. Although the Task Force work has achieved a fairly high level of interest, more work is needed in order to reach a stage where a truly robust prototype can be demonstrated.

The development of the RRBDIN was predicated on an understanding that the Task Force would stay active through the year 2000 and that matching funds from the Global Disaster Information Network (GDIN) would continue. These funds have not materialized. It is estimated that an additional $300,000 (US) will be needed to carry the RRBDIN development through December 2000. By that date a prototype DSS will be available. Also, a dynamic virtual data set will be posted that will allow for basin-wide geo-spatial queries to be made. The various modules that are displayed on the RRBDIN Web site will be functional and additional recommendations based on user feedback will be incorporated into the system.

The RRBDIN holds particular promise by promoting the most advanced collaborative technologies. It would be most unfortunate to see these developmental activities curtailed at this critical stage.

It would be most unfortunate to see these developmental activities curtailed at this critical stage.

Recommendation 42: ***Relevant federal, provincial, state agencies and transboundary agencies should meet to determine the interest in continuing the work of RRBDIN and if there is agreement to continue it, draw up a funding and action plan to ensure its continuation.***

Virtual Forum

An important feature of the RRBDIN is its Virtual Forum. The concept provides for live discussion rooms where roundtable meetings, presentations on specific topics, or mutual help sessions can be held via the Internet. It can also distribute discussion lists so that comments and viewpoints can be aired at the convenience of the contributor. Workshop topics have included:

- Flood Forecasting Today and Tomorrow
- Recent Developments in Remote Sensing for Disaster Monitoring
- The International Flood Mitigation Initiative
- International Flood Mitigation Initiative (IFMI) Update
- A Process for Developing an International Watershed Board
- Issues in Professional Floodplain Management: The Association of State Floodplain Managers
- Cross-Border Issues in Disaster Response
- Women, Work, and Family in the 1997 Flood: Ten Lessons Learned
- The Role of Technology for Floodplain Management in the Next Millennium

Transcripts of the online workshops and other background information are available from the Web site.

This Virtual Forum capability is also available for meetings and on-line discussions by any group in the basin. The Pembina River Technical Committee has used the forum to hold a number of coordination meetings.

> **Recommendation 43:** ***A decision on whether to continue operation of the Virtual Forum should be included in the discussions on the continuation of the RRBDIN.***

11

Hydrologic and Hydraulic Modeling

Mathematical models of the Red River basin play an important role in forecasting floods, determining the extent of flooding, and planning for future floods. Experience during the 1997 flood demonstrated that improvements to existing models were needed, especially to account for overland flows. This chapter describes progress made on improving flood forecasting models and developing hydrodynamic models for the basin, and makes recommendations for further development.

Hydrology

The Red River, geologically a young river, can be described as having a very low gradient, slightly entrenched, meandering, silt-clay dominated, riffle-pool channel with a well developed, stable floodplain. Despite some slumping along the riverbanks, the meanders are generally stable.[44] The Red River rises slowly during a flood and is slow to recede. Flooding along the main stem, while relatively predictable, tends to be of long duration.

Major floods are inevitably spring floods, a consequence of conditions in the previous fall and winter and of conditions during the snowmelt. In 1997 the necessary preconditions for a flood were established with a wet fall, heavy winter snows and a late season blizzard. The flood could have been much worse had there been significant spring rains.

Flood forecasting is a well-established art in the region, with forecasts provided by the National Weather Service (NWS) in the U.S. portion of the basin and by the Manitoba Water Resources Branch in Manitoba. Both agencies used similar forecast techniques during the 1997 flood and exchanged information on a continuing basis. The 1997 flood pointed out the need for modifications to forecast procedures and to the way forecasts are communicated to the public. This section will review the changes in forecasting procedures since the flood and describe the current work on basin hydrology.

The 1997 flood pointed out the need for modifications to forecast procedures and to the way forecasts are communicated to the public.

Flood Forecasts

In general, improvements in flood forecasting have been directed at updating existing procedures and improving the physical basis for the forecasts to reduce the dependence on statistical relationships. A number of tasks have been accomplished, including expanding the data networks to support the forecasts. These network improvements are described in Chapter 10.

United States. The technical procedures used by the U.S. National Weather Service (NWS) to produce forecasts for the Red River have been examined in detail. Several efforts to improve on these procedures are under way.[45] These include:

- developing a dynamic routing hydraulic model (FLDWAV) for the Red River;
- reviewing some of the unusual flow paths that water took during the 1997 flood to add an empirical estimate of these overland flows to the NWS models;
- modifying the NWS forecast software to provide a more explicit warning when a rating curve extension is in use;
- reviewing the established flood stage for every forecast point on the Red, along with the associated detailed information about flood forecast services and flood impacts;
- recalibrating the Red River forecasting system by means of more complete historical data and models that are compatible with the latest NWS forecast methods;
- developing an enhanced system for analysis and use of snow information; and
- analyzing the existing flood outlook procedures to determine whether a useful estimate can be provided of the chances that the outlook flood crest will be exceeded.

Until recently, the NWS used an Antecedent Precipitation Index (API) technique in calculating soil moisture inputs to Red River forecasts. This is a statistical procedure based on previous experience. The NWS has now implemented a continuous streamflow simulation model, known as the Sacramento soil moisture accounting model, that is physically based and can be applied to individual sub-basins. The model has been running in parallel with the API for a year and will be introduced to forecasts in the spring of 2000.

Work is also under way to improve regional precipitation estimates at the Mayville, North Dakota, radar site by examining archived data and performing adaptable parameter optimization and statistical evaluations. These results should be transferable to other radar sites in the Red River basin.

Advanced Hydrologic Prediction System (AHPS) is ideally suited to forecasting in the Red River basin where floods are generally slow to develop.

Nationally, the NWS has started to implement an Advanced Hydrologic Prediction System (AHPS) which takes into account the relative uncertainty in hydrologic variables. The system takes into account long-term changes in variables and is thus ideally suited to forecasting in the Red River basin where floods are generally slow to develop.

Recommendation 44: ***The U.S. National Weather Service should implement its Advanced Hydrologic Prediction System in the Red River basin as an early priority.***

Canada. In Manitoba, efforts have focused on improvements to the forecast networks and implementation of the MIKE 11 hydraulic model described below. Data from the 1997 flood was used to extend existing flood forecasting relationships.

Manitoba's River Forecast Centre uses an index model to predict runoff volume and peak discharge at Emerson, treating the entire U.S. portion of the basin as one basin for computational purposes. Daily predicted flows at Emerson are routed together with daily predicted flows for the 13 Manitoba tributaries, including the Assiniboine River. Following the 1997 flood, all the statistical relationships for the Manitoba tributaries were updated and extended to incorporate the unusually high soil moisture conditions.

Improved channel routing procedures were developed and adopted for the Pembina and Roseau Rivers, the two major tributaries shared by both countries. Flood routing on the main stem from Halstad, Minnesota, to Winnipeg was also examined.

Canada is an automatic beneficiary of any forecast improvements made in the much larger United States portion of the basin. For the most part, needs in Manitoba relate to improved tributary runoff models and flow routing.

Canada is an automatic beneficiary of any forecast improvements made in the much larger United States portion of the basin.

Communication of Forecasts. The NWS currently releases two flood outlooks to the public. The crest value in the first is based on the pre-runoff snow water equivalent only, while the second is based on snow water equivalent plus normal precipitation through the runoff period. The Manitoba Department of Conservation (Water Resources) outlook uses three figures, one based on normal weather conditions through the runoff period and others based on less favorable conditions (upper decile forecast) or more favorable conditions (lower decile forecast). Each agency therefore has one equivalent forecast for normal conditions and one forecast that is lower than normal (but not identical); in addition, the Department of Conservation has one that is higher than normal. There is some public confusion about the various forecasts, particularly as they are not released at exactly the same time.

The National Weather Service is considering public release of the water equivalent plus normal crest value and second crest value based on a higher percentage of normal precipitation. When the Advanced Hydrological Prediction System is implemented in the Red River basin, it will produce probabilistic forecasts.

It will be possible in the future to make very precise site-specific forecasts to aid basin residents and emergency workers.

That said, the existing and proposed forecasts are aimed at forecasting elevations at specific basin communities. With the development of accurate digital elevation models, highly detailed geographic information systems, and hydrodynamic models capable of simulating overland flow, it will be possible in the future to make very precise site-specific forecasts to aid basin residents and emergency workers. Such forecasts will present new communications challenges for forecast authorities.

The Task Force, following up on its recommendations on improving flood forecasting communications in the 1997 Interim Report*, examined means to ensure a common understanding of flood forecasting activities among the different basin jurisdictions and to communicate more effectively to the public.

> **Recommendation 45:** ***A binational Red River Flood Forecasting Liaison Committee should be established by government to improve communications among forecasters and with the public.***

See box on page 109 for proposed terms of reference for the Committee.

Hydrologic Models

A number of the many models developed to simulate hydrologic processes in a watershed have been applied in the Red River basin, either for forecasting or for studies. Hydrologic models use the moisture input to a basin, apply basin storage components, and calculate the streamflow at a given location by applying channel routing relationships.

Some models use statistical precipitation-runoff relations with routing equations, while others models are much more complex. Models could be classified as lumped or distributed, single event or continuous. Probabilistic models that take data uncertainties into account are also available. Model selection will depend on available data, basin or sub-basin characteristics, and the needs of the user.

A lumped model treats the watershed as a single unit for acquiring data and calculating runoff. The calculations are statistically based and relate to the underlying hydrologic processes as a spatially averaged process.

* *Recommendation 8: Simplify and clarify communication between flood forecasters and those with local flood emergency responsibility, throughout the basin. The dissemination of forecast information to the public through the media should be simple and the variables inherent in those forecasts easily understood.* Interim Report of the International Red River Basin Task Force, Red River Flooding: Short-Term Measures, *December 1997.*

Some lumped models allow the watershed to be subdivided or allow some parameters to be physically estimated and modeled. When subdivisions of a basin are combined to produce an output, this modeling approach is termed semi-distributed. The present flood forecast models and the HEC-1 models used in the wetlands analysis are semi-distributed.

A distributed model simulates the key hydrologic processes that occur in a watershed using distributed data inputs and processes. These commonly include precipitation, interception, infiltration, interflow, and baseflow. Overland flow and channel routing may be incorporated into the model or calculated in a hydraulic model. Distributed models require much more data and knowledge of watershed processes than lumped, or semi-distributed, models. When the model is first established, gridded precipitation and land-cover characteristics may be the only distributed features.

Models used in channel routing calculate the travel time of the flood wave and its attenuation. Storage-flow relationships are often incorporated into hydrologic models. The one-dimensional unsteady flow hydraulic models described later in this chapter are used to route flows through multiple channels or where overland flow is a serious concern.

Red River Forecasting Liaison Committee - Proposed Terms of Reference

Review and implement procedures for the interchange of hydrometeorologic and related data among forecasting and operational agencies concerned with flow forecasting in the Red River basin in Canada and the United States.

Facilitate collaboration and information exchange on forecast methodology, data networks, data acquisition and communication systems, model development, and other related matters that would result in improved accuracy and timeliness of forecasts.

Consider how communication of forecasts to flood response agencies, other specialists, the media, and the general public could be improved.

Submit an annual report for each calendar year to member agencies and the IJC combined board by May 31of the following year. The report should identify progress during the year, specify data network changes, make recommendations as appropriate, and identify any changes to membership of the Committee.

Probabilistic models apply a mathematical distribution to input parameters such as precipitation forecasts, perhaps apply some random variables, and produce a large number of model runs that are statistically analyzed. The resulting forecast, rather than being a single outcome, provides an entire distribution of the future conditions. This approach is taken in the AHPS methodology used by NWS.

Simplified probabilistic methodologies that provide a range of possible forecasts have been used in the basin for some time. In them, the forecaster makes assumptions about future precipitation to determine runoff under normal and other conditions.

Issues concerning land use change, drainage, and runoff during summer floods and smaller spring floods can be approached through the application of distributed hydrologic models to one or more tributaries in the basin and eventually to the entire basin.

The issues raised in Chapter 3 concerning land use change, drainage, and runoff during summer floods and smaller spring floods can be approached through the application of distributed hydrologic models to one or more tributaries in the basin and eventually to the entire basin. This modeling would determine how sensitive the basin is to previous land use changes and would be able to examine the potential effects of permanent cover programs and changes to tillage practices on runoff. Coupling these models with medium-scale atmospheric models could lead to improvements in forecast models and some understanding of the effects of climate change on basin hydrology.

Recommendation 46: ***Confirm the flood peak reduction findings of Chapter 3 for large floods and examine reductions for smaller floods by implementing distributed models on tributaries such as the Mistinka, Wild Rice and Maple Rivers.***

Recommendation 47: ***As a long-term priority for government and academic research, implement a basin-wide coupled atmospheric-hydrologic model in the Red River basin.***

Hydraulics

In general, the channel of the Red River is capable of handling the runoff from a relatively modest flood, of a size that might occur one year in two. When the capacity of the channel is exceeded, the river overtops its banks and flows over the land. The extent of flooding depends on available water and the topography.

In larger floods, the river can overtop adjacent roads and railway embankments. The flow then moves north controlled not only by floodplain topography but also by roads and railways. These features confine the flow and sometimes act as obstructions to the flow. Consequently, water elevations in overland flow areas can be higher than those in the adjacent main channel. The overland flow may then return to the main channel with destructive force by breaching embankments. The 1997 flood resulted in a flooded area up to 25 miles (40 km) in width; many residents were flooded by overland flows.

The nature of the overland flow is highly variable in both space and time; some tributary streams may flow in reverse as the flood wave moves down the Red.

The nature of the overland flow is highly variable in both space and time; some tributary streams may flow in reverse as the flood wave moves down the Red. Sudden washouts of road and rail embankments and road cuts made by government personnel to reduce local water levels further complicate the picture.

The Red River basin models that existed at the time of the 1997 flood were not capable of dealing with complex overland flows. The Task Force sought computer models able to forecast overland flows during a flood and determine the effects of new dikes or reservoirs. Such models would be able to simulate:

- passage of a flood wave through complex topography and structures;
- flow over road and railway embankments;
- flow and storage changes related to new structural measures or modifications to existing structures;
- dividing flow among overland flow corridors; and
- changes in water levels caused by sustained wind.

