FLOODING
IN THE
GRAND FORKS-EAST GRAND FORKS
NORTH DAKOTA AND MINNESOTA
AREA

by
Julie A. LeFever, John P. Bluemle,
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Educational Series No. 25
North Dakota Geological Survey
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Cover Photo: Looking east over DeMers Avenue, downtown Grand Forks-East Grand Forks. Photograph taken Wednesday, April 23, 1997, by Richard Larson, University of North Dakota Office of University Relations.

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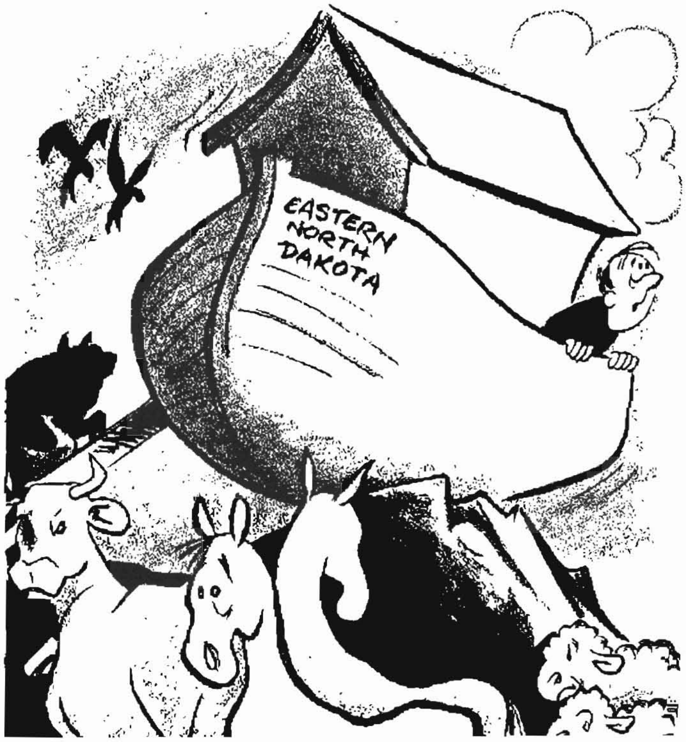
PREFACE

Low-lying areas in Grand Forks-East Grand Forks are flooded moderately nearly every other year. Since official record keeping began in 1882, major floods affecting large areas of both cities have occurred, on the average, once in every six years. Since 1950, however, such severe flooding in the Red River Valley has occurred every four years. The extensive flooding of the Red River in 1997 has forced awareness of the flood problem in Grand Forks-East Grand Forks and necessitated re-examination by the city, state, and federal government of measures required to prevent, or at least reduce, future flood losses.

This report was prepared to provide information not otherwise readily available to the public. An understanding of flood potential and flood hazards is important in land-use planning and for management decisions concerning flood-plain utilization. The report includes a history of flooding in Grand Forks-East Grand Forks and identifies areas subject to future floods. Although we do not necessarily provide specific solutions to flood problems, we do suggest the adoption of various land-use controls for more effective flood-plain development, to reduce flood damage and flood-control efforts.

The North Dakota Geological Survey published earlier versions of this booklet in 1968 and 1980. Although some of the methods and terminology we have used are necessarily technical, sufficient explanation is provided for the layman.

The predictions of the frequency and extent of future flooding set forth in this booklet are based on records of past floods, a record that is only 117 years long. This report discusses the statistical method of prediction, because it is widely used in describing floods. However, the statistical prediction changes with every significant flood and, because it continually changes, these predictions can never be close to 100 percent accurate. Therefore, the North Dakota Geological Survey suggests that the river crest elevation be used to describe inundation for both of the cities as this presents a more accurate picture of potential flooding. The area inundated is then restricted by the land-surface elevation, and is not based on a predicted elevation that changes over time. We have included a series of maps using this method showing the projected inundations for the cities of Grand Forks and East Grand Forks.



Cartoon by Stuart McDonald. Published in the Grand Forks Herald.

THE FLOOD PROBLEM IN THE RED RIVER VALLEY

Floodwaters frequently cover large areas of the Red River Valley during the spring snowmelt and occasionally after heavy summer rains. When flooding occurs, cropland, farmsteads, private residences, transportation facilities and businesses can be heavily damaged.

Grand Forks-East Grand Forks is included in the nation's 100 million acres of floodplain-areas subject to periodic flooding (Hertzler, 1961). Throughout the early history of the two cities, floods were simply endured, with little organized effort made to combat the muddy waters of the Red and Red Lake Rivers. As low-lying areas along the rivers have become more thickly settled, however, vast amounts of money have been spent on temporary and permanent flood-protection measures and, after a flood occurs, on repair and cleanup.

Flooding in the Red River Valley usually occurs in the spring, following the snowmelt, and can be aggravated by rainfall that occurs coincident with spring thaw. The usual type of flooding is associated with streambank overflow. Flooding also occurs when runoff from snowmelt or heavy rainfall is impounded along sections of land bounded by raised roadways where culverts and ditches are either plugged or of inadequate capacity to accommodate large, infrequent discharges. This type of flooding can submerge the roadway embankments, inundating section after section of farmland as it moves overland toward major stream channels and drainage ditches.

The northward flow direction of the Red River can be an important factor influencing the magnitude of floods. Rising spring temperatures, which produce the snowmelt runoff, begin in the southern headwater portion of the basin and progress northward toward Canada. Flood peaks of local and tributary runoff, particularly in the southeastern part of the Red River Valley, often tend to coincide with the Red River main channel flood peak stage, thereby increasing the volume of flooding. Furthermore, the spring floodwaters can flow northward into channels still blocked by winter ice cover. The channel ice can act as a dam, causing backwater and a rise in river levels. However, if warmer temperatures arrive through the entire area at about the same time, the snow cover melts everywhere at once, significantly increasing the volume of water that must be drained by the main channel Red River. In this scenario, flood crests of local and tributary runoff tend to coincide with the main channel Red River peak flood stage, greatly increasing the volume of flooding. This is more likely to happen when the spring thaw is late, as it was in 1979 and 1997.

The flatness of the Red River Valley is an important factor influencing tributary floods. Outside the valley, high flows are most commonly confined within the deeply entrenched channels in the escarpment and beach ridge areas near the edge of the Red River Valley, causing little damage. However, the stream slopes become gentler and the channel capacities decrease in the flat valley areas. In these areas, the floodwaters can escape the channels and move overland, inundating thousands of acres of farmland and even entire communities.

Snow and ice accumulate in the tributary stream channels, particularly at river bridges and constricted parts of the channel. These ice jams sometimes increase upstream levels, causing localized flooding. Standing and fallen trees, brush, and sediment deposited within the channel banks all tend to reduce the flow capacities of streams and ditches. Windblown soil from previous years may also have accumulated in stream valleys, ditches, and channels, further reducing flow-carrying capacities.

North of the Grand Forks-East Grand Forks area, the capacity of the main channel of the Red River is less than it is upstream at Grand Forks. Floodwaters near Oslo can spread out over a vast area of the flat Red River Valley. The river spreads out over broader areas in Canada,where during the 1997 flood the area inundated measured 25 miles across (Manitoba Natural Resources, Water Resources, 1997; International Joint Commission, 1997).

Sediment deposited during past floods has built natural levees up to 5 feet high in many places along the main channel of the Red River and the lower reaches of some of its tributaries. During floods, the river surface may be well above ground levels behind the natural levees. If the natural levees are over-topped or circumvented, the land for several miles on either side of the river can be rapidly inundated.

The extensive tributary and main channel floodplain area of the Red River is heavily populated as a result of the regional agricultural economy. Consequently, urban and rural residences, businesses and transportation facilities all suffer damage during flooding. During most years, when flooding is moderate, minor damage occurs, mainly in the approximately 600,000 acres of floodplain farmland along either side of the Red River in North Dakota and Minnesota. When flooding is severe, as it was in 1997, most of the damage occurs in urban areas.

Damage from floods includes both tangible and intangible losses. Tangible losses include: (1) agricultural damage (fig. 1), (2) water damage to structures, utilities, and transportation facilities (figs. 2 and 3), (3) cost of fighting floods (fig. 4), (4) business losses, (fig. 5), and (5) increased expenses for normal operations during floods. The monetary value of damage caused during several floods is listed in table 1. Intangible losses, which cannot

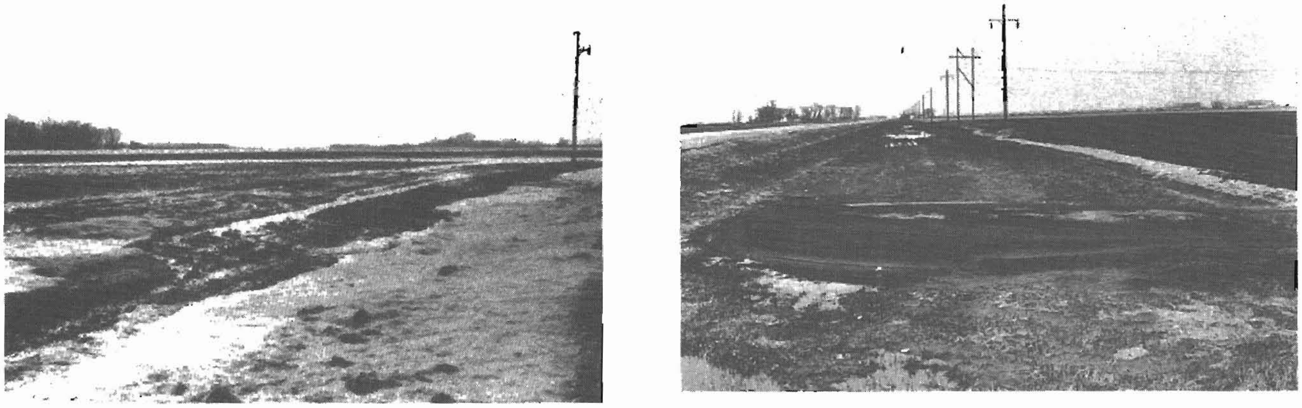


Figure 1. Two photos of runoff-damage to fields in the Grand Forks area. Perhaps the single most important money loss to agricultural land during spring floods is the damage to fields and loss of topsoil due to erosion by running water. Millions of tons of precious black soil are moved by the flowing water, although only a small fraction actually reaches the Red River. Here, a flow from a field (left) results in a small "delta" of black soil being deposited in the road ditch (right). (Photos by J. Bluemle)

be measured in dollars, include: (1) loss of life and threat of loss of life, (2) human misery during and after the flood, (3) disruption of normal community activities, (4) potential health hazards from contaminated water and food supplies, and (5) flooding of sewage collection and treatment facilities.

Under the present limited flood-protection philosophy in the Red River Valley, all tangible and intangible losses now sustained during floods will continue on an increased scale as the result of future floods. Reduction in the type and extent of flood damage can be achieved only with community-renewal programs, land-use shifts, and changes in agricultural practices.

In rural areas, clearing of timber, intensive wetland drainage, fall tillage, conversion of grassland to cropland, drainage-ditch construction, and construction of railroad and highway embankments and bridges have all contributed to the flooding problem. In urban areas, the potential for infiltration by precipitation and snowmelt has been decreased by paving extensive areas. The flooding problem has been compounded by development of flood-prone areas such as the English Coulee drainage. Finally, changes in land use in the headwaters area can increase erosion there and result in sedimentation in downstream areas.

River gaging data for the Red River prior to 1882, when a river gage was established at Grand Forks, are not available in the United States. However, historic accounts from Canada at the Selkirk Colony and from Alexander Henry's journal (Henry was a liquor dealer-fur trader living in the region from 1798-1806) describe significant flooding in 1776, 1798, and 1801. Early records from Winnipeg, Manitoba indicate that major flooding also occurred in 1824, 1825, 1826, 1851, 1852, and 1853. These historic accounts, in addition to early records maintained near Winnipeg, indicate that numerous major floods occurred before official record keeping began. Some of these floods apparently exceeded the spring flood of 1997 by several feet. It is interesting to note that, if data from these early floods are included in the calculations for recurrence interval (Weibul Method), the 1997 event becomes a "37-year flood," rather than a 118-year flood.

Since the installation of the river gage at Grand Forks in 1882, floods exceeding 45 feet have been officially recorded ten times. It is common for several floods to occur in a single year at different points in the river basin and along the various tributaries. Additionally, a river may also have multiple crests at a particular point along its course during a single year. All of the 45-foot and higher floods of record were caused by spring snowmelt. The greatest recorded floods in the Grand Forks-East Grand Forks area were those of 1882, 1887, 1979, 1996, and 1997 (Appendix 1B). Summer floods resulting from heavy summer rains are destructive in a different way. The July 1975 flood crested at 43.30 feet and was particularly devastating because it occurred after crops were well on the way to maturity; consequently, a great deal of swathed grain was lost.

FLOOD TERMINOLOGY

Because the use of some technical terminology is both unavoidable and desirable, a few general definitions are given here (fig. 6).

Backwater: The upstream rise in water surface elevation resulting from a temporary obstruction (such as a bridge or ice dam) or a sudden decrease in stream gradient. The effect causes the main stream to overflow into low-lying land and back up water into its tributaries. It is characterized by an expansion in width of the body of water and by a slackening in the current.

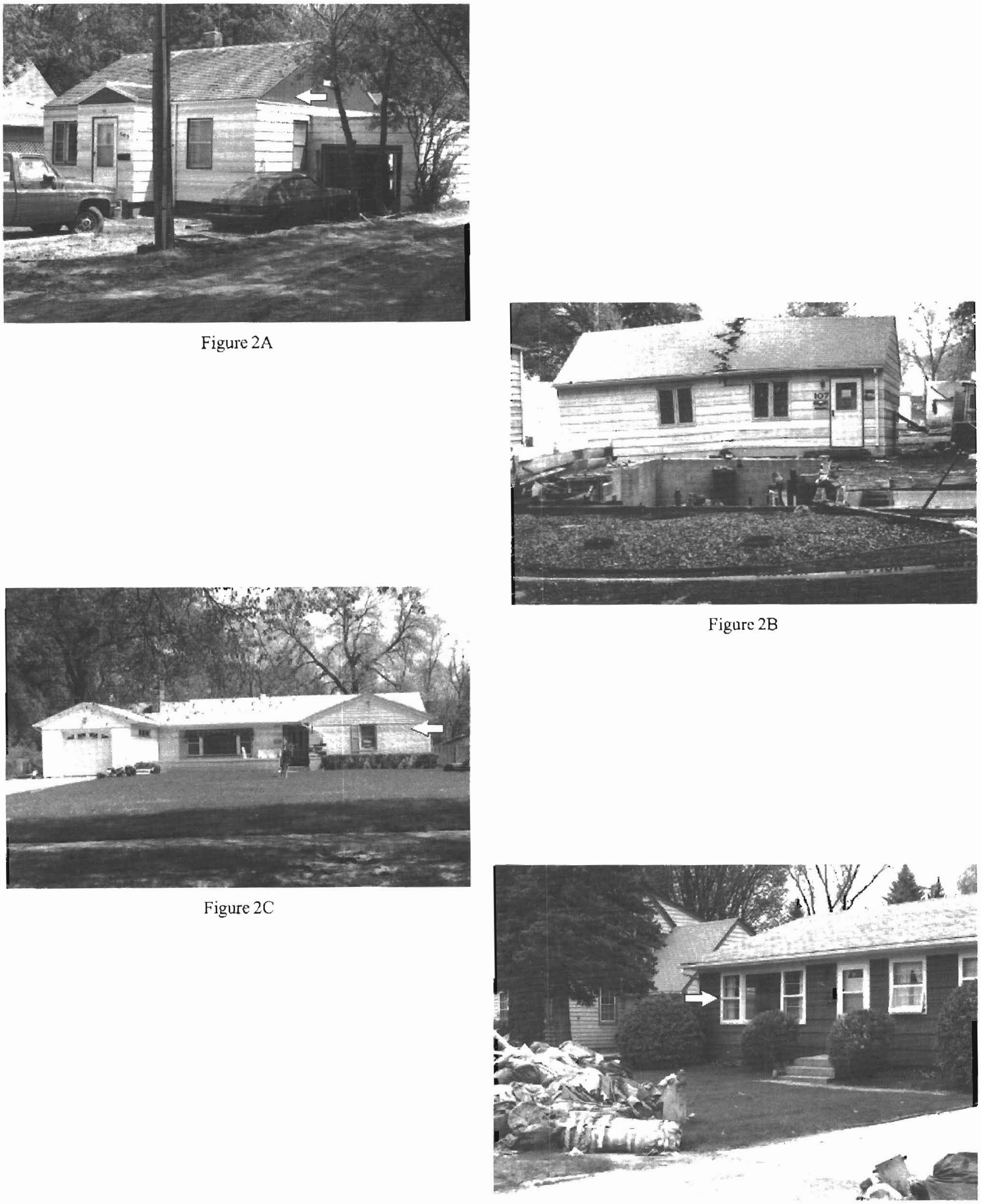


Figure 2A

Figure 2B

Figure 2C

Figure 2D

Figure 2. Loss of personal property was great during the Spring flood of 1997, especially in areas of town closest to the river. Arrows indicate maximum water depth. A) Flooded home and vehicles in the Central Park area, Grand Forks. B) Flooded home on Polk Avenue in the Lincoln Drive area of Grand Forks. The home was completely removed from its foundation by flood waters. C) Flooded home on Lewis Blvd., Grand Forks, in the Riverside Park area. D) Flooded home in the 1500 block of Walnut Street, Grand Forks. Lower elevations are found in the vicinity of this home due to the removal of clays by a brick factory that operated in the vicinity at the turn of the century. (Photos by K. Hollands)

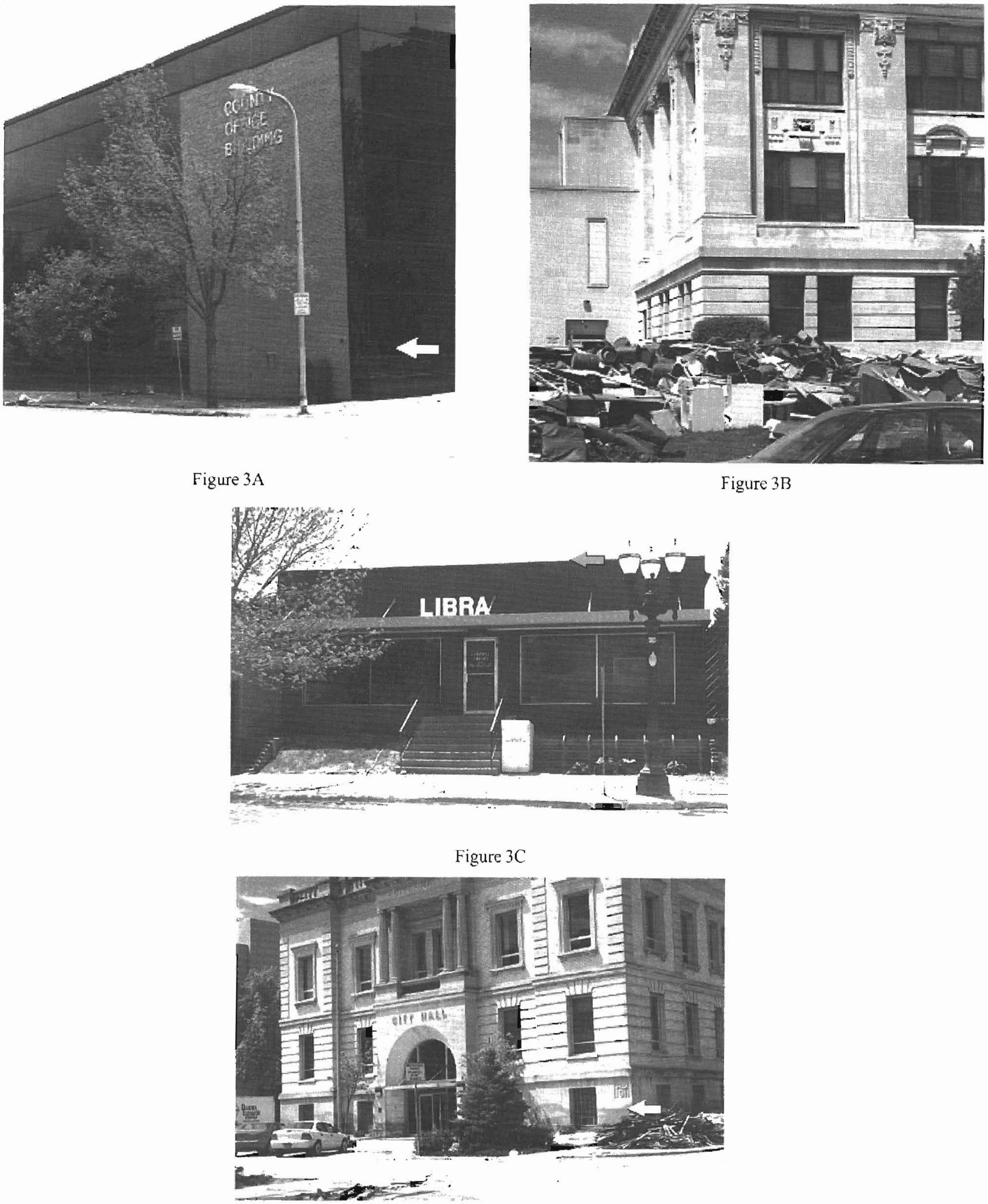


Figure 3A

Figure 3B

Figure 3C

Figure 3D

Figure 3. Government buildings located in the downtown areas of Grand Forks-East Grand Forks were forced to temporarily close or relocate following the flood. Arrows indicate maximum water depth. A) Water damage to the Grand Forks County Office building on 4th Street in downtown Grand Forks made it necessary to relocate the office to Larimore, North Dakota for several months after the flood. B) Debris from the Grand Forks County Courthouse on 5th Street in downtown Grand Forks. C) The East Grand Forks Public Library was submerged by floodwaters. The building has since been demolished and the public library has been relocated to higher ground. D) Photograph of the Grand Forks City Hall with main floor flooding. (Photos by K. Hollands)

Figure 4A

Figure 4B

Figure 4C

Figure 4D

Figure 4. The expense of building massive sandbag dikes can be staggering. Over 3.5 million sandbags were used in Grand Forks-East Grand Forks in fighting the 1997 flood. The volunteer labor that constructed the sandbag dikes usually "dries up" as soon as the crest is reached. Therefore, the expense of cleanup generally lies on the city after significant floods. Because the damage to Grand Forks-East Grand Forks was so extensive during the 1997 flood and the volume of debris was enormous, the cleanup operation was contracted out by U.S. Army Corps of Engineers. A) Sandbag dike behind a house on Belmont Road. Extensive diking around residential areas throughout Grand Forks-East Grand Forks. As previously mentioned, the labor that placed the dikes was unavailable for their cleanup. B) Cleanup operations funded by the federal government worked daily hauling flood debris to the landfill. When the operation was in full swing, it was estimated that 6 million pounds of debris was hauled to the landfill per day (Grand Forks Herald, 1997) C) Debris piles after the flood lined the streets throughout Grand Forks-East Grand Forks. These were commonly 4 to 5 feet high and as wide as the parkway. D) Debris piles were associated with businesses, especially in the downtown areas. (Photos by K. Hollands)

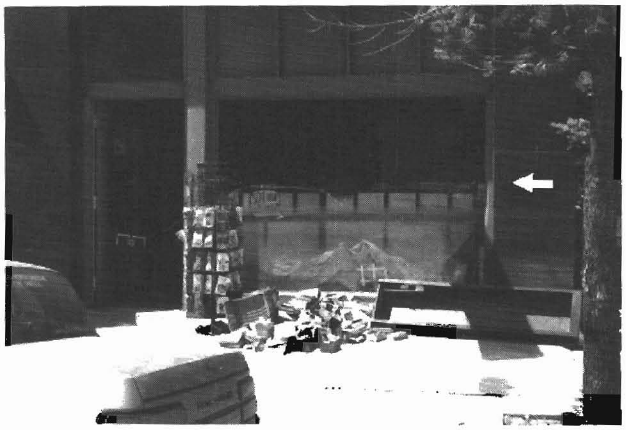


Figure 5A

Figure 5B

Figure 5C

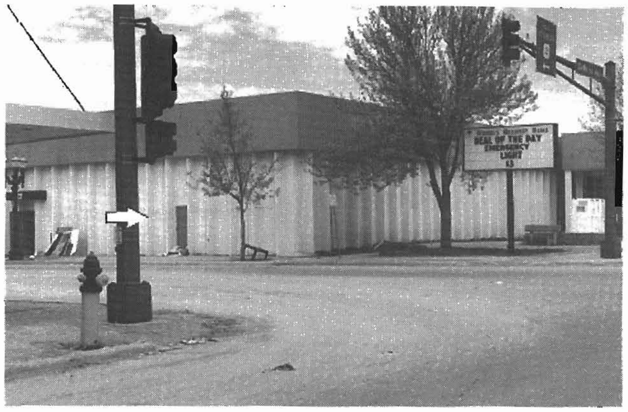


Figure 5D

Figure 5. Business losses were significant through a large portion of the town with damage to structures and merchandise, as well as down time related to cleanup and repair. Businesses in the downtown areas of Grand Forks-East Grand Forks were forced to either temporarily or permanently relocate after the flood. Water levels showing first floor damage to the following businesses: A) Book Fair, downtown Grand Forks, B) Popplers Music Store, DeMers Avenue, downtown Grand Forks, C) American Legion Club, 3rd Street , downtown East Grand Forks, D) Holiday Mall, DeMers Avenue, East Grand Forks. (Photos by K. Hollands)

TABLE 1. Annual flood damage along the Red River.