Based on some preliminary work by Environment Canada's 1-D model, one-dimensional unsteady flow models met these needs for the most part. There are several of these models, all of which solve the same mathematical equations. They can simulate two-dimensional flows resembling those in the Red River basin.

The Task Force commissioned the development of two models aimed at simulating water levels to an accuracy of ±0.15 m, or 0.5 feet.

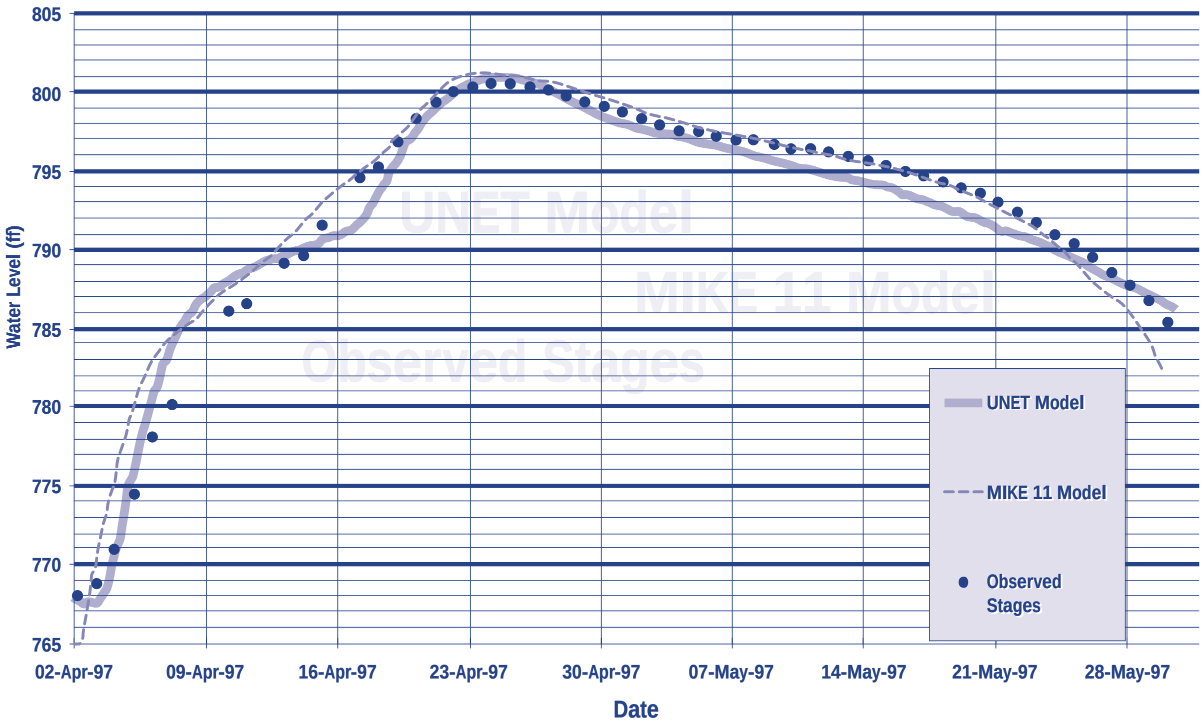
The Task Force commissioned the development of two models aimed at simulating water levels to an accuracy of ±0.15 m, or 0.5 feet. In addition to developing models for real-time flood forecasting and planning purposes, the Task Force wished to examine the downstream effects of flood peak reduction scenarios, evaluate the spatial extent of floods larger than 1997, and define data and monitoring requirements associated with the models. With the exception of the lower Pembina River, discussed in Chapter 7, and the Sheyenne River, the models were applied only to the Red River itself, not the tributaries. Tributary inputs were based on streamflow data.

To identify communities and roads on a map, and even individual homes and buildings at risk of flooding, the model output had to have a Geographic Information System format. The visual element greatly aids decision making.

The U.S. Army Corps of Engineers developed the one dimensional Unsteady NETwork (UNET) model of the basin for the IJC. It runs from the headwaters at Lake Traverse to Letellier, Manitoba. Under contract to the IJC, Klohn-Crippen Consultants Ltd. developed the MIKE 11 model, another one dimensional unsteady-state model with two dimensional capabilities, to run from Grand Forks to Selkirk. The overlapping sections of the models use the same input data. Both models were calibrated using the 1997 flood data and verified using 1996 and 1979 data. Calibration concentrated on meeting target accuracy near the peak water levels. Figure 12 shows an example of the performance of each model compared to recorded water levels.

Figure 12

Comparison of Hydraulic Model Results at Drayton



The UNET model was constructed to assess large-scale impacts of storage on hydrographs and to study timing and travel time of flood waves.

UNET Model

The UNET model was constructed to assess large-scale impacts of storage on hydrographs and to study timing and travel time of flood waves. Discharge hydrographs were routed down the rivers utilizing storage derived from cross-sectional geometry.

The model was constructed using river cross sections and other data previously developed for available HEC-2 one-dimensional steady state hydraulic models. These HEC-2 model inputs were converted to the UNET model by various methods using small computer programs and manual editing.

The UNET model covers 441 miles (710 km) of the Red River and Bois De Sioux River from the White Rock Dam near Lake Traverse to the town of Letellier in Manitoba. The Sheyenne River is also modeled from Kindred to its mouth on the Red River, some 87 river miles (140 km). There are 954 cross sections in the model and 11,000 lines of input.

Calibration of the UNET model involved a series of steps. First, inflow hydrographs from 27 gages were input along the main stem river at appropriate river mileage. Drainage area ratios of these gage records were used to produce initial inflow hydrographs for the ungaged areas as tributary gages record only a portion of the flows entering the Red River.

The model was initially run and discharges were computed at the USGS Red River gages. Based on a number of interactions, discharge is calibrated and water levels produced. Conveyance factors are used to adjust stage hydrographs to match recorded hydrographs and high water marks.

MIKE 11 simulates flooding in nine major Red River overland flow corridors and provides output to a geographic information system.

MIKE 11 Model

The MIKE 11 model, which extends 174 miles (280 km) from Grand Forks to Selkirk, becomes much more detailed from the confluence of the Pembina River north to Selkirk. A detailed sub-component of the model treats the lower Pembina River from upstream of Neche, North Dakota, to the Red River. MIKE 11 simulates flooding in nine major Red River overland flow corridors and provides output to a geographic information system.[46]

Several hundred Red River basin cross-sections were incorporated into the model. Road and rail embankments form the main hydraulic controls in the valley. Accurate elevations of rail lines and principal roads obtained in 1997 and 1998 were used in the model. This information was incorporated into a 500 m (1,640 feet) grid Digital Elevation Model to portray flooded areas and depths of flooding in the Geographic Information System.

Streamflow and water level data from 25 gaging stations helped calibrate the model. Water elevations from the overland flow areas and miscellaneous flow measurements taken during the 1997 flood supplemented this information. A particular problem was the flooding of some tributary gaging stations during the flood peak, which made data unavailable at those points. Estimated flows for this period were based on comparisons with upstream and adjacent sites.

Special measures were taken to account for ungaged flow in the UNET model.

Modeled water levels for 1997 met the target accuracy along the river and in the floodplain. The effects of ice cover prior to break-up were successfully simulated. The model was verified using 1996 and 1979 data. There were significant differences between the modeled peak water levels and recorded levels from Morris north to the Floodway inlet for 1979. These differences are likely caused by infrastructure changes in the last 20 years, notably construction of the Turnbull Drive dike and the raising of provincial road 200.

The model simulated two floods of 1826-type magnitude, analyzed the effects of upstream storage, determined the impact of the Seine River on Grande Pointe flooding, and reviewed the impact of a proposed drain from the Morris River to the Red River. The model demonstrated the sensitivity of water levels in the area upstream of the Floodway inlet to the quantity of water in the system. In effect, a river 25 miles (40 km) in width is suddenly confined to a very narrow cross-section at the Floodway. Accurate determination of effects in the area upstream of the Floodway is dependent therefore on having the accurate digital elevation model that was produced for the IJC.

The model indicates that water levels in floods of the order of 1826 would rise by less than a foot (0.3 m) over those experience in 1997 from Grand Forks to Morris. However, the effect at the Floodway entrance would be dramatic.

The model indicates that water levels in floods of the order of 1826 would rise by less than a foot (0.3 m) over those experience in 1997 from Grand Forks to Morris. However, the effect at the Floodway entrance would be dramatic. Levels could be expected to increase by six to seven feet (1.8 to 2.1 m) from 1997. If structural measures held, a questionable assumption under current conditions, water levels at James Avenue in Winnipeg would rise to 32 feet (9.75 m) compared to the flood protection level of 25.8 feet. (7.86 m)

FLDWAV Model

Like the UNET and MIKE 11 models, the NWS's Flood Wave (FLDWAV) model is a one-dimensional unsteady flow model. It was originally developed by the NWS to determine the water surface profile of the dynamic wave downstream of a dam failure.

The NWS first applied the model to the reach extending some 30 miles (42 kilometres) upstream from Oslo, North Dakota, to examine the water level discharge relationships at Grand Forks during the 1997 flood.[47] It simulated this situation well and has now been extended to include the reach from Halstad, Minnesota to Emerson, Manitoba. It is used by NWS hydrologists for post-flood analysis and real-time forecasting of natural and dam-break floods.

The topographic data used to represent the Red River and its floodplain came from cross-sections provided by the U.S. Army Corps of Engineers that were augmented by USGS 30-meter digital elevation model (DEM) derived cross-sections. Cross-sections for modeled tributary rivers were solely derived from the DEM. Streamflow information is provided from gaging stations and National Weather Service simulation models.

Phase 1 model development extends from Halstad to Emerson on the main stem Red River with five modeled tributary rivers. Initial calibration and testing of a simple model was completed in 1999 and is represented in this report. Complexities such as bridges, road embankments, and levees will be added in 2000.

Phase 2 development will extend from the headwater reservoirs of Lake Traverse on the Bois de Sioux River and Orwell Lake on the Ottertail River to Halstad. There are four modeled tributary rivers to the Red River in this phase. This work began in 1999 and will conclude in 2000.

The boundary conditions for the Phase 1 model comprise:
- discharge hydrographs from NWS hydrologic models for Halstad and the five gaged tributary rivers;
- five discharge hydrographs for the ungaged tributary areas from NWS hydrologic models; and
- water levels at Emerson.

The downstream boundary water levels are recorded values for calibration purposes and forecast values provided by Manitoba Water Resources for real-time forecast purposes.

The model was calibrated with data from two flood seasons: the extreme flood of March–May 1997 and the minor flood of 1999. Peak stages were simulated to within 0.5 feet (0.15 m) of the observed peak, with flow at the time of peak stage simulated to within 5 percent. The timing of the simulated-to-observed peak is within 12 hours. The calibration was validated with data from a moderate to major flood occurring from March to May 1996. The accuracy at the peaks is within that attained during calibration.

Future enhancements of this work will add complexities to the model to aid in the forecasting of extreme events as well as in the development of additional value-added products derived from the model, such as flood inundation maps for communities along the Red River.

Future Needs: Basin-wide

The accuracy of hydraulic models can be improved with more detail about the topography of the basin, enhancement of real-time data networks, and strengthened hydrologic understanding. The current models are for spring runoff. A separate calibration would be needed to make them useful during summer floods.

The goal remains to achieve a seamless, high-accuracy DEM for the basin.

During the course of the Task Force study, the topographic data were improved as described in Chapter 10. The Task Force conducted highly accurate Lidar surveys for the lower Pembina basin and south of Winnipeg. Other agencies collected Lidar data at Breckenridge and Fargo. The Task Force augmented this data with experimental IFSAR data in the lower Pembina and by GPS surveys of roads and rail lines in many parts of the basin. The goal remains to achieve a seamless, high-accuracy DEM for the basin. As surveys already exist for major roads and railways, the most significant topography-related improvement to benefit hydraulic modeling would come from GPS surveys of secondary roads.

> **Recommendation 48:** ***Conduct surveys of secondary roads, particularly in the central portion of the basin, with differential global positioning systems, and incorporate the results into the hydraulic models.***

Another asset for modeling floods in real time would be an ultrasonic flow meter at the narrows upstream of the Floodway. These devices measure stream discharge on a continuous basis. They would be invaluable for floodway operations and model calibration. This installation should be held in abeyance until decisions are made on Winnipeg flood protection. A similar flow meter at Grand Forks would also aid flood forecasts.

In addition, water level recorders at Breezy Point, Manitoba on the Red River and other floodplain locations would provide valuable data for the model. Streamflow data at key overland flow points such as Emerson and Morris would also improve model accuracy. Model calibration would be further enhanced through improved estimates of ungaged inflow using hydrologic models.

Recommendation 49: ***The U.S. Army Corps of Engineers and Manitoba Conservation, operators of the UNET and MIKE 11 models respectively, should maintain the existing models and continue to seek improvements through collaboration with other agencies.***

Recommendation 50: ***Measures should be taken to ensure that data supporting the operation of the hydraulic models and model outputs can be made widely available.***

Site Specific Future Needs

Flood flows at the entrance to the Red River Floodway are complex.

Floodway Entrance. Flood flows at the entrance to the Red River Floodway are made complex by the narrowing of the Red from a broad floodplain as it approaches the Floodway inlet structure. Existing and proposed community ring dikes have the potential to affect water levels in this area. Furthermore, wind and wave action make the West Dike vulnerable. The Floodway entrance is part of the existing MIKE 11 model, which can be used to simulate water levels for forecast operations and overcome some of the issues at the Floodway entrance. Despite that, a need has been identified for a more complex model to be used in a planning mode.[48] This portion of the basin is now being modeled using a two-dimensional finite element model known as TELEMAC.

The TELMAC model will simulate wind set-up on the West Dike, effects of dikes on water levels, and effects of modifications to the Floodway embankment on upstream water levels. The National Research Council of Canada is conducting this work under a Canada–Manitoba agreement.

12

Flood-Related Institutional Arrangements

Major floods capture attention and stimulate remedial action. But in a quiet period, between floods, the commitment to action declines as the immediacy and the apparent threat from flooding recedes. Flooding is a long-term problem, longer than most people's memories. The memory of 1997 needs to be kept alive.

Flooding is a long-term problem, longer than most people's memories. The memory of 1997 needs to be kept alive.

The actions recommended by the Task Force are not a one-time fix. They need to be implemented over time and adapted as circumstances change. The modeling and database work funded by the Task Force is leading-edge flood-management technology. Funding cutbacks, however, have limited what the Task Force hoped to accomplish. The virtual database and decision-support system work remains incomplete. The framework is in place, but government organizations will have to take responsibility for seeing the original conception through to completion, operation, expansion, and maintenance. The overlapping, compatible American and Canadian hydraulic models for the river developed by the Task force have proved useful. Because of funding limitations, however, much of the basin, particularly in the United States, has not been modeled. The tools that now exist will need to be maintained and improved as new information and new technologies emerge. And, as always, because the responsibility centers are in two countries, compatibility and integration of the systems being developed will remain an essential objective.

Need for an institution with a basin-wide binational perspective to help keep flood management issues alive and to make progress toward resolving them.

The Task Force sees the need for an institution with a basin-wide binational perspective to help keep flood management issues alive and to make progress toward resolving them for the people and governments of the basin. Management issues must, of course, remain the responsibility of the various governments. The governments themselves, however, have only a partial and occasionally a parochial perspective of flood- and water-related issues. They have at times worked effectively together, but it will always be difficult to bring a long-term cohesiveness of purpose and effective mutual support to a variety of agencies and governments, including federal governments, within and between jurisdictions.

The recommendations in the Task Force report, if accepted by the governments, will require ongoing monitoring, maintenance, development, and adjustment through existing or new institutions. Flood-related institutional arrangements are needed to:

1. ensure ongoing institutional support and full multi-jurisdictional participation for legacy projects, the distributed data base and computer models;
2. monitor implementation of recommendations designed to ensure basin-wide flood preparedness and community resiliency;
3. monitor and report on the implications of specific flood-related recommendations;
4. promote a culture of flood preparedness and flood resiliency in the basin;
5. support early warnings and early action in the face of impending major floods;
6. ensure binational coordination of flood forecasting and communications of forecasts to the public;
7. provide a forum for multi-jurisdictional problem solving;
8. provide a forum for the exchange of best practices information; and
9. provide knowledgeable and credible advocates to interact with the highest levels of government in order to help decision makers become aware of the requirements of the people of the basin on flood-related issues and associated issues of water management.

Flood management is part of the broader field of water management, and flood-related issues must often be part of broader water management strategies. For that reason, flood functions may need to be included in institutions with broad water-related responsibilities.

Current Institutional Setting

Any discussion of institutional arrangements must examine existing organizations.

Multiple interests coexist in the basin, and a number of organizations with flood-related functions support those interests. Any discussion of institutional arrangements must examine existing organizations with flood-related responsibilities, as well as proposals for new institutions that may be able to take on flood-related functions.

The Red River Basin Board, a major organization with water-related functions, represents a grass-roots effort to address issues in a basin-wide context. The Board is a not-for-profit corporation chartered under the laws of Manitoba, North Dakota, Minnesota, and South Dakota.

The board of directors has 21 members representing local government (cities, counties, and rural municipalities), watershed boards, water-resource districts, First Nations and Native Americans, a water supply cooperative, and a lake improvement association. There are also three at-large members, and some members have been appointed by the governors of North Dakota, Minnesota, and South Dakota and the premier of the Province of Manitoba.

The Board's mission is to develop a comprehensive water management plan, that would then be implemented by other agencies within the basin. It also seeks to serve as an information clearing house; to provide public information on basin issues; to serve as a forum for discussion, consensus building and dispute resolution, including inter-jurisdictional differences, in the management of surface and groundwater supplies in the Red River basin; and to provide advice to governments.

Red River Basin Board

Vision – The Red River Basin Board safeguards the region's lifeblood, its water, and the well-being of its residents. By 2010, residents of the region will be able to count on an ample year-round supply of good quality water. The Board will continue to work to ensure that lives and property will be safe from serious flooding.

Mission – The Red River Basin Board's mission is to create and implement a comprehensive water management plan for the Red River Basin. The Board also provides a forum for resolving interjurisdictional issues

The International Joint Commission itself has two boards with transboundary responsibilities in the basin, the International Red River Pollution Board and the International Souris–Red Rivers Engineering Board. The International Red River Pollution Board, established in 1969, maintains continuous surveillance over the quality of water and health of the transboundary aquatic ecosystem, and keeps the Commission informed of conditions and plans, policies, and developments which may adversely affect the quality of the water and the health of the ecosystem.

The International Souris–Red Rivers Engineering Board was established by the Commission in 1948 in response to a government request that it report on the use and apportionment of the waters within the Souris–Red River basin and that it develop plans of mutual advantage for these waters. The Board has been involved in numerous issues, including Red River flooding and diking problems, water supplies, and storage possibilities on the Pembina River.

The IJC, in cooperation with its two boards, is in the process of combining the boards and their responsibilities into one advisory board. This approach is intended to result in a more efficient and effective means for the IJC to fulfil its mandate in the basin.

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There are other basin-wide organizations. The Red River Water Resources Council works to enhance communication and cooperation between the governments and citizens of Minnesota, North Dakota, and Manitoba in managing water and related land resources for the benefit of the citizens of the Red River basin. Its predecessor, the Souris–Red–Rainy Basin Commission, was terminated by federal budgetary action in 1981. The seven-member board is made up of government-appointed representatives.

The International Coalition (TIC), a non-profit organization organized in 1979, was formed to see whether the Red River watershed could be managed on a regional basis. Its primary areas of involvement include building partnerships and establishing communication and cooperation among the people of Manitoba, Minnesota, North Dakota, and South Dakota in the Red River Basin. TIC's purpose is to educate and build consensus on basin-wide land and water issues.

International Flood Mitigation Initiative (IFMI)

Vision: By the year 2010, the community of the Red River Basin will address flooding through mitigation that achieves strong flood damage reduction goals and enhances economic, social, and ecological opportunities.

Strategies:

1. Comprehensive watershed storage and retention
2. Safe and sensible floodplain management
3. Landscape management for flood mitigation and other benefits

The International Flood Mitigation Initiative (IFMI) is a non-permanent organization formed following the 1997 flood by the North Dakota Consensus Council with funding from FEMA and the Province of Manitoba. The Initiative brings together representatives with a wide range of interests and expertise to focus on flood-related issues. IFMI seeks consensus among its members on recommendations for action and new institutional arrangements to prompt united action among basin residents to reduce the risk and consequences of Red River flooding. The Initiative terminates in 2000.

Within Minnesota and North Dakota there are a number of Red River basin institutions. In Minnesota, the Red River Watershed Management Board was created to institute, coordinate, and finance projects to alleviate flooding and to assure beneficial use of water in the watershed of the Red River and its tributaries. The scope of this board's jurisdiction and authority encompasses the area managed by the individual watershed districts represented on the board. The member districts include the Bois De Sioux, Buffalo–Red River, Joe River, Middle River–Snake River, Red Lake, Roseau River, Sand Hill River, The Two Rivers, and Wild Rice River.

The Minnesota Red River Basin Joint Powers Board was formed to enable participating counties to work together to develop comprehensive local water plans. Since completing the initial plans, the board has continued to meet on a regular basis to share information, discuss projects, and address land and water issues.

The North Dakota Red River Joint Water Resources Board is made up of 12 water-resource districts in the Red River Basin of North Dakota. It was formed to allow a coordinated and cooperative approach to planning and implementing a comprehensive water management program in the Red River Basin. Member districts include Ransom, Richland, Sargent, Walsh, Grand Forks, Traill, Maple, North Cass, Southeast Cass, Pembina, Nelson, and Steele.

The North Dakota/Minnesota Watershed Cooperation Board is formed from the Red River Joint Water Resources Board in North Dakota and the Red River Watershed Management Board in Minnesota. These two boards meet twice a year, once to exchange information and once to tour projects in either North Dakota or Minnesota.

In addition to these basin boards, there are tribal councils, conservation districts in Manitoba, water-resource districts and soil conservation districts in North Dakota, watershed districts and soil and water conservation districts in Minnesota, and special purpose water boards, as well as counties, municipalities, and cities within the basin that have a direct interest in water and flood management issues. The provinces, states and federal governments all have direct interests.

In 1998, the Commission recommended the creation of international watershed boards, including one for the Red River.

IJC Watershed Board Concept

In 1998, the IJC reflected on the issues facing Canada–United States transboundary environmental relations in the twenty-first century. In its report *The IJC and the 21st Century*, the Commission recommended the creation of international watershed boards, including one for the Red River. The proposal builds on cooperative efforts and successes achieved by the Commission in past binational initiatives. The boards would apply an ecosystem approach to transboundary watershed issues. They would seek to prevent and resolve transboundary disputes and promote transboundary cooperation on matters of mutual interest by building a capacity at the watershed level to anticipate and respond to water-related and other environmental challenges. The boards would be independent, objective bodies that could link local residents and organizations to the national decision-making structures, and ensure a binational watershed focus.

Watershed Board Reference

After publication of the IJC report *The IJC and the 21st Century*, the governments of Canada and the United States approved the watershed board concept in principle and asked the IJC to:

1. define the general framework under which watershed boards would operate, including the scope of activities of the watershed boards and the operating principles of such boards;
2. recommend the location of the first watershed board;
3. recommend the structure, composition and terms of reference of the first international watershed board, including the priority issues it would address;
4. develop cost projections and possible sources of funding, including innovative funding mechanisms, for the formation and operation of the first international watershed board and for financing special studies that would be projected for its first few years of operation; and
5. consult provinces, states, and both federal governments to identify locations and to develop, plan and establish additional international watershed boards at appropriate times.

The governments of Canada and the United States have accepted the watershed board concept in principle and asked the Commission to develop the concept further (see box). If the governments and the Commission decide to implement the watershed board concept, they may consider establishing one of the boards in the Red River basin.

New Basin-wide Approaches

There are a number of considerations and criteria in proposing institutional arrangements for transboundary river basins. For one, they need to able to deal with issues in a timely and efficient manner. Ideally, the line dividing the countries should not hinder the achievement of outcomes that could be attained within a single jurisdiction. Realistically, ideal technical solutions must be modified by political considerations. International and domestic equity issues are part of these considerations.

For Canada and the United States, domestic equity requires an accommodation of contending political, economic, and other interests. Institutional arrangements must therefore be responsive to public concerns and interests. They must also be accountable to the public that will be affected by actions taken. An underlying consideration for both efficiency and equity concerns is the need for good information. Information is needed to keep governments and the public abreast of emerging problems and opportunities, their nature, the options for dealing with them, their costs and benefits, and how they will be distributed between and within the countries. Where there is agreement on international action, it is also essential to evaluate the problems encountered and the progress being made.

International institutional arrangements must be situated within a context that reflects the legitimate concerns of national governments and the interests they represent. To be relevant, they must be able to reconcile technical possibilities with the political realities of how governments work with their citizens and their neighbors.

A basin-wide approach to water management is generally accepted within the Red River basin.

The concept of a basin-wide approach to water management is generally accepted within the Red River basin. Opinions differ as to the most suitable types of institutions and their mandates. The Red River Basin Board embodies the view that a basin-wide institution should emerge from local authorities. Other views favor an even broader representative approach. Some people look to other river basin institutions, such as the Tennessee Valley Authority, for an institutional model. However, there is recognition that there may be insuperable problems in removing institutional authority from sovereign state, provincial, and federal governments through legislation and international agreements.

In contrast, IJC boards are established by the IJC under authority derived from the Boundary Waters Treaty and the references given to the Commission by the two national governments. The Commission in its work seeks to engage the public and local interests. While the legitimacy of groups like the Red River Basin Board comes from its support at the local level, the legitimacy of IJC boards stems from the authority granted by senior levels of government. Members of IJC boards are generally federal, state, and provincial officials acting in a personal or professional capacity.

A two-tier approach, in which basin institutions work cooperatively, could meet the institutional need for flood-related and associated issues.

There is debate about which approach is the most appropriate to prepare the basin for flooding problems. The Task Force believes that to accommodate the considerations raised above, a two-tier approach, in which basin institutions work cooperatively, could meet the institutional need for flood-related and associated issues. A first-tier organization is one established by the authority of state, provincial, and federal governments, although, like IJC boards, they may operate independently of governments. Second-tier organizations emerge from initiatives at the local, regional, or basin level. The interests of the two types of organizations may overlap, but their membership, accountability structures, and the way they operate will differ.

There is no doubt about the need for regional and basin-wide organizations that are accountable to basin communities and groups, that can reflect and advocate local and regional interests and present consensus among them. The Red River Basin Board, one organization that currently has this function, would be characteristic of a second-tier organization.

There is also a case for a first-tier organization attuned to the complexities of dealing with international issues while interacting with governments and basin interests. Such an organization would need to develop the confidence of federal, state, and provincial governments, and be accepted by local governments, non-governmental organizations, and the public as the appropriate body for dealing with basin issues having transboundary implications.

...first-tier organization attuned to the complexities of dealing with international issues while interacting with governments and basin interests.

The strength of such an organization would be in its advisory role in relation to national, state, and provincial governments. It would have no water management responsibilities. It would not alter current federal, provincial, and state responsibilities. It would build on existing IJC institutions and be designed to help ensure that each jurisdiction fulfills its water-related responsibilities to the public and to each other.

No first-tier transboundary flood-related organization or board now exists, and a number of issues need to be fully considered before one can be created. The Task Force has heard concerns about the duplication of existing institutions and possible over-representation of federal perspectives and under-representation of state, provincial, and local perspectives. These concerns are addressed in the discussion that follows.

Principles

The following principles would be crucial to ensuring the acceptability, credibility, and effectiveness of a first-tier international transboundary body for flood-related purposes:

1. Equality of representation between the two countries
2. Appropriate expertise of members serving in their personal and professional capacity
3. Decision-making by consensus
4. Public consultation with second-tier organizations and the public
5. Consultation with the public and the media on public policy issues
6. Direct access to governments
7. Access to sufficient funds to undertake essential research and analysis in support of assigned functions

No single organization could effectively encompass the total array of interests and views within a basin.