Flood	Urban	Agricultural	Transportation	Total
1950	42.3	77.4	136.2	255.9
1965	17.0	38.9	11.7	67.6
1966	16.1	47.2	6.3	69.6
1969	23.4	107.5	12.2	143.1
1975 (April)	3.9	38.9	NA	42.8
1975 (July)	19.5	720.5	NA	740.0
1978	3.9	25.8	2.4	32.1
1979	44.3	155.2	16.1	215.6
1997	3600.0	NA	NA	3600.0
Total	3770.4	1211.4	184.9	5166.7

NA - Not Available; $ = millions

The dollar amounts listed in this table are not the same as those mentioned in the descriptions of each flood in the text. This is because they are keyed to the retail consumer price index (CPI) so that a more meaningful comparison can be made of damages attributed to each flood. Adjusting flood losses with the CPI attempts to measure the quantitative loss. The (money) loss of 1979 seems greater than the (money) loss of 1950 because of pure monetary inflation. A 1979 dollar does not buy what a 1950 dollar did so to compare the losses in current terms would be to compare dissimilar units of measurement. Thus, for example, the total damage attributed to the 1950 flood was 33 million dollars (1950 dollars); the total damage caused by the 1979 flood was 91 million dollars (1979 dollars). In terms of constant (1998) dollars the totals became 255.4 million for 1950 and 215.5 million for 1979.

The flood losses were computed in terms of constant, 1998 dollars, using information from the U.S. Department of Labor, Bureau of Labor Statistics, Consumer Price Index, All Urban Consumers - (CPI-U), U.S. city average (5-14-98) < http://stats.bls.gov/ >

Figures for the flood of 1997 are estimates from the U.S. Department of Commerce (1998). The estimates represent the total monetary damage to the Grand Forks-East Grand Forks area for the event.

Bankfull Stage: The height of the water when it is level with the top of the natural banks of the river channel is referred to as bankfull stage. If water rises above bankfull stage, inundation of the floodplain begins.

Breakout Flow or Trans-basinal Flow: At extreme flood levels, water may flow from the main-stem channel into areas where it has never been observed to flow before, including overland flows of water across low points between two streams.

Discharge: The rate of flow of a river past a specific point, usually expressed as a number of cubic feet in a given time, for example, cubic feet per second (cfs). Sometimes expressed as gallons per second.

Flood: A rise in a body of water (such as a river, stream, lake, etc.) that overflows its natural or artificial confines and inundates the adjacent land not normally covered by water.

Normally, a "flood" is defined as any temporary rise in streamflow or stage that results in significant adverse effects in the vicinity. Adverse effects may include damages from water overflowing land areas, temporary backwater effects in sewers and local drainage channels, creation of unsanitary conditions or other unfavorable situations by deposition of materials in stream channels or on floodplains during time of inundation, rise of groundwater with increased streamflow, or other problems. Water standing in fields prior to running off is not considered to be floodwater.

Flood Crest: The highest level that any particular flood attains at a given point along the river is referred to as the "flood crest" or peak of that flood.

Flood Forecast: The flood forecast is an attempt by the National Weather Service to predict a specific flood crest and the date of that crest, based on variable weather conditions. The modeling uses current conditions of soil

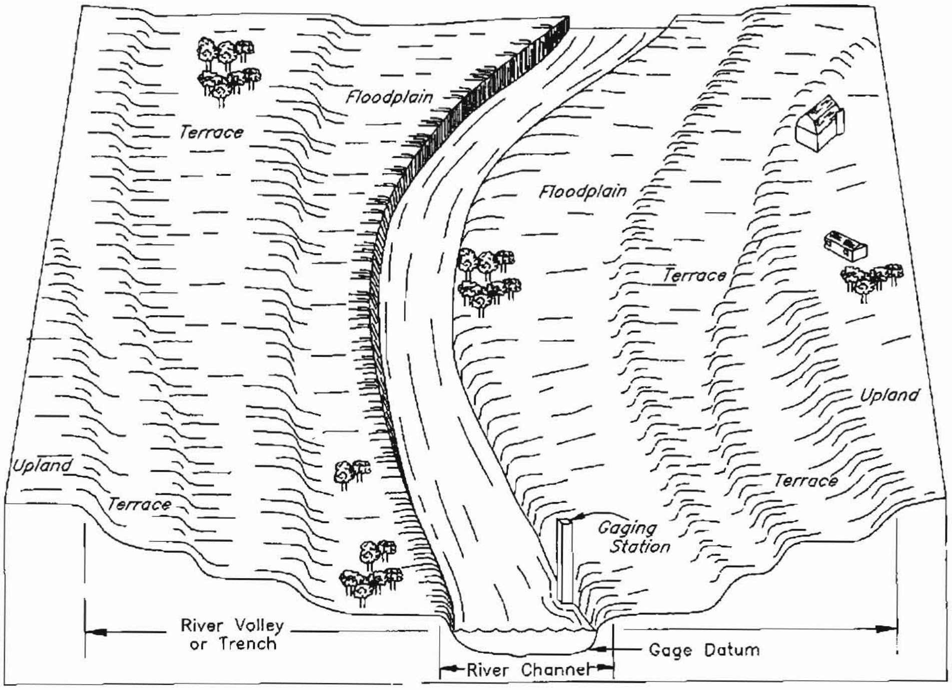


Figure 6. Diagram showing floodplain features.

moisture, frost, snow, stream flow, and river ice. Additionally, a 24-hour precipitation forecast and the daily high and low temperatures for the next five days are factored in.

Flood Outlook: A flood forecasting method by the National Weather Service that is based upon actual conditions before spring runoff. Data used include the amount of snow cover, soil moisture, frost conditions, river ice, and river base flows. Additionally, normal precipitation from the date of the outlook to the end of the normal snowmelt period is considered. Normal temperature sequences for snowmelt and ice breakup are also included.

There is a transition from flood outlook to flood forecast. When the river starts to flood, the forecasts are issued by the National Weather Service as a three-day stage forecast. At this point, the outlook is used to determine the projected crest. The crest forecast is issued when the snowmelt is near completion.

Flood Plain or Floodplain: Again, the definitions vary. In this report, a floodplain consists of the relatively flat land areas bordering a river or stream above the level of the banks. As the name implies, these areas are periodically inundated and become part of the river channel during floods.

Flood Stage: The height of the water at which flooding begins to occur is called flood stage (generally the same as bankfull stage).

Gage Reading: Floods in Grand Forks-East Grand Forks are referred to by numbers such as 44.6, 35.7, etc. These numbers represent the height of the river surface in feet above the reference datum or base of the U.S. Geological Survey gage. The base or **datum** of the Grand Forks gage is 779.00 feet above sea level; thus, the river surface during a 40.00-foot flood crest is 779.00 feet plus 40.00 feet or 819.00 feet above sea level at the gage. Due to the gradient of the river, the water surface at the south end of Grand Forks-East Grand Forks is from ½ to 2 feet higher than the gage reading. The gage readings are roughly equal to the depth of the water in the main channel of the river.

Prior to October, 1962, the river level gage was housed in a concrete tower about 50 feet high located 500 feet downstream from the dam in Riverside Park on the left bank (Grand Forks side) of the river. The gage was moved in April, 1965 to the second floor of the old Grand Forks sewage disposal plant about 1/4 mile north of the old site. In October, 1983, the gage was moved again to its present location. It is currently located on the right bank 200 feet upstream from the DeMers Avenue ("Sorlie") Bridge and 0.4 mile downstream from the Red Lake River. The reference datum of the gage remains at 779.00 feet above sea level.

Gaging Station: A specific location along a river where systematic observations of river elevation, discharge and water quality are made.

Historical Flood: Floods that have occurred during historic time.

Hydrograph: A graph showing discharge plotted against time at a given location, usually measured in cubic feet per second (cfs). The area under the curve indicates total volume of flow.

Intermediate Regional Flood: A flood having an average frequency of occurrence of about 100 years, although the flood may occur during any year. The Intermediate Regional Flood (IRF) is based on statistical analyses of streamflow records available for the watershed and analyses of rainfall and runoff characteristics in the general region of the watershed. There is a one percent chance an intermediate regional flood will occur in any given year.

Left Bank: The bank on the left side of a river, stream, or watercourse, looking downstream (North Dakota side of the Red River).

Operational Flood Forecast: A forecast that considers current river stages, five days of forecasted temperatures, and the amount of precipitation expected through the next 24 hours. The operational forecast is issued daily or more often, if required.

Right Bank: The bank on the right side of a river, stream, or watercourse, looking downstream (Minnesota side of the Red River).

River Channel: The deepest or the most central portion of a stream bed where surface water flows or may flow.

River Valley: An elongate area that is nearly flat and extends for a considerable distance. It is drained or watered by a large river and its tributaries.

Recorded Flood: Floods that have systematic hydraulic data.

Recurrence Interval: The recurrence interval of a flood is the average number of years separating floods of a given magnitude or greater. The recurrence interval value is based on the flood record, which extends back to 1882 in Grand Forks-East Grand Forks. To understand how recurrence interval is computed, assume that a flood 40 feet high or higher has occurred 20 times in the past 100 years. We could expect, therefore, to have a flood at least this high on an average of once in 5 years; thus the recurrence interval of a 40-foot flood would be 5 years. Another way of expressing recurrence interval is to say that the chances of having a flood 40 feet or higher is one in five or 1/5 or 20 percent for every year (using our assumed data). It is important to note, however, that the recurrence interval does not imply that if a 40-foot flood occurs this year, another of that magnitude will not occur for 5 years. This is a common misconception. Rather, over a period of 20 years, about four floods of this magnitude can be expected; when they will occur or how many years will separate them cannot be predicted.

Flooding of an area may be described more accurately by using the height of the river (river stage) rather than recurrence interval. The elevation of the river at various flood stages can be overlain on a topographic base map to determine the possible area of inundation. Multiple layers showing a variety of flood stages can be represented on a single map. The inundated area remains constant because it is based on an actual, gage-based, river elevation and surface topography, not an elevation based on a statistical prediction that changes with each major flood. The use of river stage also helps to eliminate the misconception that multiple, severe floods could not occur in sequential years as implied by the recurrence interval.

Runoff: Runoff is that part of the total precipitation throughout the drainage basin that eventually reaches the river.

Stage: The river stage is the elevation of a water surface above a reference datum. *Synonyms*: Gage height or gage reading.

Terrace: A nearly flat surface along the margin and above the level of the river. It marks the former river level.

Upland: The area of land above flood level.

500-Year Flood: The flood that may be expected from the most severe combination of meteorological and hydrological conditions that are considered reasonably characteristic of the geographical area in which the drainage basin is located, excluding extremely rare combinations. A 500-year flood has a 1 in 500 chance of occurring in any given year.

GEOLOGY AND TOPOGRAPHY

The Red River of the North is formed by the confluence of the Otter Tail and Bois de Sioux Rivers at the cities of Wahpeton, North Dakota and Breckenridge, Minnesota. From this point, the Red River flows northward for a distance of about 294 miles to the Grand Forks-East Grand Forks area and another 98 miles before reaching the international boundary. In Canada, the river continues northward through the City of Winnipeg to Lake Winnipeg, which is drained by the Nelson River to Hudson Bay.