A first-tier transboundary flood-related body of the kind contemplated by the Task Force would need to be able to respond to emerging local issues and, where appropriate, to help resolve the issues at the local level. It would have enough flexibility to be able to act to prevent local issues from becoming issues of wider or binational concern. It would work with local interests and, where appropriate, with other basin institutions in the kind of two-tier approach suggested above.

Principles considered critical for the operation of second-tier organizations include:

1. Involvement to the highest degree possible with people of the basin
2. Adequate representation of stakeholders
3. A wide range of representative views in the basin in organization discussions
4. Consensus in views brought forward to governments and first-tier organizations
5. Access to sufficient funds to support assigned functions

It should be recognized that no single organization could effectively encompass the total array of interests and views within a basin. Single-issue interests and broad-based interests may not be able to work together. What is important is that the range of organizations should reflect the issues and interests of concern to people in the basin, and that these views should be fully considered by governments and first-tier institutions.

An important principle that distinguishes the IJC from other international river institutions is that its board members are asked to serve in their personal and professional capacities.

Representation

A first-tier transboundary flood-related institution would require state and provincial membership. An important principle that distinguishes the IJC from other international river institutions, such as the International Commission for the Protection of the Rhine, is that its board members are asked to serve in their personal and professional capacities. The members of most other international commissions are appointed by and represent their governments. The IJC approach promotes a problem-solving, rather than negotiating approach to transboundary issues. This representation principle encourages a basin-wide public interest perspective.

While serving in their professional capacity, government members would have a special role in coordination, facilitation, and consensus building. Their knowledge and direct contact and consultation with their agencies would facilitate appropriate action on emerging and current issues.

With only state, provincial, and federal members, a transboundary flood-related body might not sufficiently reflect local concerns and interests. On the other hand, if it tried to include a representative range of basin interests, the problem would arise as to who should be included and excluded, and how large the board could be and still function effectively.

Canadian and American members might be included from the Red River Basin Board or non-governmental organizations. The Red River Basin Board includes representatives from many local government organizations, as well as the states and provinces, but it does not encompass the full range of basin interests, for example those of environmental and other non-governmental organizations.

The choice is between institutional effectiveness and representation.

Ultimately, the choice is between institutional effectiveness and representation. In the view of the Task Force, large numbers limit effectiveness. An optimal number may be roughly from 10 to 12 members, an equal number from each country in keeping with the equality principle. Such a body could include state and provincial members with water-related and environmental responsibilities, as well as federal officials and others with similar interests, including emergency management. The body could include some members from outside of government who can bring special expertise to bear.

Whichever approach is adopted, a transboundary flood-related body could function effectively only if it enthusiastically sought consultation and public discussion. Clearly not everyone can be represented, but the vast majority can be heard and their views respectfully considered. Major institutions, such as the Red River Basin Board and other second-tier non-governmental organizations, should be an essential part of consultations. Formal arrangements could be established to ensure the participation of the Red River Basin Board and other organizations in deliberations of the transboundary flood-related institution.

Reporting Relations

State and provincial governments should be able to raise questions and make proposals to the body on issues of concern and request it to take action.

A transboundary flood-related institution would be expected to work closely with federal, state, and provincial governments. If part of the IJC structure, it would report regularly to the Commission and through it to the federal governments. It should also formally and regularly present its proposals and recommendations directly to state and provincial governments. Moreover, state and provincial governments should be able to raise questions and make proposals to the body on issues of concern and request it to take action.

Resources

Much of the normal work of a transboundary flood-related institution could be carried out with relatively modest financial resources. As with IJC boards, home agencies of board members should be able to absorb much of the membership costs. But agency volunteerism has its limits. Government departments are increasingly unwilling to divert scarce agency resources to outside initiatives. For a transboundary institution to be fully effective, it would need to be able to obtain funds from the federal governments to address issues of particular importance requiring the work of specialists and consultants.

In addition, a transboundary institution would need resources for a small secretariat to ensure continuity and ongoing support for its regular work. The secretariat would include co-secretaries whose duties in their home organization would include work with the institution.

Conclusion 9: ***It is for the Commission and the governments to ratify an international watershed board for the Red River basin. The Task Force, however, considers that such a board, if established, might appropriately be assigned a mandate to advocate and report on flood-related issues, including the progress of governments in implementing the recommendations in this report and in maintaining and advancing the work of the Task Force's legacy projects. More particularly, this mandate could include the flood-related functions identified earlier in this section, namely, to:***

1. ***Ensure ongoing institutional support and full multi-jurisdictional participation for legacy projects, the distributed data base, and computer models;***
2. ***Monitor implementation of recommendations designed to ensure basin-wide flood preparedness and community resiliency;***
3. ***Monitor and report on the implications of specific flood-related recommendations;***
4. ***Promote a culture of flood preparedness and flood resiliency in the basin;***
5. ***Support early warnings and early action in the face of impending major floods;***
6. ***Ensure coordination of flood forecasting information;***
7. ***Provide a forum for multi-jurisdictional problem solving;***
8. ***Provide a forum for the exchange of best-practices information; and***
9. ***Provide knowledgeable and credible advocates to interact with the highest levels of government in order to make decision makers aware of the requirements of the people of the basin on flood-related issues and associated issues of water management.***

Given these functions, the Task Force advocates including the following in the Board's structure and reporting responsibilities:

- ***A membership of 10 to 12 members, with representatives from the states of North Dakota and Minnesota, the province of Manitoba, and the two federal governments, plus outside experts as appropriate***
- ***Regular formal and informal consultation with other basin organizations and local governments***
- ***Reporting to the two federal governments and, as appropriate, the state and provincial governments***
- ***Direct communication with the public and media***

Flood-related institutional arrangements of this nature would have the great advantage of being founded on the IJC's time-proven principles of equality of representation, independence, and objectivity.

Recommendation 51: ***If the International Joint Commission pursues the watershed board concept, the Commission should consider establishing its initial board in the Red River basin and assigning to this board the flood-related responsibilities outlined above.***

13

Conclusions and Recommendations

Conclusions

Red River in History

Conclusion 1: Analysis of the geological record, historic floods of the nineteenth century, statistics, and the hydrometeorological factors that cause floods in the Red River basin indicate that floods of the same size as in 1997, or even greater, can be expected in the future.

Flow Management

Conclusion 2: It would be difficult if not impossible to develop enough economically and environmentally acceptable large reservoir storage to reduce substantially the flood peaks for major floods.

Conclusion 3: Large-scale micro-storage has some potential to reduce flood peaks on the Red River but is likely to be impracticable and costly. There are many obstacles to its effective and efficient implementation.

Conclusion 4: Wetland storage may be a valued component of the prairie ecosystem but it plays an insignificant hydrologic role in reducing peaks of large floods on the main stem of the Red River.

Conclusion 5: There may be many good environmental and other reasons to restore wetlands, but wetland restoration is an economically inefficient method of reducing flood damages for infrequent large floods, like the Red River flood of 1997.

Winnipeg at Risk

Conclusion 6: Under flow conditions similar to those experienced in 1997, the risk of a failure of Winnipeg's flood protection infrastructure is high.

Lower Pembina River Flooding

Conclusion 7: There is general recognition in the region that flooding in the lower Pembina River basin has been profoundly affected by the construction of dikes and of roads that act as dikes on both sides of the boundary. Rectifying the transboundary flooding consequences of these structures will require action in both countries and there appears to be a general readiness to take such action.

Data and Decision Support for Flood Management

Conclusion 8: Further improvement and maintenance of the Red River floodplain management database is required. Federal, state and provincial governments and local authorities must maintain a high level of involvement in further database development and in improving data accessibility.

Flood Related Institutional Arrangements

Conclusion 9: It is, of course, for the Commission and the governments to ratify an international watershed board for the Red River basin. The Task Force, however, considers that such a board, if established, might appropriately be assigned a mandate to advocate and report on flood-related issues, including the progress of governments in implementing the recommendations in this report and in maintaining and advancing the work of the Task Force's legacy projects. More particularly, this mandate could include these flood-related functions:

1. Ensure ongoing institutional support and full multi-jurisdictional participation for legacy projects, the distributed data base, and computer models.
2. Monitor implementation of recommendations designed to ensure basin-wide flood preparedness and community resiliency.
3. Monitor and report on the implications of specific flood-related recommendations.
4. Promote a culture of flood preparedness and flood resiliency in the basin.
5. Support early warnings and early action in the face of impending major floods.
6. Ensure coordination of flood forecasting information.
7. Provide a forum for multi-jurisdictional problem solving.
8. Provide a forum for the exchange of best-practices information.
9. Provide knowledgeable and credible advocates to interact with the highest levels of government in order to make decision makers aware of the requirements of the people of the basin on flood-related issues and associated issues of water management.

Given these functions, the Task Force advocates including the following in the Board's structure and reporting responsibilities:

1. A membership of 10 to 12 members, with representatives from the states of North Dakota and Minnesota, the province of Manitoba, and the two federal governments, plus outside experts as appropriate
2. Regular formal and informal consultation with other basin organizations and local governments
3. Reporting to the two federal governments and, as appropriate, the state and provincial governments
4. Direct communication with the public and media

Recommendations

Flow Management

Recommendation 1: Wetland restoration projects for flood control should be evaluated on the basis of their local benefits and costs rather than imputing a basin-wide benefit.

Recommendation 2: Future ice jam information from the entire basin should be incorporated into the CRREL Ice Jam Database so that ice problems in the basin can be analyzed further. Where feasible, historic ice jams from the Canadian portion of the basin should be entered.

Communities at Risk

Recommendation 3: Communities in the United States portion of the Red River basin should ensure that community-built flood damage reduction projects are certified by FEMA for 100-year or greater protection, or should participate in the Non-Federal Flood Control Works Inspection Program.

Winnipeg at Risk

Recommendation 4: The design flood used as the standard for flood protection works for Winnipeg should be the highest that can be economically justified or, at a minimum, the flood of record, the 1826 flood.

Recommendation 5: Based on results from hydraulic model studies, modify the east embankment of the Floodway to improve the performance of the Floodway entrance to lower upstream water levels and increase capacity.

Recommendation 6: The west dike should be raised to allow a water level elevation of 778 feet (237 m) at the Floodway inlet structure with appropriate freeboard.

PFRA

West Dike, Winnipeg, Manitoba

Recommendation 7: The primary diking system should be raised where economically feasible to the elevation specified in existing legislation.

Recommendation 8: The City of Winnipeg, the province, and the federal government should cooperatively finance detailed feasibility studies of the two major projects that would protect Winnipeg against very large floods.

Recommendation 9: The three jurisdictions should work towards a Winnipeg Protection Agreement to finance the development of a long-term protection plan that would include construction of the Ste. Agathe Detention Structure or Floodway expansion.

Recommendation 10: Modifications to the sewer and land drainage systems should be optimized and undertaken once the overall plan for Winnipeg flood protection is determined.

Recommendation 11: The City of Winnipeg should give immediate high priority to the preparation of a detailed emergency preparedness and response manual.

Recommendation 12: Operating rules for new flood control measures should be designed to accommodate all flow regimes, even those beyond design capacity. The public should be consulted on any proposed new operating rules.

Flood Preparedness and Resiliency

Recommendation 13: In the U.S. portion of the Red River basin, the 100-year floodplain should continue to be defined in light of the best available information and the revised flood elevations should be used as the basis for floodplain regulations.

Recommendation 14: In Manitoba, either the flood of record or the one-percent flood should be used for Red River basin regulations.

Recommendation 15: The 500-year flood (0.2 percent flood) should be defined throughout the Red River basin and used to inform the public of the potential risks of flooding from rare events, including the need to buy flood insurance in the United States, and as the basis of regulations for siting and floodproofing critical facilities.

Recommendation 16: Both North Dakota and Minnesota should consider adopting the new International Building Code that includes requirements for design and construction in flood hazard areas.

Recommendation 17: The National Building Code of Canada should specify design and construction standards for buildings in flood hazard areas such as the Red River basin. Floodplain construction requirements should be incorporated into the Manitoba code when available.

Recommendation 18: Federal, state, provincial, and local governments in the Red River Basin, in conjunction with the private sector, should continue to develop, refine, and implement effective strategies to improve the disaster resiliency in basin communities. Efforts should be made to increase public awareness of flood risks throughout the basin.

Recommendation 19: State, provincial and other appropriate authorities should review the effectiveness of and compliance with the floodplain management regulations in the basin and take steps as needed to improve enforcement.

Recommendation 20: While the restriction of reuse of acquired properties is prudent as applied to residential, commercial or other non-flood damage mitigation purposes, FEMA should revise its interpretation of "structures" under the Hazard Mitigation Grant Program regulations to exempt water level control devices, dikes, levees, flood walls and any other feature that would mitigate future flood losses.

Recommendation 21: The Canadian federal government should include in the Disaster Financial Assistance Arrangements provisions to allow for the permanent removal of structures in areas subject to repeated flooding.

Recommendation 22: FEMA and Emergency Preparedness Canada should develop an integrated approach to mitigation initiatives at all political levels based on a comprehensive mitigation strategy for the entire basin. In the United States, the strategy should be integrated within the National Mitigation Strategy.

Recommendation 23: The Canadian federal government should establish a national flood mitigation strategy, or a broader disaster mitigation strategy, and support it with comprehensive mitigation programs.

Recommendation 24: In the U. S. portion of the Red River basin, FEMA should expand current efforts to market the sale and retention of flood insurance both within and outside the 100-year floodplain. Innovative marketing should be considered to attract and retain policy holders, including increasing the waiting period from 30 days to 60 days before flood insurance comes into effect.

Recommendation 25: Recovery, rebuilding, and mitigation expertise and information should be widely shared across the border in advance of flooding.

Recommendation 26: Measures of flood resilience should be developed, and a system should be established to monitor resilience in the Red River basin.

Flooding in the Lower Pembina River

Recommendation 27: The International Technical Working Group, formed in 1996 but currently inactive, should be re-activated to examine the findings of the hydrodynamic model. Working with local interests, such as the Pembina River Basin Advisory Board, it should develop, implement, and fund a solution that is sustainable in the long term.