Throughout its entire length, the Red River meanders along the exceptionally flat floor of the lake bed of the former glacial Lake Agassiz (fig. 7). The shape of the valley resulted from the deposition of flat-lying beds of sediment on the old lake floor, not as a result of river action. The floodplain is poorly defined, and high water can spread great distances from the river over fields and municipalities (Stoner et al., 1993). Lake Agassiz drained about 9,000 years ago, when the last of the great Ice Age glaciers melted in this area. When glacial Lake Agassiz was at its maximum extent, about 12,000 years ago, the water was more than 200 feet deep in the Grand Forks-East Grand Forks vicinity and more than 100 feet of clay and silt was deposited on the lake bed (Bluemle, 1991; Harris, 1997). Bedrock lies at an elevation of about 500 feet above sea level in this area, or about 330 feet beneath the two-city area (Hansen and Kume, 1970). Along the margins of Lake Agassiz, wave action at the shore washed the glacial sediment and formed beaches and other nearshore deposits composed of gravel and sand. These deposits are especially prominent near Arvilla and Emerado, North Dakota, and near Erskine, Minnesota. They serve as the only local source of sand for construction of "sandbag" dikes during floods.

The central portion of the Red River Valley in North Dakota is marked by long, almost imperceptible grooves that may have a pronounced influence on flooding in the area (Bluemle, 1991). These grooves can be up to 6 miles long, 3 to 10 feet deep, and 75 to 100 feet wide (fig. 8). Most of them trend northwest to southeast, and are best observed from the air. The grooves probably were gouged by icebergs dragging on the floor of the glacial lake. It is thought that ice-groove marks ("ice-drag marks") may channelize the water present in the fields. The floodwaters enter the groove from the southeast. Water then flows northwestward, following the groove until the elevation is too high for it to flow any farther. It then exceeds the capacity of the grooves and bursts northeastward, either by overpowering the groove or by following a cross groove, and cascades toward the river. In this way, an area may be "hit" by water from two directions, from the ice-grooves and the river.

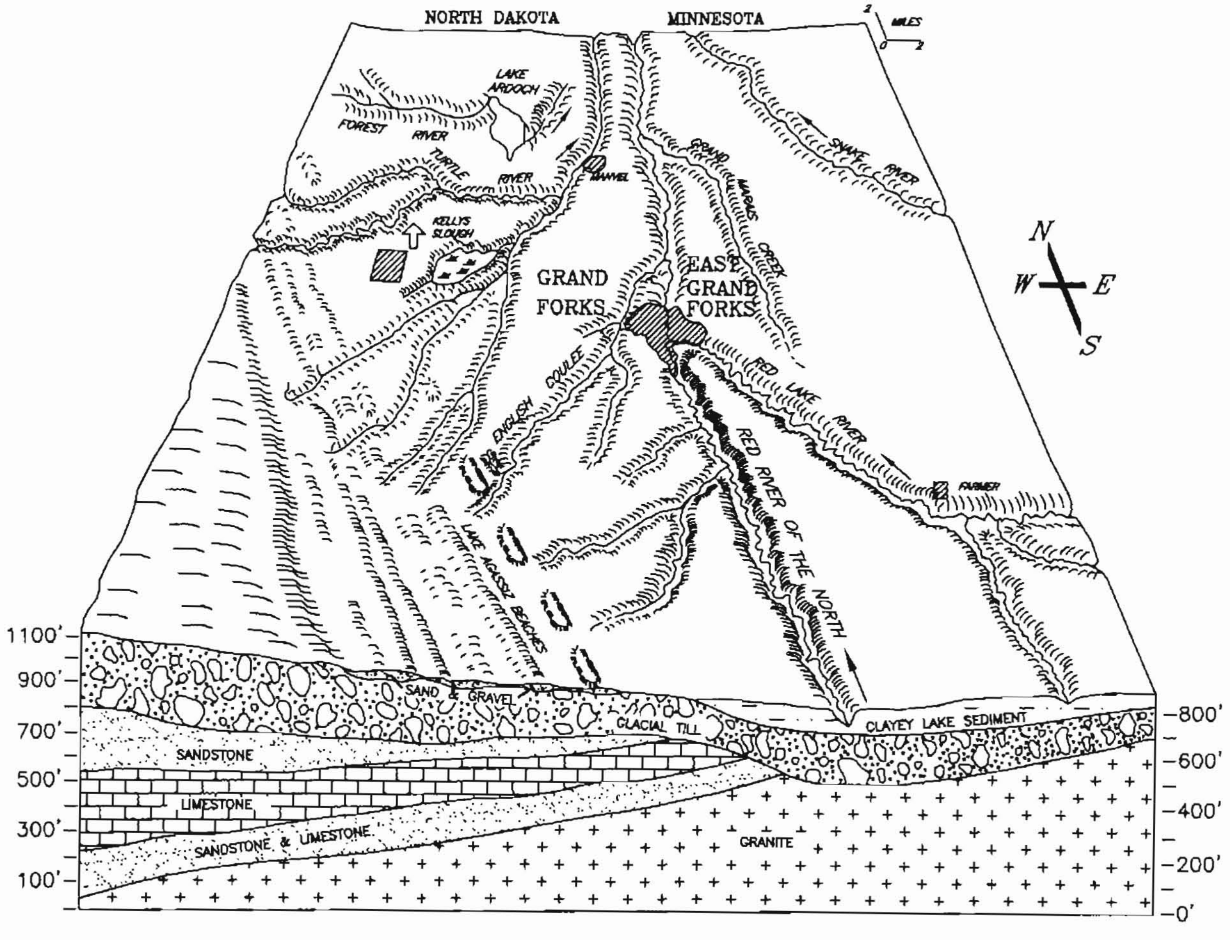


Figure 7. Physiographic map of the Grand Forks-East Grand Forks area showing subsurface stratigraphy.

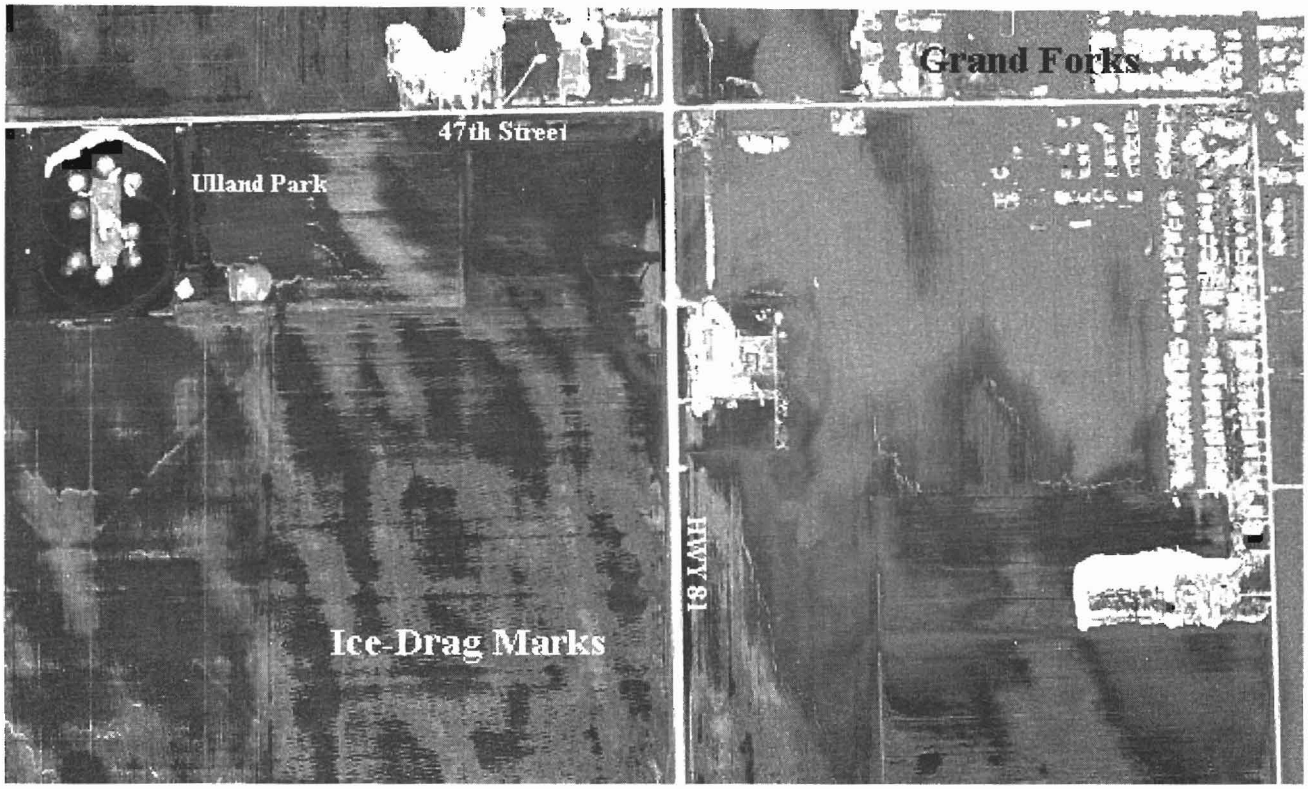


Figure 8. Ice-drag marks south of 47th Street in Grand Forks. The grooves appear on the aerial photo as long, dark (water-filled), linear features trending northwest-southeast. This aerial photo was taken April 21, 1997 by Ag Imaging, Inc. near peak flood. The area northeast of Highway 81, light grey, is inundated by flood waters.

The Red River flows along the axis of the gently northward-sloping bed of the former lake. The gradient of the river averages about 0.5 feet in a mile, ranging from about 1.3 feet per mile in the Wahpeton-Breckenridge area to only 0.2 feet per mile at the Canadian border. At bankfull stage, the channel widths of the river vary from 200 to 500 feet and average depths range from 10 to 30 feet. At Grand Forks-East Grand Forks, the discharge at bankfull stage is about 32,000 cfs; to the north, in the Oslo area, the discharge is only about 23,000 cfs at bankfull stage.

CLIMATE

The Grand Forks-East Grand Forks area receives an average of 18.56 inches of precipitation annually (NOAA-CIRES/Climate Diagnostics Center, 1998; U.S. Historical Climatology Network, 1998), ranging from a low of less than half an inch in December to over three inches in August (table 2). More than three-quarters of the annual precipitation falls between April and September. The remaining quarter, about four inches, normally accumulates throughout the winter as snowfall. Average winter snowfall totals 34.6 inches. As we shall see later, the manner in which the melting of the winter snow cover takes place in the spring is a major factor determining the severity of floods in this area. An average monthly winter temperature (November through March) of 14° F results in the buildup of considerable thicknesses of ice on the rivers, and this can also be an important factor in determining the severity of flooding.

HISTORY AND GENERAL ECONOMY OF THE AREA

The first settlers arrived in Grand Forks in 1870 (Robinson, 1966). They found the land bordering the river a natural place for settlement. The river provided an avenue of transportation, as well as water for themselves and for stock. The floodplain provided timber for fuel and building. Prior to 1900, considerable steamboat traffic served Grand Forks-East Grand Forks, but by 1920 the last of the steamers had disappeared, and transportation on the Red and Red Lake Rivers ceased.

The Red River Valley is predominantly an agricultural area. Crops grown include wheat, small grains, sugar beets, sunflowers, and potatoes. Almost all local industries are dependent on agricultural production. They include beet and potato processing plants, grain elevators, creameries, food-processing plants and other related services. Large manufacturing facilities are scattered throughout the Red River Valley, but the majority of them

TABLE 2. Mean annual and monthly temperatures and precipitation for Grand Forks-East Grand Forks from 1887-1996. Data are from the NOAA-CIRES/Climate Diagnostics Center, U.S. Interactive Climate Pages <http://www.cdc.noaa.gov/> and U.S. Historical Climatology Network <http://cdiac.esd.ornl.gov/epubs/ndp019/ndp019.html>.

	Temperature		Precipitation	
	(°F)	(°C)	(inch)	(cm)
Annual	38.44	3.57	18.56	47.16
January	2.73	-16.26	0.60	1.53
February	7.68	-13.51	0.50	1.27
March	24.50	-5.23	0.74	1.88
April	41.10	5.06	1.25	3.17
May	54.22	12.34	2.13	5.41
June	62.53	16.96	3.02	7.67
July	67.21	19.56	2.34	5.93
August	65.02	18.34	3.26	8.28
September	57.11	13.95	2.05	5.21
October	44.61	7.00	1.00	2.54
November	26.13	-3.26	0.68	1.72
December	9.98	-12.23	0.49	1.25

are located near or adjacent to the Red River itself.

Of the total land in the Red River Valley, 81% is agricultural, with 64% used for cropland (Stoner et al., 1998). About three million acres of forest land are located mostly in Minnesota along the eastern edge of the area drained by the Red Lake River. The forest land accounts for the second largest land use in the Red River Valley.

The flood-prone area of the Red River Valley includes about 600,000 acres. The major land use is agricultural, with cropland occupying 486,000 acres and pasture or rangeland, 60,000 acres. Other uses, such as woodlands, wildlife, urban, and built-up areas, occupy the remaining flood-prone acreage. The cropland of the floodplain is used for growing small grains, potatoes, and sugar beets.

The population of the two cities has increased steadily over the years. In 1997 prior to the April flood, Grand Forks had 49,425 inhabitants and East Grand Forks 8,658. The land-use inventory for the cities of Grand Forks and East Grand Forks (table 3), shows that the space occupied by both cities in 1993 was 10,133 acres of which 34% was designated as residential. Acreage used or zoned for industrial purposes was second to residential at 20%. Government buildings, schools, churches, hospitals, and cemeteries all fall into the category of public/semi-public land use and account for 14% of the total city acreage. The remaining 32% is used for commercial developments, street right-of-ways, recreation or is currently undeveloped.

THE RED RIVER AND ITS DRAINAGE BASIN

The "Red River Valley," through which the Red River of the North flows, is not a true river valley, but rather the broad, flat bed of former glacial Lake Agassiz. The lake bed, although very flat, slopes gently inward at about 3 to 10 feet per mile toward its axis along the North Dakota-Minnesota border. Tributaries such as the Sheyenne, Goose, Turtle, Forest, and Park Rivers in North Dakota flow northeast and the Red Lake, Sandhill, Tamarac, and Wild Rice Rivers in Minnesota flow northwest down the gentle slope of the lake bed to the Red River. Their gradients, controlled by the slope of the sides of the lake bed, are too gentle to permit much active erosion, and they have cut only shallow valleys. The north-south axis of the lake bed slopes about 3/4 foot per mile northward, giving the Red River a low gradient. In fact, the Red River drops only 229 feet in elevation from its headwaters at Wahpeton (943 feet) to its mouth at Lake Winnipeg (714 feet). The gradient is decreased even more by the intricate meanders or twisting of the channel. Between Grand Forks-East Grand Forks and Pembina, the river gradient is less than ½ foot in a mile. Like its tributaries, the Red River is unable to accomplish much erosion with this low gradient. In most places, the banks of the river are only about 25 feet below the surrounding upland.

The Red River at Grand Forks-East Grand Forks is about 200 feet wide and perhaps 8 to 10 feet deep during normal summer flow with banks about 30 feet above the

TABLE 3. Land use in Grand Forks-East Grand Forks (U.S. Army Corps of Engineers, 1998b).

Grand Forks (1992)		**East Grand Forks (1993)**	
Space within City Limits	7325.0 acres	Space within City Limits	2807.9acres
Residential (Total) single-family multiple-family single-family attached; mobile homes	2879.0 acres 2015.3 acres 403.0 acres 460.7 acres	Residential (Total) (single- or multi-family)	577.2 acres 577.2 acres
Industrial (Total) developed zoned	1571.0 acres 519.0 acres 1052.0 acres	Industrial	409.8 acres
Commercial	698.0 acres	Commercial	88.6 acres
Right-of-way/undeveloped	452.0 acres	Right-of-way	630.3 acres
Public/Semi-public	1175.0 acres	Public/Semi-public	271.0 acres
Recreational	550.0 acres	Recreational	360.2 acres
		Vacant	470.8 acres

bottom of the channel. Once water overflows the banks and spreads over the floodplain, however, the river width increases rapidly. During severe floods, the river can be as much as several miles wide just north of the two-city area.

The velocity at which the river flows varies considerably with time and place, and depends on many factors. The velocity is highest during floods. The velocity varies from nearly zero along the sides and bottom of the river channel to a maximum just beneath the surface of the water near the middle of the river. The average velocity of the Red River in Grand Forks-East Grand Forks during the summer is about 1 foot per second (2/3 miles per hour), whereas during floods it probably reaches speeds of 8 feet per second (5½ miles per hour). Compared to other rivers, this flow is relatively slow because of the gentle northward slope of the lake plain.

Flood damage along the Red River is seldom the result of the flow of water and its ice. The velocity may be high within the main channel of the river during floods. However, the velocity is generally low in the flooded reaches bordering the river where damage due to water flow and ice could occur.

The drainage basin of the Red River at Grand Forks-East Grand Forks includes all the land upstream from the two cities that contributes water to the river (fig. 9). Any water running off the land within this portion of the drainage basin (about 30,100 square miles) can flow into the Red River and pass through the two cities.

A one-inch rainfall throughout the basin produces about 70 billion cubic feet of water that could flow past Grand Forks-East Grand Forks (Harrison, 1968). Of the total 19 inches of annual precipitation in the drainage basin, only about 10 percent ever reaches the Red River. The remaining 90 percent is lost, mostly to evaporation and plant use (transpiration). Early spring rains, which often accompany flooding in this area, may produce a much higher percentage of runoff if the ground is frozen or saturated and unable to soak up moisture.

The volume of water that passes through the two cities has averaged about 76 billion cubic feet annually, or 2,432 cubic feet per second since 1882. Harrison and Bluemle (1980) stated that from 1950 to 1980 the average flow was 3,094 cfs. They used this to suggest a trend toward greater precipitation during the 1950-1980, thirty-year period, than during the previous 67 years of record. They also attributed a part of the increase to improved drainage resulting from human activities. The average flow from 1980 to 1996 has been 3,502 cfs. This suggests that the trend toward greater precipitation is continuing and the region appears to be in a relatively long-term wet cycle.

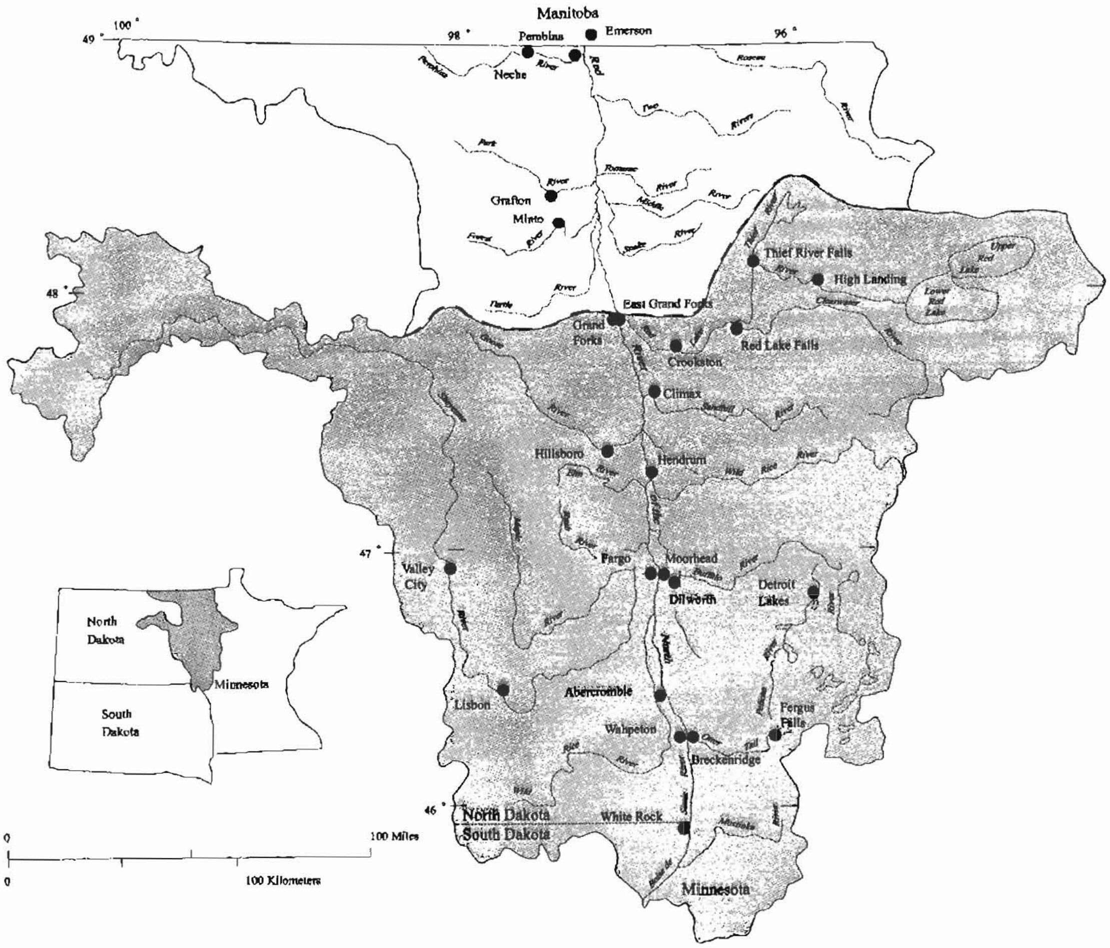


Figure 9. Drainage basin of the Red River at Grand Forks-East Grand Forks.

The increase in farmland drainage over the past few years may also add to the increased flow on the Red River as does urban development of the major cities along the Red River, Fargo-Moorhead and Grand Forks-East Grand Forks. Of the total amount of water passing through Grand Forks-East Grand Forks, the Red Lake River contributes about 40 percent of the flow.

The Red River is a muddy river. Its muddiness, or turbidity, is caused by fine-grained sediment (silt and clay) being carried in suspension in the water. Measurements made during the summers of 1965 and 1966 show that the water in the Red River in this general area contains from 0.008 percent to 0.023 percent suspended sediment (80 to 230 parts per million; Alan Cvancara, personal communication). If 0.015 percent (150 ppm) is an average value, then during a typical summer day more than 1,620 tons of suspended sediment (mud) pass through the two cities. This is like 162 ten ton-capacity trucks filled with mud traveling from south to north through Grand Forks each day during the summer! During peak flows, when the river reaches heights of over 45 feet, more than 34,000 tons of sediment can pass between the two cities in a day. The unusually large amount of suspended sediment in the Red River is eroded from the clays and silts of the lake sediment of the valley. It is likely that modern-day agricultural practices have increased the amount of suspended sediment in the river. Tillage of cropland after the growing season allows the farmer to plant earlier the next spring, but it also increases the potential for soil erosion by wind and water.

Rapidly moving river water can carry more sediment. Examination of the aerial photographs for the flood of 1997 showed a definite increase in the amount of sediment load in the rivers. The Red Lake River is normally less muddy than the main stem Red River. However, significant overland flow over tilled cropland into the Red Lake River during the 1997 flood caused it to be noticeably dirtier than usual.

The Red River abruptly slows down upon reaching the still waters of Lake Winnipeg in Manitoba. The slower river current can no longer keep the sediment suspended so most of it settles to the bottom, forming a delta at the southern end of Lake Winnipeg. Much the same thing happens during floods. When the river water flows into flooded backwater areas, the suspended sediment settles out of the slowed-down water, resulting in a coating of mud when the water recedes.

The river also carries dissolved salts in solution. The amount of dissolved material is measured periodically by the Water Resource Branch of the U.S. Geological Survey at the Grand Forks gaging station. These measurements show that during the 1997 water year (October 1, 1996 to September 30, 1997) an average of 45,533 tons of dissolved solids were carried through Grand Forks-East Grand Forks every day for the months of April and May (Harkness et al., 1997).

Based on available data, water quality in the headwaters areas of the Red River is fair, except where affected by human activity. As the river flows toward the international boundary, the water quality is steadily degraded and appears to be significantly affected by the larger communities. Water entering the Red River, particularly from the North Dakota side of the valley, contains high mineral concentrations of dissolved solids, sulfates, and chlorides (Stoner et al., 1998). Much of the contamination is from mineralized groundwater escaping to the surface from artesian aquifers that subcrop just west of the Red River. In places the escaping groundwater forms ponds or sloughs, such as Kelly Slough or Lake Ardoch (fig. 7). Contamination is also a by-product of erosion, associated with the high suspended sediment load.