Recommendation 28: Given the transboundary nature of the basin and the potential for federal involvement in funding and monitoring any agreement, federal agencies from both countries should be engaged in this process as well.

Recommendation 29: Changes in the road network and diking system in the lower Pembina basin should be modeled by the hydrodynamic model prior to implementation of any plan to ensure that there are no unintended consequences.

Recommendation 30: The virtual database and decision support system prototype that the Task Force has begun to develop for the Pembina basin should be continued by relevant agencies in Canada and the United States.

Hydraulic Connections at Lake Traverse

Recommendation 31: Engineering studies should be immediately undertaken to examine all means of eliminating the potential for the hydraulic inter-basin connection in the vicinity of Browns Valley. Governments should then implement the most feasible option. During the interim, the Little Minnesota River system should be closely monitored for undesirable species. If such species appear, immediate action should be taken to prevent their transfer to the Red River basin.

Since benefits accrue basin-wide from coordinated actions taken to prevent the movement of non-native species between adjacent basins, local governments should not be held responsible for costs associated with monitoring or implementing corrective measures. While the U.S. Army Corps of Engineers will need to take the lead role in implementing this recommendation, cost-sharing options should be negotiated with Canada because of the basin-wide benefits.

Recommendation 32: Any modification to existing operating plans or physical structures associated with Lake Traverse that could increase pool elevation must be accompanied by features that eliminate the southward movement of water into the Little Minnesota River.

Lake Winnipeg Water Quality

Recommendation 33: Governments should take immediate steps to ensure that all banned materials such as toxaphene are removed from storage areas in the Red River basin and that potentially hazardous materials are not stored in the 500-year floodplain. Reasonable quantities of such substances could be maintained in the floodplain for immediate use.

Recommendation 34: Governments should continue to monitor toxaphene in the Lake Winnipeg ecosystem until concentrations decline to pre-1997 levels.

Data and Decision Support for Flood Management

Recommendation 35: Hydrometric and meteorological data networks necessary for flood forecasting should be improved and maintained in a state of readiness to forecast future floods.

Recommendation 36: New geographically related data collection in the United States should be in accord with the North American Vertical Datum of 1988.

Recommendation 37: For consistency and accuracy data used in models should take into account the differences in data at the border. Because datum conversions can affect data accuracy, any conversions between standards should be noted and reported along with the data.

Recommendation 38: U.S. National Geodetic Survey and the Geodetic Survey of Canada should convene a forum of datum experts in the year 2000 to discuss Red River basin datum issues and develop a long-term transition plan.

Recommendation 39: All key data providers in Canada should make available at no cost and with no restriction the data sets necessary for the Red River floodplain management and emergency response, and regional or basin-wide modeling activities.

Recommendation 40: Data providers should remain responsible for maintaining and replicating the data sets.

Recommendation 41: Development of the digital elevation model for the Red River Basin should be completed by collaborative initiatives of the relevant agencies.

Recommendation 42: Relevant federal, provincial, state agencies and transboundary agencies should meet to determine the interest in continuing the work of RRBDIN and if there is agreement to continue it, draw up a funding and action plan to ensure its continuation.

Recommendation 43: A decision on whether to continue operation of the Virtual Forum should be included in the discussions on the continuation of the RRBDIN.

Hydrologic and Hydraulic Modeling

Recommendation 44: The U.S. National Weather Service should implement its Advanced Hydrologic Prediction System in the Red River basin as an early priority.

Recommendation 45: A binational Red River Flood Forecasting Liaison Committee should be established by government to improve communications among forecasters and with the public.

Recommendation 46: Confirm the flood peak reduction findings of Chapter 3 for large floods and examine reductions for smaller floods by implementing distributed models on tributaries such as the Mistinka, Wild Rice and Maple Rivers.

Recommendation 47: As a long-term priority for government and academic research, implement a basin-wide coupled atmospheric-hydrologic model in the Red River basin.

Recommendation 48: Conduct surveys of secondary roads, particularly in the central portion of the basin, with differential global positioning systems, and incorporate the results into the hydraulic models.

Recommendation 49: The U.S. Army Corps of Engineers and Manitoba Conservation, operators of the UNET and MIKE 11 models respectively, should maintain the existing models and continue to seek improvements through collaboration with other agencies.

Recommendation 50: Measures should be taken to ensure that data supporting the operation of the hydraulic models and model outputs can be made widely available.

Flood Related Institutional Arrangements

Recommendation 51: If the International Joint Commission pursues the watershed board concept, the Commission should consider establishing its initial board in the Red River Basin and assigning to this board flood-related responsibilities.

Appendix 1

ACRONYMS

AHPS – Advanced Hydrologic Prediction System

API – Antecedent Precipitation Index

ASCE – American Society of Civil Engineers

BWT – Boundary Water Treaty (of 1909)

CCME – Canadian Council of Ministers of the Environment

CCREL – Cold Regions Research and Engineering Laboratory, U.S. Army Corps of Engineers

CCRS – Canadian Centre for Remote Sensing

CSDGM – Content Standard for Digital Geospatial Metadata

DEM – Digital Elevation Model

DFAA – Disaster Financial Assistance Arrangements

DGPS – Differential Global Positioning System

DSS – Decision-Support System

EPC – Emergency Preparedness Canada

EPRP – Emergency Preparedness & Response Plans

FCWIP – Flood Control Works Inspection Program

FEMA – Federal Emergency Management Agency

FGDC – Federal Geomatic Data Committee

FIRM – Flood Insurance Rate Maps

FLDWAV – U.S. National Weather Service flood routing model

GDIN – Global Disaster Information Network

GIS – Geographic Information System

GPS – Global Positioning System

HEC – Hydrologic Engineering Center (U.S. Army Corps of Engineers facility)

HUD – US Department of Housing and Urban Development

IFSAR – Interferometric Synthetic Aperture Radar

IFMI –International Flood Mitigation Initiative

IJC – International Joint Commission

Lidar – Light Detection and Ranging (airborne laser system)

MEMO – Manitoba Emergency Management Organization

MIKE 11 – DHI Water & Environment one dimensional hydraulic model

MLI – Manitoba Land Initiative

MNR – Manitoba Natural Resources (Department)

NAVD88 – North American Vertical Datum of 1988

NFIP – National Flood Insurance Program

NGO – Non-Government Organization

NWS – United States National Weather Service

PFRA – Prairie Farm Rehabilitation Administration, Agriculture and Agri-Food Canada

PRBAB – Pembina River Basin Advisory Board

PTH – Provincial Trunk Highway

RADARSAT – radar images collected via satellite

RRBB – Red River Basin Board

RRBDIN – Red River Basin Disaster Information Network

RRBVDB – Red River Basin Virtual Database

SAR – Synthetic Aperture Radar

SCADA – Supervisory Control and Data Acquisition

TIC – The International Coalition for Land/Water Stewardship in the Red River Basin

UNET – Unsteady NETwork (one-dimensional hydraulic flow model)

USATEC – United States Army Corps of Engineers Topographic Engineering Center

USGS – United States Geological Survey

Appendix 2

PUBLICATIONS SPONSORED BY THE TASK FORCE

(Most of these publications are available at http://www.ijc.org/boards/rrbtf.html)

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Appendix 3

Community Flood Damage Reduction Activities And Projects In The Red River Basin

(Non-emergency local protection measures)

Flood Damage Reduction Activities in the Red River Basin

Minnesota **(Non-Emergency Local Protection Measures)**

Community	Measures in place prior to 1997 flood	Actions during and since 1997 flood	FEMA certified?	Current levee design standards (see legend)	Comments
Ada	Temporary levee	Upgrade levee & COE feasibility study	No, unless provided by permanent project	2	Also 8 residences acquired
Alvardo	Permanent federal levee system		Yes	1	
Argyle	Permanent federal levee system		Yes	1	
Breckenridge	Temporary levee	Upgraded levee & COE feasibility study	No, unless provided by permanent project	2	Also 112 residences acquired
Crookston	Temporary levee	Permanent project is authorized	No, but authorized for 100-year protection	2	
Dilworth	Temporary levee	Upgraded levee & COE feasibility study	No	4	
Dumont	Temporary levee	Upgraded levee	No	4	
East Grand Forks	Temporary levee (overtopped)	Floodwall (HUD) & Permanent levee project is authorized	No, but authorized for 210-year protection	2	Also 520 commercial and residential properties acquired
Fisher	Temporary levee	Installed Diversion	No	4	
Gentilly	Temporary levee		No	2	
Georgetown	Temporary levee	COE feasibility study for 205 Project	No, unless provided by permanent project	2	
Grygla	Temporary levee	Upgraded levee	No	4	
Hallock	Temporary levee	Upgraded levee	No	2	
Halstad	Permanent federal levee system	Raised road, upgraded pumps	No	1	
Hendrum	Temporary levee	Upgraded levee	No	2	Has requested FCWP eligibility inspection
Kennedy	Temporary levee	Upgraded levee	No	4	
Moorhead	Temporary levee	Upgrade levee & pumps	No	2	Also 16 residences acquired

Community	Measures in place prior to 1997 flood	Actions during and since 1997 flood	FEMA certified?	Current levee design standards (see legend)	Comments
Noyes	Permanent federal levee system		Yes	1	
Oakport Township	Temporary levee	COE feasibility study for 205 Project	No, unless provided by permanent project	2	
Oslo	Permanent federal levee system		Yes	1	
Perley	Temporary levee	Upgraded levee	No	4	
Roseau	Temporary levee	Upgraded levee	No	2	
Shelly	Temporary levee	Upgraded levee	No	4	
St. Vincent	Temporary levee	Upgraded levee	No	4	
Stephen	Temporary levee	Considering upgraded levee	No	4	
Twin Valley	Temporary levee	Installed diversion	No	4	
Waubun	Temporary levee	Installed diversion	No	4	
White Earth River Community	Temporary levee	Upgraded levee	No	4	

Levee Design Standard

1 Meets federal permanent levee design criteria
2 Temporary levee built with federal PL 99 funds
3 Temporary levee that has been accepted into the Non-Federal Flood Control Works Program (FCWP) and meets minimum federal standards
4 Locally built levee not in the FCWP

Additionally, floodplain residences have been acquired in these counties (number in parentheses):
Clay (8), Kittson (13), Marshall (2), Norman (18); Polk (16), Roseau (2).
Farmstead ring dikes: 82 constructed, 60 under construction, 42 scheduled for 2000, 178 scheduled for 2001.

Flood Damage Reduction Activities in the Red River Basin

North Dakota (Non-Emergency Local Protection Measures)

Community	Measures in place prior to 1997 flood	Actions during and since 1997 flood	FEMA certified?	Current levee design standards (see legend)	Comments
Argusville	Permanent federal levee system		Yes	1	
Bois de Sioux	Temporary levee	Initiated reconnaissance study for permanent levee	No	4	
Casselton	Temporary levee	Upgraded levee	No	4	
Drayton	Temporary levee	Upgraded levee	No	2	
Enderlin	Permanent federal levee system		Yes	1	
Fargo	Permanent federal levee & temporary levees	Upgraded levee	Yes (limited areas)	1/2	
Fort Ransom	Temporary levee		No	2	
Grafton	Temporary levee	Reactivated authorization for permanent levee	No	2	
Grand Forks (a)	Permanent federal levee & temporary levees	Upgrade temporary levees, acquired homes & businesses, authorized permanent levee	No, but authorized for 210-year protection		Acquired 571 residences
Grand Forks (b)		English Coulee permanent dam and reservoir	Yes	1	
Harwood	Temporary levee		No	3	One separable levee (3) - HUD levee
Horace	Temporary levee		No	2	
Lisbon	Temporary levee		No	2	
Kindred		Temporary levee & infrastructure mitigation	No	4	
Mapleton	Temporary levee		No	4	
Neche	Temporary levee	Cutoff & initiated reconnaissance for permanent levee	No	4	
Pembina	Permanent federal levee system	Temporary raise on permanent levee	Yes	1	
Reiles Acre	Temporary levee		No	4	
Valley City	Temporary levee		No	2/3	One separable levee (3)

Community	Measures in place prior to 1997 flood	Actions during and since 1997 flood	FEMA certified?	Current levee design standards (see legend)	Comments
Wahpeton	Temporary levee	Initiated feasibility study for permanent levee	No	2	
West Fargo	Temporary levee	Permanent flood diversion	Yes	1	

Levee Design Standard

1 Meets federal permanent levee design criteria
2 Temporary levee built with federal PL 99 funds
3 Temporary levee that has been accepted into the Non-Federal Flood Control Works Program (FCWP) and meets minimum federal standards
4 Locally built levee not in the FCWP

Additionally, 51 residences were acquired in Cass County.

Manitoba

Community	Situation at time of 1997 flood	Actions taken since the 1997 flood	Comments/Timing
Aubigny	Temporary dike	2 km (1.2 miles) of diking protecting 27 homes and businesses was planned. Feasibility and design were negotiated with the consultant.	Start of construction anticipated in 2000 or 2001
Brunkild	Permanent dike	Pumps and outlets were upgraded.	
Dominion City	Permanent and temporary dike	Pumps and outlets were upgraded and 0.5 km (0.3 miles) of new dike and upgrading of 0.2 km (0.125 mile) protecting 188 homes and 22 businesses was planned. Feasibility and design work was completed.	Start of construction anticipated in 2000 or 2001
Emerson (West Lynne)	Temporary dike	1.4 km (0.9 mile) of diking was planned; feasibility & design work completed and land expropriation initiated.	Start of construction for the West Lynne section uncertain
Emerson	Permanent dike	Pumps and outlets were upgraded.	
Glenlea	Temporary dike	It was agreed that individual properties would be eligible for floodproofing.	Community project proposal lacked economic feasibility
Gretna	Permanent and temporary dike	1 km (0.62 miles) of dike along the Canada–U.S. border and 1.75 km (1.1 miles) was planned west of town for 200 homes and businesses. Feasibility and design work was completed. Right-of-way purchase was initiated.	Start of construction anticipated in 2000 or 2001
Landmark		Improved drainage to mitigate overland flooding was planned.	Local municipality was not in favor of a dike
Letellier	Permanent dike	Pumps and outlets were upgraded.	
Lowe Farm	Temporary dike	A relatively small dike 1.6 km (1 mile) long to protect 100 homes and 7 businesses was planned. Feasibility and design work was completed and right-of-way was purchased.	Start of construction anticipated in 2000 or 2001
Morris	Permanent dike	Pumps and outlets were upgraded.	
Niverville	Temporary dike	8 km (5 miles) of dike to protect 548 homes and businesses was planned. A feasibility study was completed.	Municipal agreement required for the project to proceed
Osborne	Temporary dike	It was agreed that individual properties would be eligible for floodproofing	Community project proposal lacked economic feasibility
Riverside	Temporary dike	2 km (1.2 miles) of dike protecting 17 homes was planned. Feasibility and design work was completed. Land acquisition was initiated.	Start of construction anticipated in 2000 or 2001
Roseau R. Indian Reserve	Permanent dike	Additional permanent diking was undertaken.	Associated bank/dike failure being investigated
Rosenfeld	Temporary dike	2.5 km (1.5 miles) of diking was planned. A feasibility study was completed and design work was essentially completed. Land acquisition was initiated.	Start of construction anticipated in 2000 or 2001
Rosenort	Permanent and temporary dike	A diversion of the Morris River on the west side of town and 16 km (10 miles) of diking on the other three sides protecting 146 homes and businesses were planned. A feasibility study was completed. Final project design was essentially completed. Land acquisition was initiated.	Start of construction anticipated in 2000 or 2001

Community	Situation at time of 1997 flood	Actions taken since the 1997 flood	Comments/Timing
Seine River Diversion Along PTH #1E	Temporary dikes	A feasibility study for the diversion was completed.	Start of construction anticipated in 2001 or 2002
South of Red River Floodway	Temporary dike	12 km (7.2 miles) of diking and a diversion of the Seine River to the Red River Floodway protecting 204 homes and 28 businesses were planned. Agreements were negotiated with municipal partners. Design work was completed for a section of PTH59 where it forms part of the dike.	Construction anticipated to start in summer 2000 on PTH 59 where it forms the east side of the Grande Pointe Dike
St. Adolphe	Permanent dike	Pumps and outlets were upgraded.	
St. Jean Baptiste	Permanent dike	Pumps and outlets were upgraded.	
St. Pierre-Joly	Permanent and temporary dike	0.3 km (0.2 mile) of new dike, upgrading of 0.8 km (0.48 mile), and pumping station protecting 21 homes and 3 businesses were planned. Feasibility and design work was completed.	Land purchase scheduled for winter; start of construction anticipated in 2000 or 2001
Ste. Agathe	Temporary dike	Feasibility and design work was completed and land acquisition and construction were initiated on 13.5 km (8.4 miles) of permanent dike protecting 134 homes and businesses.	Dike building expected to start in 2000 or 2001 on Pembina Trail [road] where it forms part of the proposed dike

Appendix 4

WATER STORAGE IN THE RED RIVER BASIN (U.S.)[1]

Water Storage in the Red River Basin: Minnesota

Minnesota **(Flood Retention Projects In Place At Time Of '97 Flood)**

Project	County	Owner	River	Flood Storage (Acre-Feet)
Frazee	Becker	Village Of Frazee	Ottertail River	25
Melissa Lake	Becker	City Detroit Lakes	Pelican River	3,660
Little Bemidji Lake	Becker	State of MN	Ottertail River	832
Little Toad Lake	Becker	Dnr	Toad River	1,700
Many Point Lake	Becker	Dnr	Ottertail River	4,800
Round Lake	Becker	Dnr	Ottertail River	3,500
Height of Land Lake	Becker	Dnr	Ottertail River	12,000
Amer Froysland	Becker	Amer Froysland U	Buffalo River	730
Nelson Pond	Becker	August Nelson	Tr-Buffalo River	-
Marshall Lake	Becker	Becker County	Unnamed	37
Koenig & Elton F Area	Becker	Elton And Koenig	Buffalo River	116
Amer Froysland F	Becker	Amer Froysland	Tr-Buffalo River	-
Lehman Pond	Becker	Gary Lehman	Tr-Ottertail River	-
Hamden Gun Club	Becker	Hamden Gun Club	Tr-Buffalo River	-
Kath-2 Pond	Becker	Ted Kath	Tr-Buffalo River	117
Town Lake	Becker	State of MN		558
South Branch Wild Rice Upper	Becker	Wild Rice Watershed Dist	South Branch Wild Rice River	2,400
Stinking Lake	Becker	Buffalo Red Wsd	Hay Creek	6,748
South Branch Wild Rice Lower	Becker	Wild Rice Watershed Dist	South Branch Wild Rice River	2,205
Long Lake	Becker	State of MN	Tr-Pelican River	970
Hubbel Pond	Becker	State of MN	Ottertail River	1,280
Cotton Lake Diversion Dam	Becker	State of MN	Ottertail River	1,280
Muskrat Lake Locks and Dam	Becker	City of Detroit Lakes	Muskrat Lake	50
White Re Lake	Becker	Dnr-Dow	White Re River	4,150
Stakkelhouse Lake	Becker	R.Greggerson & S.C.Peterso	Tr-Pelican River	10
Amer Froysland-New F	Becker	Amer Froysland		28
Mud River	Beltrami	Red Lake Fisheries Assoc	Mud River	50
Moose River Project	Beltrami	Red Lake Wsd	Moose River	48,000
Forster Rice Paddies	Beltrami	Douglas Forster	Rustad Creek	350
Dry Sand Lake Wma	Cass	State of MN	Farnham Crk-Lat 4 Jd 7	875
Girl Lake	Cass	State of MN	Boy River	1,159

Project	County	Owner	River	Flood Storage (Acre-Feet)
Moorhead Lagoon	Clay	City of Moorhead	Tr-Red River	30
Buffalo River State Park	Clay	Dnr-Parks	Buffalo River	50
Buffalo-Red Wsd	Clay		Hay Creek	3,000
Buffalo-Red Project #8	Clay	Buffalo Red Wsd	Stony Creek	2,840
Buffalo-Red Project #5	Clay		Spring Creek	496
Ganz	Clay	Paul Horn Farms Inc.	Buffalo River-S. Branch	-
Clearwater	Clearwater	State of MN	Clearwater River	7,793
Rice Lake Upper	Clearwater	State of MN	Wild Rice River	3,720
Ferdi Anderson F Pond	Clearwater	Ferdi Anderson	Tr-Clearwater River	20
Little Pine Wma	Clearwater	Dnr-F	Tr-Lost River	600
Abraham Detention	Clearwater	Roy Abraham	Tr-Lost River	50
Lower Red Lake Dam	Clearwater	Cemvp	Red Lake River	884,000
Long Lake	Douglas	State of MN	Chippewa River	615
Stowe Lake	Douglas	State of MN	Chippewa River	1,095
Albert Lake	Douglas	State of MN	Chippewa River	195
Mustinka River	Grant	State of MN	Mustinka River	600
Barrett Lake	Grant	Village of Barrett	Pomme De Terre River	1,016
Giese Wetland	Grant	Walter Giese	Mustinka-Off Stream	167
Bronson Lake	Kittson	State of MN	Two Rivers-S. Branch	2,300
Two Rivers	Kittson	State of MN	Two Rivers-S. Branch	25
Joe River Watershed F	Kittson	Joe River Watershed Dist	Tr Joe River	47
State Ditch #90	Kittson	Dnr-Game & Fish	Tr-S. Branch Two Rivers	-
Red River Drayton	Kittson	City of Drayton North Dakota	Red River of The North	8,197
Roseau River	Lake Of The Woods	State of MN	Roseau River	40
Beaulieu Lake	Mahnomen	Mahnomen Co	Tr-Marsh Creek	70
Frog Lake	Mahnomen	State of MN	Marsh Creek	340
Marsh Creek 3	Mahnomen	Wild Rice Watershed Dist	Tr-Marsh Creek	345
Middle River	Marshall	State of MN	Middle River	75
Old Mill State Park	Marshall	State of MN	Middle River	49
East Park Wma Pond	Marshall	Marshall Co. Swcd	Jd #19	5,160
Elm Lake	Marshall	Dnr-F	Tr-Thief River	15,000
Eckvoll Wma	Marshall	Dnr-F	J Ditch 11	2,500
Lost River Pool	Marshall	Dnr-F	Lost River	9,500
Tamarac River R1 Structure	Marshall	Marshall County Swcd	Tamarak	1,123
Wild Rice River	Norman	Wild Rice Watershed Dist	Wild Rice River	50
Faith	Norman	Faith Flour Mill	Wildrice River	50
Green Meadow Group Pond	Norman	East Agassig Swcd	So. Br. Spring Creek	1,584
Olson-Agasiz	Norman	Wild Rice Watershed Dist	Tr-Spring Creek	-

Project	County	Owner	River	Flood Storage (Acre-Feet)
Habedank-Skaurud	Norman	Norman County	Tr-Wild Rice River	190
Mashaug Creek Dam #3	Norman	Norman County	Tr-Wild Rice River	404
Rockwell	Norman	Norman County	Tr-South Branch Wild Rice	271
Sunny Hill-Upper	Norman	Norman County	Tr Wild Rice River	175
Sunny Hill-Lower	Norman	Norman County	Tr Wildrice River	107
Blanche Lake	Otter Tail	State of MN	Tr-Ottertail River	4,100
Little Pine Lake	Otter Tail	State of MN	Otter Tail River	4,200
Big Pine Lake	Otter Tail	State of MN	Ottertail River	14,460
Rush Lake	Otter Tail	State of MN	Ottertail River	26,015
Otter Tail Lake	Otter Tail	State of MN	Ottertail River	51,200
Otter Tail River	Otter Tail	Otter Tail Co	Otter Tail River	340
Dead Lake West	Otter Tail	State of MN	Dead River	23,124
Mcdonald Lake	Otter Tail	State of MN	Tr-Dead River	2,694
Pelican Lake	Otter Tail	State of MN	Pelican River	8,300
Lizzie Lake	Otter Tail	State of MN	Pelican River	11,703
Prairie Lake	Otter Tail	State of MN	Pelican River	6,150
Pelican River	Otter Tail	Warren B. Diedrich	Pelican River	10
Pelican Rapids	Otter Tail	City of Pelican Rapids	Pelican River	50
Dead Lake East	Otter Tail	State of MN	C.D. 28	23,124
Orwell Reservoir & Dam	Otter Tail	Cemvp	Otter Tail River	12,550
Jorgenson Dam	Otter Tail	Dell Jorgenson	Tributary to the Pelican River	14
Estlick Wildlife Wetland Development	Otter Tail	Wallace Wifall	Tributary to the Pelican River	110
Kugler Structure	Otter Tail	Al Kugler	Tributary to the Wing River	57
Hoot Lake	Ottertail	Otter Tail Power Company	Ottertail	99
Friberg (Taplin Gorge)	Ottertail	Otter Tail Power Company	Ottertail	1,500
Central (Wright)	Ottertail	Otter Tail Power Company	Ottertail	100
Pisgah	Ottertail	Otter Tail Power Company	Ottertail	50
Dayton Hollow Dam	Ottertail	Otter Tail Power Company	Ottertail	1,500
Thief River Falls	Pennington	City of Thief River Falls	Red Lake	-
Grand Forks East	Polk	East Grand Forks	Red Lake River	20
Nielsville	Polk	Robert Brekke Sr	Tr-Red River Of North	25
Red Lake River	Polk	Ottertail Power Co	Red Lake River	50
East Grandforks	Polk	City of East Grand Forks	Red River Of The North	50
Sand Hill Lake	Polk	State of MN	Sand Hill River	976
Hill River Lake	Polk	State of MN	Hill River	160
Oak Lake Outlet	Polk	Polk County	Co Ditch 85	712
Sand Hill River	Polk	Unknown	Sand Hill River	40
Maple Lake	Polk	County of Polk	Cyr Creek	8,480

Project	County	Owner	River	Flood Storage (Acre-Feet)
Brekke Pond	Polk	Robert Brekke Sr	Tr-Red River	120
Sand Hill No. 2	Polk	Sand Hill River Wsd	Tr-Sand Hill River	698
Seeger Group Pond	Red Lake	Walter Seeger	Tr-Red Lake River	239
Black River	Red Lake	Red Lake Wsd	Black River	4,900
Miller Wildlife Dam	Red Lake	Miller	Tr-Clearwater River Offstream	155
Hayes Lake	Roseau	State of MN-Parks	Roseau	760
Hansen Creek	Roseau	Dnr-F	Hansen Creek	130
Nereson Wma	Roseau	Dnr-F	Tr-So. Br. Two Rivers	3,800
Roseau River Wldlf Mngmnt Area Pool 3	Roseau	State of MN- F	Tr-Roseau River	5,600
Roseau River Wldlf Mngmnt Area Pool 2	Roseau	State of MN-F	Tr-Roseau River	5,800
Roseau River Wldlf Mngmnt Area Pool 1	Roseau	State of MN F	Pine Creek Diversion	4,400
Brown's Valley	Traverse	Cemvp	Bois De Sioux/Minnesota River	-
White Rock Dam	Traverse	Cemvp	Bois De Sioux	89,000
Breckenridge Lake	Wilkin	City of Breckenridge	Ottertail River	696
Total				**1,369,780**

1 Although the Lower Red Lake Dam has up to 2,218,000 a-f of flood storage available between the maximum pool level and the maximum drawdown level, realistic drawdowns provide only 884,000 acre-feet, only 365,000 acre-feet of flood storage was used during the 1997 flood.