The water quality of the Red River is affected by variations in flows in the river and its tributaries. During winter, it is common to have low dissolved oxygen concentrations in the river water when aeration is restricted by the ice and snow cover. In the summer, nutrient-rich agricultural runoff, which consumes oxygen, taken in combination with prolonged periods of low river flow, occasionally produces low dissolved oxygen levels. Such conditions seriously affect surface water supplies of good water, periodically kill fish and other aquatic life, and impair aesthetic and recreational values of the river.

In our previous Grand Forks flood report, we noted that total dissolved solids in the Red River at Grand Forks-East Grand Forks average 565 parts per million (Harrison and Bluemle, 1980). This was higher than the recommended maximum value set by the U.S. Environmental Protection Agency for total dissolved solids in drinking water, which is 500 parts per million. Red River water commonly exceeds maximum levels of state water-quality standards for both North Dakota and Minnesota for fecal coliform, turbidity, and total hardness (Souris, Red, Rainy River Basin Commission, 1972). Reports from the U. S. Geological Survey indicate that, since 1980, the values for total dissolved solids at Grand Forks-East Grand Forks rarely exceed the recommended maximum for drinking water. This decrease may be related, in part, to the increased flow rates in the river since 1980.

FACTORS AFFECTING FLOODING

Flooding in this area is the result of several factors. During the winter, snow accumulates over the entire drainage basin, more than 30,000 square miles of land upstream from Grand Forks (fig. 9). Much of the snow and ice is retained until spring, when it is released, sometimes nearly instantaneously, by melting. The effect is as if the precipitation for several months fell within a few days time. As this water is carried out of the basin by the Red River, at least some flooding usually occurs. The magnitude of the flooding depends on the amount of moisture stored in the drainage basin, how fast it is released by melting, how much can be absorbed by the ground, how much is evaporated, and how much water is added by spring precipitation.

Many factors affect this accumulation-melting-flood relationship. The most important of those factors can be categorized as: "Constant" or "Variable."

"Constant" Factors: Basin and Channel Characteristics

We have already discussed some of the hydrologic and physical characteristics of the Red River Valley. The gentle northward slope of the river results in low streamflow velocities. As a result, the area drains slowly. Moreover, the flatness of the lake bed allows floodwater to spread out over a large area. The pooling associated with slow drainage increases the likelihood of flooding. The ability to contain this water before it spreads out determines the severity of the flooding. This is shown by previous floods. Efforts that successfully contained the floodwaters in 1979 proved unsuccessful in 1997, greatly increasing the damage.

Some of the effects of the northerly flow direction of the Red River have already been mentioned. However, the northerly flow of the river plays an important part in flooding and should probably be reviewed. Its principal effect is on the timing of the thaw. Areas to the south (upstream) may start melting long before northern areas start to thaw, and this allows water to flow northward into a frozen area, resulting in ice jams, and other problems (Bluemle, 1997).

Obstructions such as bridge foundations restrict the flow of water by constricting the channel and greatly increasing the likelihood of ice jams. The four bridges in Grand Forks-East Grand Forks can increase river stages up to a foot during severe floods (Miller and Frink, 1984; Department of Commerce, 1998). Although dikes do, in many cases, prevent floodwaters from inundating lowlands along the river, they also tend to restrict the river to a narrow, artificial channel. The net result is an increase in the height of the river just upstream from the dikes as the water is forced through a relatively narrow neck in the channel during floods. At high water levels this can be a crucial factor in determining the severity of flooding.

Artificial drainage ditches facilitate draining of valuable farmland, but they also result in faster and more complete transfer of rainfall and snowmelt to the river. Water that was once stored on the flatlands bordering the river is now poured into the river during the critical spring thaws at a rate faster than through the tributaries. The Red River Valley in North Dakota and Minnesota has more than 28,000 miles of legal, manmade ditches facilitating more rapid runoff (Bluemle and Harrison, 1980; Bluemle, 1997).

Drainage of wetlands and farmland is widely thought to decrease natural basin storage and increase runoff thereby increasing the flood hazard. However, Miller and Frink (1984) find no conclusive evidence for a change in flood response due to basin-wide land-use changes in the Red River Valley. Similarly, Galloway (1995) concluded that extensive restoration of wetlands would likely impact only minor flood events, such as a 25-year flood, not the high magnitude floods like the one in 1997.

The rural road system can also play an important

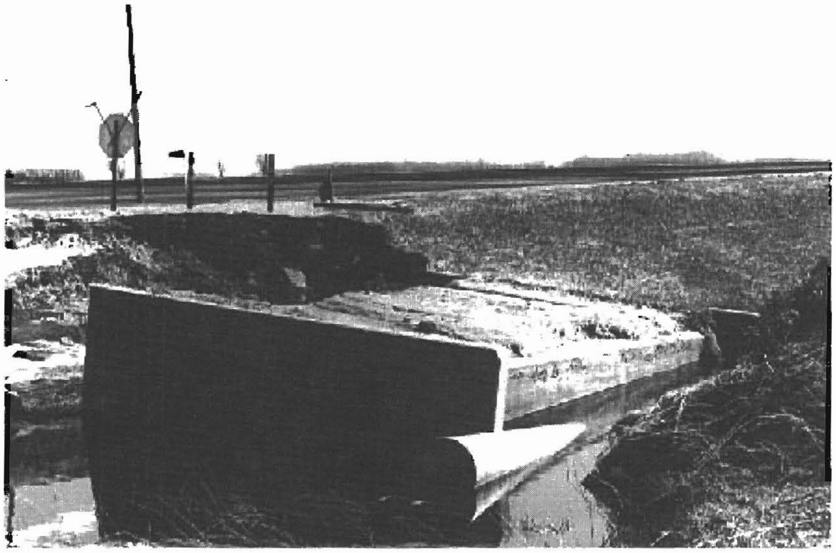


Figure 10. Damage to rural roads south of Grand Forks. A small bridge at the northeast corner of a section was washed out when floodwater breached the road surface. The lower photo shows how the gravel has been washed off the road into the ditch north of the road. (Photos by J. Bluemle)

role in determining the manner in which meltwater runs off the land. In many places where culverts are too small to handle a large flow, water becomes dammed against the roads, forming lakes in the lowest corners of the sections (northeast in North Dakota; northwest in Minnesota). Water then flows over the roads, washing out bridges and stripping the gravel off the road surface or even washing out the roads (fig. 10). Following the 1997 flood, it was proposed to utilize this configuration in the drainage by developing a "waffle" storage pattern. This plan would utilize the road system to store water for a time, releasing it only after the danger of flooding had passed.

The expansion of urban areas has resulted in a decrease in the area available for infiltration (seepage into the ground), and it has increased the speed with which an area can drain, as a result of streets and sewers. The expansion of urban areas into flood-prone areas means the cities are automatically at a greater risk during a flood.

"Variable" Factors: The Weather

It is the interplay of climatological factors from year to year that determines the magnitude of individual floods. Flooding can occur at any time of the year that temperatures are generally above freezing, but in the Red River Valley, flooding usually occurs in early spring (fig. 11). The high concentration of floods in late March and April is caused by the sudden melting of snow and ice, which accumulated throughout the winter. Flooding can also occur in the summer months after an especially heavy rainfall over a large portion of the drainage basin. "Summer floods," however, seldom reach the flood stage of 28 feet and thus have little direct effect on the two cities.

Since 1882, only two floods over 40 feet have occurred later than April. One of these occurred in 1950, as floodwaters were receding from the April crest of 43.9 feet. An early May blizzard forced the river back up to a second crest of 45.6 feet. The second major summer flood occurred in July 1975, following an extremely heavy rainfall in southeastern North Dakota in late June. The July 14 crest was 43.08 feet. The flooding season is dependent on factors involving temperature and precipitation, which are discussed below.

1. Snow Accumulation. The history of flooding in the Red River Valley shows that nearly all large floods were preceded by unusually heavy winter snowfall (fig. 12) or late spring precipitation, or both.

2. Thaw Rate. Following a winter of unusually heavy snowfall, the factor that then becomes most important in determining whether or not a large flood will occur is the rate at which the snow melts. The shorter the melt-

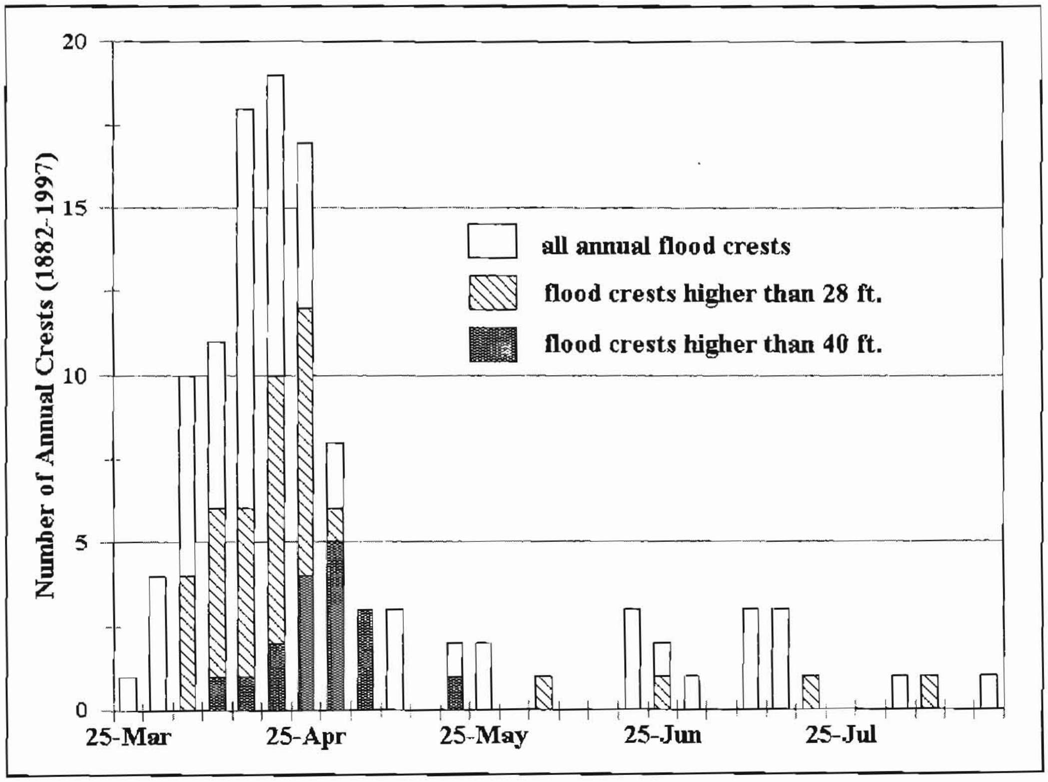


Figure 11. Time distribution of annual flood crests at Grand Forks-East Grand Forks.

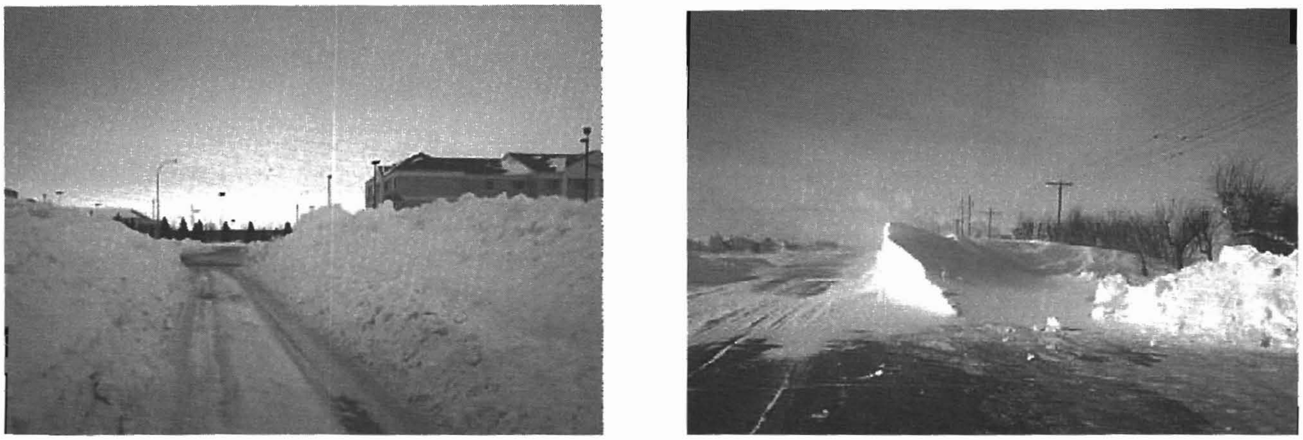


Figure 12. Photographs of snow amounts (1997). (Photos by K. Hollands)

ing period, the greater the flow on the river must be to carry the meltwater away. Cool days with temperatures in the low 30s and night temperatures below freezing allow for slow release of the meltwater. However, an unusually cool or late spring with temperatures remaining below freezing is likely to be followed by a sudden warming trend, which causes a rapid release of moisture. Floods occurring after April 15 are apt to be more severe than are earlier floods (fig. 11).