Water Storage in the Red River Basin: North Dakota

North Dakota		(Flood Retention Projects In Place At Time Of '97 Flood)		
Project	**County**	**Owner**	**River**	**Flood Storage (Acre-Feet)**
Hansen Dam	Barnes	Barnes Co Wrd	Sheyenne-Tr	24
Valley City Park Dam	Barnes	City of Valley City	Sheyenne	56
Berckerley Dam	Barnes	Barnes Co Wrd	Sheyenne-Tr	25
Valley City Mill Dam	Barnes	Valley City Mun Util	Sheyenne-Tr	186
Cuba Dam	Barnes	Barnes Co Wrd	Sheyenne-Maple-Tr	40
Heinze Dam	Barnes	Barnes Co Wrd	Sheyenne-Tr	165
Anderson Dam; Lawrence	Barnes	Gale Eggart	Sheyenne-Tr	47
Triebold Dam; Vernon	Barnes	Barnes Co Wrd	Sheyenne-Maple	16
Schug Dam; Frank 1	Barnes	Virgil Etzell	Sheyenne-Tr	64
Thoreson-Monson Dam	Barnes	Private	Sheyenne-Tr	22
Stevens Dam; Joe	Barnes	Joe Stevens	Sheyenne-Tr	64
Kathryn Dam	Barnes	Barnes Co Wrd	Sheyenne	-
Dazey Dam	Barnes	Barnes Co Wrd	Sheyenne-Tr	88
Clausen Springs Dam	Barnes	Barnes Co Wrd	Sheyenne-Tr	635
Berger Dam	Barnes	Barnes Co Wrd	Sheyenne-Tr	-
Brown Dam	Barnes	Barnes Co Wrd	Sheyenne	77

Project	County	Owner	River	Flood Storage (Acre-Feet)
Blumer Dam; Oscar	Barnes	Oscar Blumer	Sheyenne-Tr	47
Olson Dam; Oscar	Barnes	Oscar Olson	Sheyenne-Tr	27
Tomahawk	Barnes	Doi Fws	Unnamed Trib To Sheyenne	392
Baldhill	Barnes	Cemvp	Sheyenne River	86,500
Bouret Dam	Benson	Benson Co Wrd	Sheyenne	-
Studeness Dam; Leo	Benson	Leo Studeness	Mauvais Coulee	380
Wood Lake Marsh	Benson	Doi Fws	Unnamed Trib To Devil's Lake	244
Elm-3	Cass	Rush River Wmd	Elm River	1,021
Sb-12	Cass	Rush River Wmd	Swan Creek	1,483
Sb-5	Cass	Maple River Wmd	Trib. Of Buffalo Creek	2,124
Sb-8	Cass	Maple River Wmd	Buffalo Creek	4,195
Brownlee Dam	Cass Maple River	Maple River Wrd	Maple	136
Nd No Name 227	Cass Maple River	Maple River Wrd	Maple	56
Maple River Dam (T-180)	Cass Maple River	Maple River Wrd	Sheyenne-Maple-Tr	2,890
Magnolia Dam & State Gma	Cass Maple River	Nd Game & Fish Dept	Sheyenne-Maple-Tr	231
Hunter Dam	Cass North	City of Hunter	Red-Tr	321
Erie Dam	Cass Rush River	Rush River Wrd	Rush	1,400
Sheyenne River Div. Dam	Cass Southeast	Se Cass Co Wrd	Sheyenne	315
Fargo Dam #3	Cass Southeast	City of Fargo	Red	204
Midtown Dam	Cass Southeast	City of Fargo	Red	743
Fargo 12th Ave. N. Dam	Cass Southeast	City of Fargo	Red	-
Fargo Dam #2	Cass Southeast	City of Fargo	Red	390
Nd No Name 224	Cass Southeast	Se Cass Co Wrd	Wild Rice	100
Seim Dam; Johnny	Cavalier	John Seim	Park-Tr	-
Senator Young Dam	Cavalier	Pembina Co Wrd	Tongue	5,524
Olga Dam	Cavalier	Pembina Co Wrd	Tongue-Tr	931
Bourbanis Dam	Cavalier	Pembina Co Wrd	Tongue-Tr	1,428
Mount Carmel Dam	Cavalier	Cavalier Co Wrd	Pembina-Tr	2,375
Mbpr-10	Cavalier	Cavalier Wmd	Trib Middle Branch Park River	2,058
Mbpr-9	Cavalier	Walsh Wmd	Trib Middle Branch Park River	2,542
T-3-5	Cavalier	Pembina Wmd	Trib Tongue River	243
Sheyenne Dam	Eddy	Eddy Co Wrd	Sheyenne-Tr	-
Warsing Dam	Eddy	Nd Game & Fish Dept	Sheyenne-Tr	670
Warwick Dam	Eddy	Eddy Co Wrd	Sheyenne	-
Torrison Dam; George	Eddy	George Torrison	Sheyenne	108
Mchenry Dam #1	Foster	Foster Co Wrd	Sheyenne-Tr	-
Upper Turtle R.Fld. Ret.#1	Grand Forks	Grand Forks & Nelson Co Wrd	Turtle-Tr	4,725

Project	County	Owner	River	Flood Storage (Acre-Feet)
Halverson Dam; Vernon	Grand Forks	Vernon Halverson	Goose-Tr	-
Upper Turtle R.Fld. Ret.#5	Grand Forks	Grand Forks Co Wrd	Turtle-Tr	1,748
Upper Turtle R.Fld. Ret.#9	Grand Forks	Grand Forks Co Wrd	Turtle-Tr	9,587
Niagara Rr Dam #1	Grand Forks	City of Niagara	Turtle-Tr	89
Grand Forks Riverside Prk	Grand Forks	City of Grand Forks	Red	-
Niagara Twp. Dam #2	Grand Forks	Grand Forks Co Wrd	Turtle-Tr	122
Jonkholding Pd Cornelis 3	Grand Forks	Cornelis Jonk	Forest-Tr	-
Jonkholding Pd Cornelis 1	Grand Forks	Cornelis Jonk	Forest-Tr	-
Jonkholding Pd Cornelis 4	Grand Forks	Cornelis Jonk	Forest-Tr	-
Turtle River Watershed	Grand Forks	Grand Forks Co Wrd	Turtle-Tr	1,922
English Coulee Dam	Grand Forks	Grand Forks Co Wrd	Red-Tr	28,908
Earl Dam; Douglas	Grand Forks	Douglas Earl	Turtle-Tr	281
Grand Forks Co. Com. #1	Grand Forks	Grand Forks County Comm	Turtle-Tr	225
Little Goose	Grand Forks	Doi Fws	Little Goose River	276
Anderson Dam	Grand Forks	Enoch Thorsgaard	Trib Fresh Water Coulee	69
Msbfr-4	Grand Forks	Walsh Wmd	South Branch Forest River	8,480
Ut-2	Grand Forks	Grand Forks Wmd	Trib North Branch Turtle River	1,253
Ut-6	Grand Forks	Grand Forks Wmd	Trib South Branch Turtle River	1,906
Ut-7	Grand Forks	Grand Forks Wmd	Trib South Branch Turtle River	1,394
Ut-8	Grand Forks	Grand Forks Wmd	Trib South Branch Turtle	1,130
Carlson-Tande Dam	Griggs	Griggs Co Wrd	Sheyenne-Tr	80
Ueland Dam	Griggs	City of Cooperstown	Sheyenne	142
Nd No Name 295	Griggs	Griggs Co Wrd	Sheyenne	-
Whitman Dam	Nelson	Walsh Co Wrd	Forest-Tr	7,979
Mcville Railroad Dam	Nelson	ND Dept of Transportation	Sheyenne-Tr	344
Sarnia Dam	Nelson	Nelson Co Wrd	Forest-Tr	1,609
Tolna Dam No. 1	Nelson	Nelson Co Wrd	Sheyenne-Tr	1,053
Gronaas Dam; Clemet	Nelson	Clemet Gronaas	Sheyenne	91
Edsrud Dam; Myron	Nelson	Myron Edsrud	Sheyenne-Tr	-
	Nelson	Osborne Galde	Trib Sheyenne River	23
Olson Dam	Pembina	Pembina Co Wrd	Tongue-Tr	1,016
Renwick Dam	Pembina	Pembina Co Wrd	Pembina-Tongue	7,174
Herzog Dam	Pembina	Pembina Co Wrd	Tongue-Tr	1,956
Cavalier City Dam	Pembina	City of Cavalier	Tongue	47
Drayton Dam	Pembina	City of Drayton	Red-Os	8,197
Pembina City Dam	Pembina	City of Pembina	Pembina	37
Crystal Water Supply Dam	Pembina	City of Crystal	Park-Tr	283
Neche Dam	Pembina	City of Neche	Pembina	15
G L D Farms Holding Pond	Pembina	G L D Farms	Park-Tr	-
Estad Holding Pond Loren	Pembina	Loren Estad	Park-Tr	2

Project	County	Owner	River	Flood Storage (Acre-Feet)
T-2-2	Pembina	Pembina Wmd	Trib Tongue River	2,995
T-2-4	Pembina	Pembina Wmd	Trib Tongue River	2,186
T-8-1	Pembina	Pembina Wmd	Trib Tongue River	1,063
Willow Creek-1	Pembina	Pembina Wmd	Willow Creek	444
Balta Dam	Pierce	Pierce Co Wrd	Sheyenne-Tr	65
Fort Ransom Dam	Ransom	Ransom Co Wrd	Sheyenne	291
Enderlin Park Dam	Ransom	Enderlin Park Board	Sheyenne-Maple	15
Soldiers Home Dam	Ransom	Nd Soldiers Home	Sheyenne	143
Lisbon Dam	Ransom	City of Lisbon	Sheyenne	239
Dead Colt Creek Dam	Ransom	Ransom Co Wrd	Sheyenne-Tr	6,693
Mirror Pool Wma #2	Ransom	Nd Game & Fish Dept	Sheyenne-Tr	114
Mirror Pool Wma #3	Ransom	Nd Game & Fish Dept	Sheyenne-Tr	47
Mirror Pool Wma #4	Ransom	Nd Game & Fish Dept	Sheyenne-Tr	41
Hanson Dam	Richland	Richland Co Wrd	Wild Rice	-
Christine Dam	Richland	City of Fargo	Red	175
Heley Dam; Howard	Richland	Howard Heley	Wild Rice-Os	37
Richland Co Wdr Dry Dam 1	Richland	Richland Co Wrb	Wild Rice River	347
Charbonneau Dam	Rolette	Rolette Co Wrd	Pembina-Tr	151
Nd No Name 247	Rolette	Rolette Co Wrd	Pembina-Tr	144
Wakopa Dam	Rolette	Nd Game & Fish Dept	Pembina-Tr	230
Silver Lake Dam	Sargent	Sargent Co Wrd	Wild Rice	533
North Bay	Sargent	Doi Fws	Wild Rice River	9,120
Cutler	Sargent	Doi Fws	Wild Rice River	1,208
Maka Pool	Sargent	Doi Fws	Wild Rice River	572
River Pool	Sargent	Doi Fws	Wild River	399
Ws-T-1-A	Sargent	Sargent Wmd	Trib Wild Rice	2,399
Ws-T-2	Sargent	Sargent Wmd	Trib Wild Rice	1,775
Ws-T-7	Sargent	Sargent Wmd	Trib Wild Rice	371
Howey Dam; Robert L	Sheridan	Robert L Howey	Sheyenne-Tr	14
Blabon Dam 2	Steele	Steele Co Wrd	Goose-Tr	192
Greenview Dam	Steele	Steele Co Wrd	Sheyenne-Tr	198
Sussex Dam	Steele	Steele Co Wrd	Sheyenne-Maple	1,440
Beaver Creek Dam (Bc-20)	Steele	Steele Co Wrd	Goose-Tr	6,250
Golden Lake Dam	Steele	Ndgfd & Ndswc	Goose-Tr	-
Rush Lake Dam	Steele	Steele Co Park Board	Goose-Tr	-
Elm-1	Steele	Steele Wmd	Elm River	5,741
Armourdale Dam	Towner	ND Game & Fish Dept	Pembina-Tr	1,039
Big Coulee Dam	Towner	Bisbee & Towner Co Wrd	Mauvais Coulee-Tr	2,880
Hurricane Lake Joint Wrd1	Towner	Hurricane Lake Joint Wrd	Mauvais Coulee	-
Belzer Holdingpd; Terry 1	Towner	Terry Belzer	Mauvais Coulee-Tr	20

Project	County	Owner	River	Flood Storage (Acre-Feet)
Belzer Holding Pd; Terry 2	Towner	Terry Belzer	Mauvais Coulee-Tr	20
Snyder Lake	Towner	Doi Fws	Mauvais Creek	946
Hillsboro Dam	Traill	City of Hillsboro	Goose	95
Mayville Dam 2	Traill	City of Mayville	Goose	42
Portland Dam	Traill	City of Portland	Goose	99
Augustadt Dam	Traill	Traill Co Wrd	Elm	5,572
Spokely Farms Dam	Traill	Spokely Brothers	Red-Tr	130
Minto Dam	Walsh	City of Minto	Forest	18
Adams Dam	Walsh	Private	Park-Tr	47
Matejcek Dam	Walsh	Walsh Co Wrd	Forest-Tr	6,253
Vigness Dam	Walsh	City of Grafton	Park-Tr	200
Chyle Dam	Walsh	Walsh Co Wrd	Forest-Tr	1,405
Grafton Rr Dam	Walsh	City of Grafton	Park	-
Jonk Holdingpd; Cornelis 2	Walsh	Cornelis Jonk	Forest-Tr	-
Gustafson Dam; Curtis	Walsh	Curtis Gustafson	Park-Tr	51
Walsh Co Wrd No 5	Walsh	Walsh Co Wrd	Park River	5,312
Ardoch	Walsh	Doi Fws	Forest River	9,691
Homme Dam	Walsh	Cemvp	South Branch of Park River	3,450
Mbpr-6	Walsh	Walsh Wmd	Trib Middle Branch Park River	721
Mbpr-8	Walsh	Walsh Wmd	Middle Branch Park River	3,484
Nbfr-1	Walsh	Walsh Wmd	North Branch Forest River	5,112
Nbfr-3	Walsh	Walsh Wmd	Trib North Branch Forest River	2,120
Nbfr-5	Walsh	Walsh Wmd	Trib North Branch Forest River	1,069
North Salt Lake	Walsh	Walsh Wmd	Willow Creek	1,050
Harvey Dam	Wells	ND Dept of Transportation	Sheyenne	5,309
Total				**314,517**

Water Storage in the Red River Basin: South Dakota

South Dakota		(Flood Retention Projects In Place At Time Of '97 Flood)		
Project	**County**	**Owner**	**River**	**Flood Storage (Acre-Feet)**
White Lake Dam	Marshall	Gf&P	Wild Rice Creek	1,490
Wild Rice Creek Watershed Wr-7	Marshall	Wild Rice Creek Watershed District	Trib Wild Rice Creek	212
Wild Rice Creek Watershed Wr-5	Marshall	Wild Rice Creek Watershed District	Trib Wild Rice Creek	242
Wild Rice Creek Watershed Wr-2	Marshall	Wild Rice Creek Watershed District	Trib Wild Rice Creek	758
Englund Dam	Roberts	Lloyd Englund	Trib Lake Traverse	66
Total				**2,768**

1 National Inventory of Dams. 1999. U.S. Army Corps of Engineers, Dam Safety Team, CECW-EP-S, 20 Massachusetts Ave., NW, Washington, D.C. 20313-1000 http://crunch.tec.army.mil/nid/webpages/nidwelcome.cfm

Appendix 5

INTERIM REPORT OF THE INTERNATIONAL RED RIVER BASIN TASK FORCE

Red River Flooding: Short-term Measures

Following the devastating floods of 1997 in the Red River basin, the governments of Canada and the United States asked the International Joint Commission (IJC) to investigate the causes and effects of flooding in the basin and to provide them with an interim report by the end of 1997. On December 31, 1997, the International Joint Commission reported to the governments of Canada and the United States on interim measures that should be undertaken to prepare for possible floods in the short-term. The interim report cautioned against complacency, noted that major flooding could occur at any time, and made 40 recommendations regarding flood forecasting, monitoring improvements, emergency measures and planning, environmental concerns, and floodplain management including zoning, legislation, and enforcement.