3. Precipitation During Thaw. The amount and kind of precipitation that falls during the thawing period is also important. Any precipitation, even snow, increases the quantity of water that must be drained by the river. Moreover, a warm rain during the thawing period results in much faster melting of snow and ice on the ground than does warm air.

4. Timing of Crests. The drainage basin of the Red River at Grand Forks-East Grand Forks is divided between the Red Lake River to the east and the Red River south of Grand Forks. In fact, the Red Lake River can typically account for as much as half of the flow during a flood; the Red Lake River supplied 45% of the flow during the 1997 flood (U.S. Department of Commerce, 1998). The timing of the flood crest on each of these rivers is controlled by factors within their respective drainage basins. If the crests from both rivers reach the two-city area at the same time, as occurred during the 1997 flood, the flood hazard is considerably increased.

5. Condition of the Soil. If heavy rainfall occurred in the fall of the previous year, the soil within the drainage basin is saturated with moisture when it freezes. It is therefore able to soak up very little moisture during the spring thaw. A wet fall, then, contributes to spring flooding by increasing the percentage of early spring moisture that must be carried by the rivers.

Like saturated ground, frozen soil is unable to soak up moisture, increasing the percentage of runoff into the rivers. The colder the winter, the greater the depth of frost penetration into the soil, and the slower the ground will thaw in the spring, thus providing a greater amount of runoff to contribute to flooding. In Grand Forks the average depth of frost penetration is 4.5 feet, but it can be as deep as 7 feet (Jensen, 1974). The coldness of the winter also affects the amount of snow remaining when the spring thaw arrives.

Problems also occur when there is an early, significant snowfall. The heavy snowfall insulates the ground from deep freezing. This occurred in the winter of 1996-1997. An early snowfall, the first of many blizzards, occurred on November 16-17, 1996 resulting in 12 inches of snowfall and a snow accumulation of 13.6 inches. The record snow accumulation prevented the ground from freezing. Frost depth for the Grand Forks-East Grand Forks area in February, 1997 was only 1 to 3 feet, far below average. Besides making it difficult to get around because of the muddy substrate during the spring thaw, the thawed ground also affected the dikes. The fact that they weren't frozen removed some of the structural stability needed for sandbagging operations.

The soil in the area can also seal itself causing increased runoff. As water flows over the area, the clay-rich particles swell and seal the underlying beds from infiltration. If water stands, then the particles dissociate and infiltration occurs (Bluemle, 1997). This is most likely to be a problem if the thaw is rapid, resulting in melting and quick runoff.

6. Ice Thickness. An unusually cold winter, especially if early winter snowfall is light, results in greater-than-average thickness of ice on the rivers. The thicker the ice, the longer it will remain on the river in the spring. Until the ice is cleared from the river, flow of floodwaters is impeded and the threat of ice jamming remains.

Summary of Factors Affecting Flooding

From the above discussions, it can be seen that the optimum (worst) flood conditions for the Red River are: (1) an unusually wet fall, (2) an unusually cold winter, (3) unusually heavy winter snow accumulation, (4) an unusually late, cool spring followed by a sudden warming trend, and (5) widespread, heavy, warm rainfall during the thawing period. No one of these factors alone is likely to cause a large flood. It is the interplay of all of them that determines just how large each spring flood will be.

FLOOD HISTORY OF GRAND FORKS-EAST GRAND FORKS

Pre-1882 Era

Information concerning floods in this part of the Red River Valley prior to 1882 is meager. A Selkirk resident, Alexander Ross, wrote about the 1825 flood. In his account, Ross discussed the large quantity of snow and the late spring with a "sudden burst of warm weather." The rapid melt resulted in the Red River and its tributaries overflowing their banks. Large quantities of water and ice moved downstream towards frozen Lake Winnipeg. The flow stopped when it encountered the lake ice, flooding the area upstream with back water. Based on reports from early settlers in the Selkirk Colony, the Red River likely reached even higher levels in 1776 and 1790 than it did in the first 50 years of the 19th Century.

Geologist David Dale Owen, traveling north on the Red River in 1848, noted that "Below the mouth of the Red Fork (Red Lake River)... is found evidence of the power of ice in this river (Red River of the North) during the winter season. Fifteen, eighteen, and even twenty feet above the level of the river, in July, we observed the trees on the brink of the river, either barked or deeply cut into, and even entirely severed across" (Owen, 1852). The debarking of trees, which he noted, was probably caused by blocks of ice floating in the floodwaters during spring breakup floods.

During 1853, no farming was done in the Red River Valley in the vicinity of Pembina because of the floods of the past three years (1851, 1852, and 1853). The 1852 flood is estimated to have reached a height "more than 52 feet" above our present Grand Forks gage datum, higher than any subsequent flood recorded except 1997 and quite possibly higher than that (U.S. Geological Survey, 1952; Miller and Frink, 1984). The worst floods known along the Red River occurred in 1824, 1825, and 1826. In 1826, the water rose to a height of 66 feet above the modern datum level near Pembina (the 1979 flood reached 53.7 feet in that area; the 1997 flood was 54.94 feet), drowning out all the land. This flood was attributed to a heavy winter snowfall, a cold winter, and rapid melting of snow and ice in April. Floodwaters did not recede until late July in 1826, and even the bison disappeared from the Pembina area.

1897: Flooding at the Turn of the Century

Grand Forks was settled about 1870. By 1882, a river-level gage had been installed near the Northern Pacific railroad bridge and accurate records of subsequent floods have been kept since then. The highest recorded flood in Grand Forks-East Grand Forks prior to 1997 occurred in 1897, when water rose to a height of 50.2 feet above the gage datum (fig. 13).

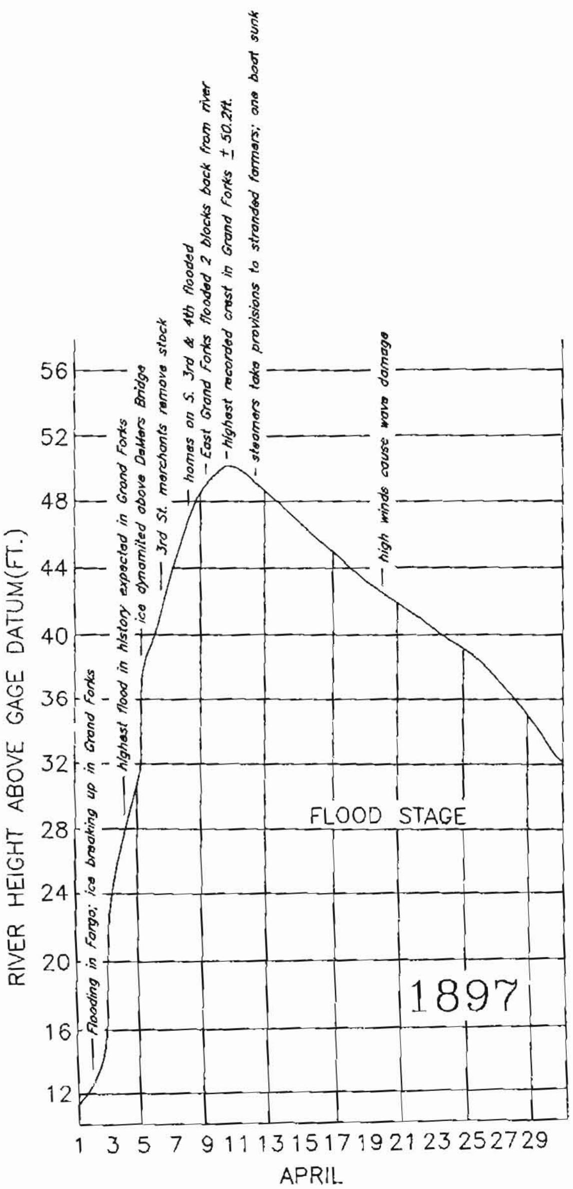


Figure 13. Hydrograph of the 1897 flood.

Figure 14. 1897 flood; view east from the Sorlie Memorial Bridge in East Grand Forks. Photo owned by Charles Garvin, Grand Forks.

Several severe blizzards during the winter of 1896-1897 produced a heavy snow accumulation with drifts as deep as 20 to 30 feet, which nearly covered many houses. Warm weather came suddenly the following spring, and snowmelt water rushed into the rivers. The swift breakup produced ice jams, which increased flood stages. In the resulting flood, much of Grand Forks and East Grand Forks was inundated (fig. 14), many livestock were lost, and small buildings were washed from their foundations.

During the 1897 flood, a strip of land 30 miles wide and 150 miles long was inundated (Bavendick, 1952). Railway and vehicular bridges connecting the two cities were badly damaged and nearly lost. Four locomotives had to be placed on the Great Northern railroad bridge to keep it from being washed completely away. About 25 city blocks of cedar-block paving were damaged in Grand Forks and, in East Grand Forks, business had to be suspended in all but a half dozen places. Water there was three feet higher than in 1882 when a steamboat landed on Third Street. Boats of all kinds were in great demand and many were hurriedly constructed during the flood. Steamboats carried provisions to stranded valley farmers; one of Grand Forks' two steamers was sunk on such a mission.

1950: One Flood, Two Crests

The 1950 flood is the eighth highest on the official record in Grand Forks-East Grand Forks, cresting at 45.61 feet above gage datum (fig. 15). Losses throughout the valley were estimated at $33,000,000 (about $223 million

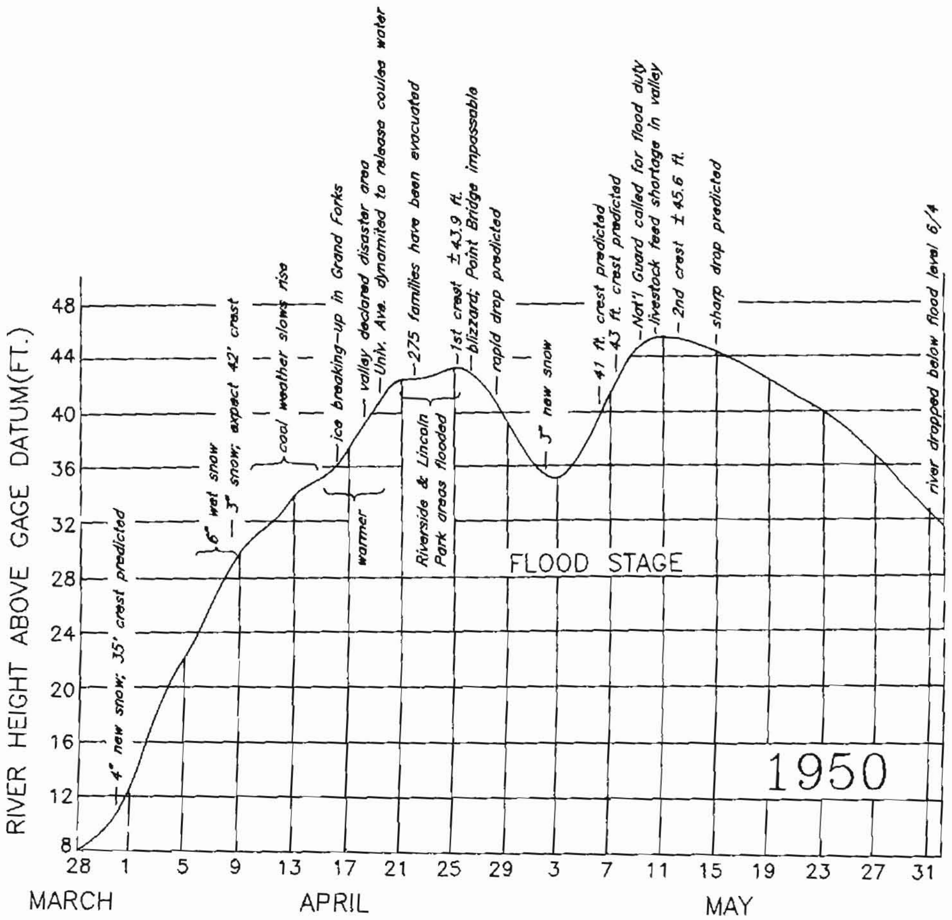


Figure 15. Hydrograph of the 1950 flood.