The IJC asked its International Red River Basin Task Force to report on governments' actions in the areas covered by the 40 recommendations. The Task Force reported in July 1998 and again in April 1999. The results of April 1999 report have been updated and are available from the Task Force Website at http://www.ijc.org/boards/rrbtf.html.

The Task Force is pleased to note that the different jurisdictions report action on virtually all of the areas where it has made recommendations.

Interim Report Recommendations

Future Floods

1. Alert the public in the Red River basin to the reality that while the 1997 flood had a return interval ranging from 100 to 500 years, depending on the location, there is a statistical probability of a similar flood each year. Flood preparedness must be part of the culture of the Red River valley. Put simply, the flood of 1997 or an even larger one could happen any year.

Flood Policy Review

2. A meeting of senior federal-provincial and federal-state officials in each country should be convened to undertake policy level discussions and an examination of the 1997 flood. Special attention would be placed on extending the positive aspects of flood preparation and management during 1997 to future events throughout the Red River valley.

3. Increased liaison on a regular basis among the emergency management organizations throughout the basin should be a priority in order to establish better appreciation for the manner in which each operates during an emergency.

4. During a flood, Canadian liaison officers should be present in U.S. flood emergency centers to immediately relay information to Manitoba.

Flood Forecasting

5. Update and enhance existing forecast models based on 1997 data and experience, focusing specifically on improvements that can be incorporated in basin-wide forecasts prior to the 1998 season. In particular, rating curve extensions should be undertaken as soon as possible.

6. Monitor the potential effects of El Nino on 1998 weather.

7. All flood-forecasting agencies should ensure that they have sufficient, experienced flood forecasting staff at all times.

Flood Forecasts for the Public

8. Simplify and clarify communication between flood forecasters and those with local flood emergency responsibility, throughout the basin. The dissemination of forecast information to the public through the media should be simple and the variables inherent in those forecasts easily understood.

Floodplain Management

9. The Province of Manitoba, and affected municipalities, should review all Designated Flood Area legislation and zoning provisions with the intent of widening the options for enforcement. A comprehensive program of early inspection and enforcement should be developed and implemented immediately. Once this program is implemented, non-compliant new structures should not be eligible for disaster assistance.

10. In the United States, more stringent adherence to existing policies is a necessary, immediate, and effective first step for better floodplain management. Emphasis should be placed on increasing participation in the flood insurance program.

11. Update profiles, maps and flood frequency curves for the Red River basin.

Structural Measures

12. Plans to implement new flood mitigation and flood-proofing measures for individuals and communities—if sound in economic, environmental, engineering and social terms—should continue as rapidly as possible. All such measures, whether by government or individuals, should be coordinated and examined to determine possible damage to others within the basin.

Coordination

13. Pursue agreement between the United States and Canada to enable comprehensive civil emergency planning and management that takes into account current trade agreements between the two countries, and in particular, allows for the cross-border transfer of supplies, equipment, contracting services and labor in the event of an emergency. The agreement should look into the possibility of developing regionally specific arrangements, including state-provincial protocols.

14. North Dakota and Minnesota should review emergency measure agreements in the light of the experience of the 1997 flood.

15. A basin-wide flood forecasting committee patterned on the Souris River Flood Forecasting Liaison Committee should be established for the Red River basin.

16. In the U.S., where regional operations of federal agencies are divided by the Red River, a lead region should be appointed for emergency operations when a flood is forecast.

Flood Emergency Plans

17. All flood emergency plans within the basin should be reviewed in the light of the lessons learned during the 1997 flood to prepare more effectively for the next event.

18. Each jurisdiction with responsibilities for evacuation within the basin should establish an evacuation protocol within its emergency operation plan. Particular attention should be given to the clarity and public dissemination of the protocols to help prevent confusion at the time of evacuation. Evacuation plans affect different parts of the population in different ways and plans should take into consideration the specific requirements of vulnerable groups, such as nursing home residents.

Emergency Communications

19. Establish sufficient information centers prior to and during a flood event, through 1-800 hot lines or other well-publicized toll-free telephone numbers, to provide critical information to residents of the flooded area before, during and after the event. Enhance the opportunities for Internet access, particularly for small communities and rural areas.

Human Impacts

20. Trauma teams, emergency response teams, and personal decision-management teams should be maintained until the current demand for services subsides.

21. In future times of crisis, such support teams should be established early and begin work as soon as possible.

22. Information about flooding and the measures in place in case of flooding in the Red River valley should be introduced into the school curriculum throughout the basin, and in particular, in the communities most at risk.

Canadian Forces

23. Earlier notice should be given to the Canadian Forces of their potential involvement in flood fighting in order to allow them additional preparation time.

24. Canadian military and civil authorities should reach a common understanding of the types of assistance available, particularly in terms of aid to local law-enforcement authorities.

Modeling

25. Develop hydraulic models for the Red River and its major tributaries, capable of being expanded for use in forecasting and analyzing overland flooding, as well as for floodplain management.

26. Document the 1997 overland flow areas within the basin, high-water marks and head losses, wind effects, timing and extent of road or dike breaches and blow-outs, and data networks used during the flood. In addition, document the shape, elevation and alignment of roads, dikes, levees and drains, including the size of bridge and roadway openings.

27. Develop a consolidated database containing hydrometric, climatic, topographical and other technical data within the basin needed to improve forecasting and modeling capability.

The Hydrometric Gaging System

28. A high priority should be given to raising existing gages above the 1997 high-water level or replacing them.

29. Add to the current gaging system in the basin and, where needed, automate reporting to increase information for flood forecasters.

Airborne Gamma Surveys

30. Depending on the flood outlook, the frequency of airborne gamma snow survey flights over the Manitoba portion of the Red River valley should be increased. Increasing the density of the network by adding more flight paths should also be considered.

Doppler Radar

31. In view of the critical need for accurate flood forecasting in the Red River valley, Environment Canada should identify Winnipeg as the highest priority location for the new radar installation.

Ice Management

32. Innovative methods of reducing ice jams should be reviewed and expert advice sought on how ice jams may be diminished. This subject should be explored at a workshop on ice control held in the winter of 1998 and attended by international experts and basin officials. The adverse and beneficial effects of ice management on flooding and the environment need to be carefully considered.

Flood Information Archives

33. Information available to individuals, government and non-government organizations and others who contributed to the flood-fighting effort in 1997 should be gathered and made available at a central basin-wide archive or archives in each country.

Hazardous Products

34. Liaison among governments and industry associations throughout the basin should be encouraged and strengthened. Communications should be extended to other businesses, individual homeowners, and farmers.

35. The development of a broad public awareness program within the Red River floodplain should be started to encourage home-owners and farm operators to collect and properly dispose of all waste products that present a contamination hazard. There should also be an immediate and concerted effort to remove or secure hazardous materials stored in the floodplain.

36. An inventory of all major potential sources of contamination should be developed and maintained, to include location, elevation, type of material, and amount. This inventory should extend to the agriculture industry and include intensive livestock operations.

37. A review of legislation on the management of hazardous materials should be conducted throughout the basin.

Groundwater Contamination

38. Conduct an inventory of all abandoned and active groundwater wells throughout the basin and institute an aggressive program of properly sealing abandoned wells and floodproofing active wells against floodwater contamination from the surface.

Levee/Dike Design

39. The natural and beneficial functions of the floodplain must be considered in the design of new levees.

Interbasin Hydraulic Connection

40. Reasonable measures should be implemented, consistent with current operating plans, to prevent (if possible), the movement of water between the Red River and Mississippi River basins at Lake Traverse-Big Stone Lake.

Appendix 6

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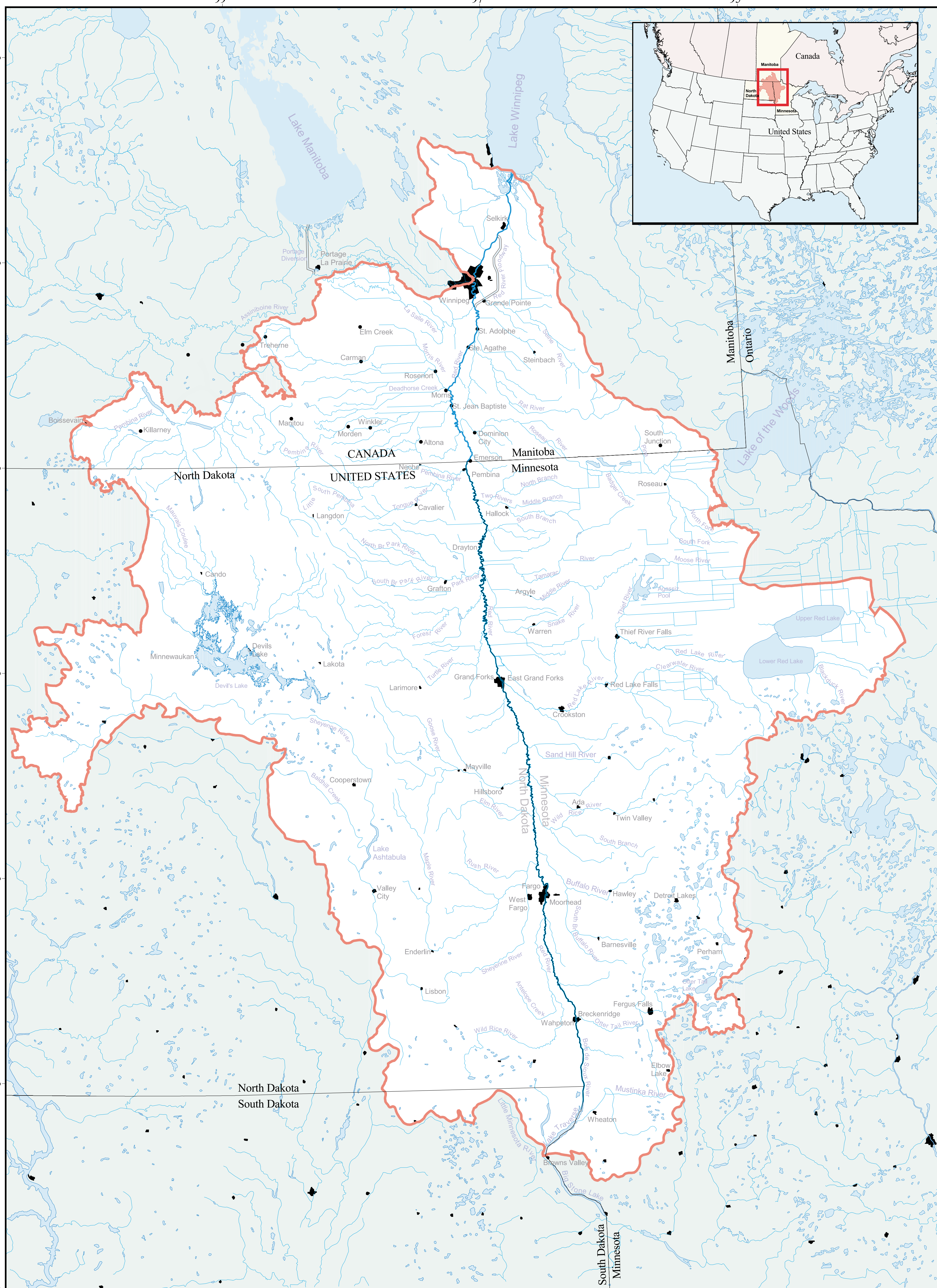


Red River Basin

(excluding Assiniboine River)

Map Projection - Lambert Equal Area
Central Meridian - 100 degrees West
Reference Latitude - 50 degrees North

Data assembled and provided by:
Ecological Research Division,
Environment Canada, Regina Office
Scale - 1 : 2 000 000

Map Generated by:
US Army Corps of Engineers,
St. Paul, MN and Hanover, NH
February 2000, Version 1.2

Data Sources

ESRI Digital Chart of the World:
Land Use Characteristics Database

United States Geological Survey:
State Boundaies
1:500,000 Hydrologic Unit Boundaries

Water Survey of Canada:
HYDAT and HYDEX databases

Canada Prairie Farm Rehabilitation Agency:
Watershed Basin

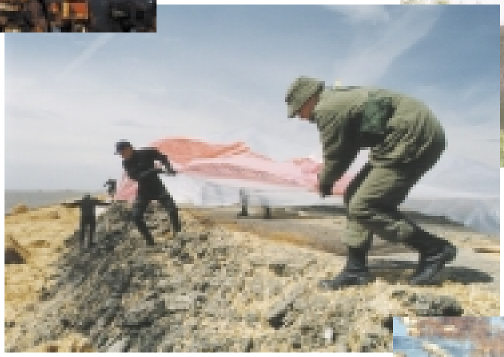
N

30 0 30 60 90 Miles

30 0 30 60 90 120 Kilometers

Red River Basin

Urban Areas



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Back cover photos:
United States Army Corps of Engineers and the Government of Manitoba