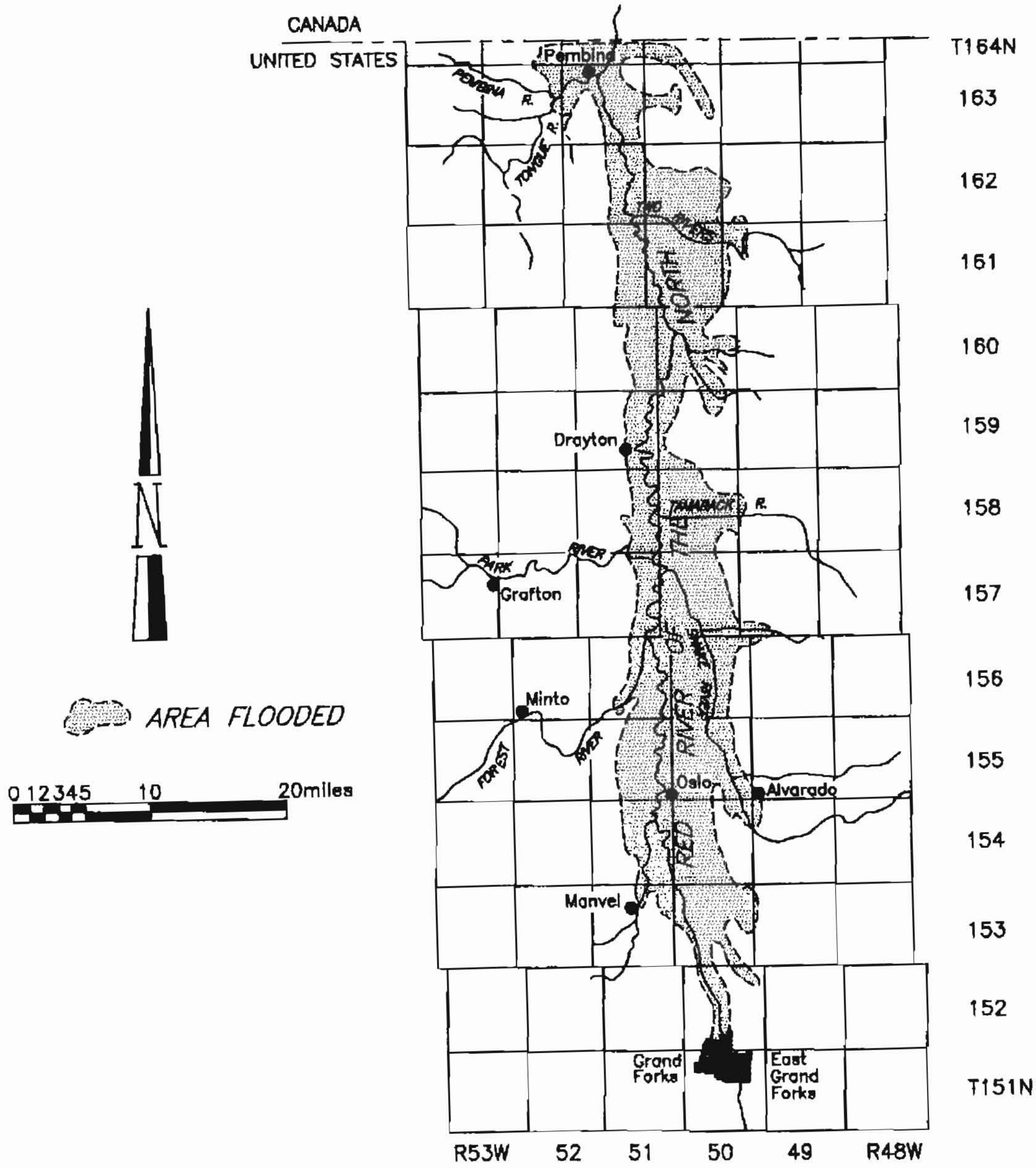


Figure 16. Area flooded between Grand Forks-East Grand Forks and the Canadian boundary during the 1950 flood.

1998 dollars). This flood was preceded by unusually heavy winter snowfall, later-than-normal spring melting, and heavy spring precipitation (Bavendick, 1952). In places, the valley was flooded to widths of 30 miles (fig. 16). In Grand Forks, 275 families had to be evacuated. Just as the first crest of the flood was receding in early May, heavy rain once again swelled the river, making this the longest duration flood on record in this area. Due to the prolonged flood, a critical livestock-feed shortage developed throughout the Red River Valley.

1965: Little Time to Prepare

In 1965, during the second week of April, the Red River began a sudden rise, peaking at 44.9 feet on April 17. The 1965 flood was triggered by heavy, widespread rainfall on deeply frozen soil. Damage was especially high in East Grand Forks, despite construction of an emergency dike consisting of over 400,000 sandbags. More than 400 civilians, students, and airmen were needed to maintain and watch these dikes, which cost an estimated $182,000. In Grand Forks, the cost of dike construction, cleanup, and sewer repair totaled $26,000. Both cities were reimbursed for these losses by the Federal Office of Emergency Planning. Damages to all urban areas along the Red River during the 1965 flood amounted to over $3,000,000. Total flood damage in the Red River Valley was $68.1 million dollars (1998 dollars).

1966: Spring Blizzard

Following the blizzard of March 3, 4, and 5, 1966,

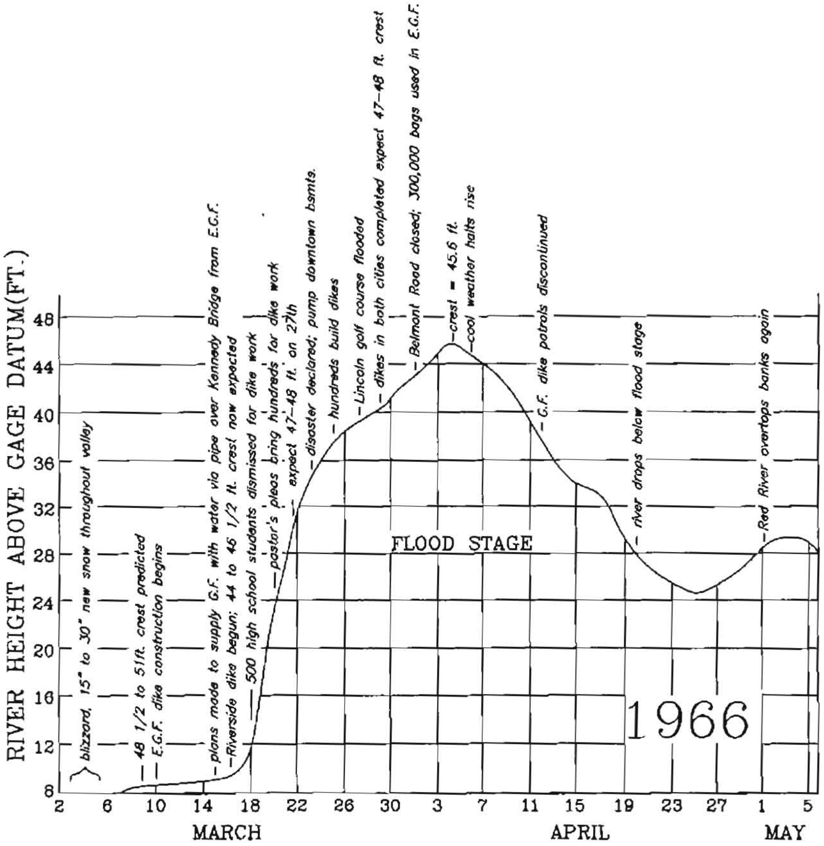


Figure 17. Hydrograph of the 1966 flood.

which dumped more than two feet of snow throughout the area (Grand Forks received about 31 inches) a prediction for a 48½- to 51-foot crest was issued by the Weather Bureau. Dike construction began immediately in both cities in anticipation of a near record-setting crest. Cool weather caused slow melting reducing the predicted flood threat to about 47 feet by the time dikes were completed. An eventual crest of 45.55 feet on April 4 (fig. 17) marked the third-highest flood recorded in Grand Forks-East Grand Forks to that time (currently ranked ninth) and the second severe flood in two years. Although it was only about a half foot higher than the 1965 flood, the cost of flood protection and damage was about 20 times as great as in the preceding year. Reasons for this are probably (1) the crest was originally predicted to be as high as 51 feet, which necessitated building much higher temporary dikes than those of 1965, at a far greater cost; (2) some existing dikes had to be made higher to accommodate the higher crest prediction; and (3) the slow rise of the floodwaters permitted much more extensive diking than in the previous year, again at greatly increased cost. Reimbursement to Grand Forks by the Office of Emergency Planning for dike construction, cleanup, and sewer damage amounted to $555,907 ($2.8 million 1998 dollars). Similar payments to East Grand Forks totaled over $500,000 ($2.5 million 1998 dollars).

1969: A New Record for the 20th Century

Heavy snowfall from October through February, during the winter of 1968-1969, resulted in far greater than normal snow water content ranging from three to seven inches as of March 21, 1969. The heavy snow cover began to melt in late March, but it stopped melting during the first week of April when cold weather moved in. The resumption of melting during the second week of April was accompanied by widespread rainfall of one to two inches. The resulting runoff produced a crest of 45.69 feet, the record flood of the century to that time on the Red River and along most of its tributaries as far downstream as Grand Forks. During the 1969 flood, approximately 790,000 acres of farmland were flooded in North Dakota and Minnesota. Total damage throughout the Red River Valley was calculated at nearly $146 million dollars, of which $107 million was agricultural damage (values in terms of 1998 dollars).

1975: Two Separate Floods

In 1975, Grand Forks-East Grand Forks experienced both spring and summer floods. The April flood resulted from snowmelt and the July flood occurred as a result of rainfall ranging from 10 to 22 inches falling on already saturated soils during the period from June 28 to 30 (the 22-inch rainfall figure was recorded at Leonard, North Dakota). The July flood was far more disastrous than the April flood as thousands of acres of small grains and specialty crops were inundated, with crop losses running to several millions of dollars. Stagnant waters remaining after the flood subsided promoted mosquito infestations with the associated health hazard of infectious encephalitis. At least two deaths were directly attributed to the disease.

The first of the two 1975 floods occurred during mid to late April with the crest on April 23 at 43.30 feet. Several small communities in low-lying areas were flooded, and some of the larger cities suffered relatively high property damages. Urban damages throughout the Red River Valley were estimated at approximately $1,300,000 ($3.9 million 1998 dollars). North of Grand Forks-East Grand Forks, floodwaters overflowed agricultural areas, inundating flood-plain areas up to 10 miles wide where normal bank-to-bank widths are only 75 to 100 feet. The total flooded area was estimated at 240,600 acres. The 1975 spring flood caused about $12,900,000 of rural damage. In addition to crop losses, many farmsteads were completely surrounded by floodwaters, and some secondary roads were impassable.

The July flood occurred from June 28 through July 15, cresting in Grand Forks-East Grand Forks at 43.08 feet on July 14. It began without warning, the result of the heavy rains mentioned earlier. Several small towns on tributaries to the Red River suffered heavy flooding and high property losses. The total area inundated in the Red River Valley by floodwaters from both overbank and overland flooding during the July flood was estimated at 2,028,000 acres. Red River Valley area urban and rural damages were calculated at approximately $6,400,000 and $238,800,000, respectively ($19.3 million and $721.3 million 1998 dollars). Of the rural damages, approximately 2 percent were to transportation facilities, 53 percent to crops, and

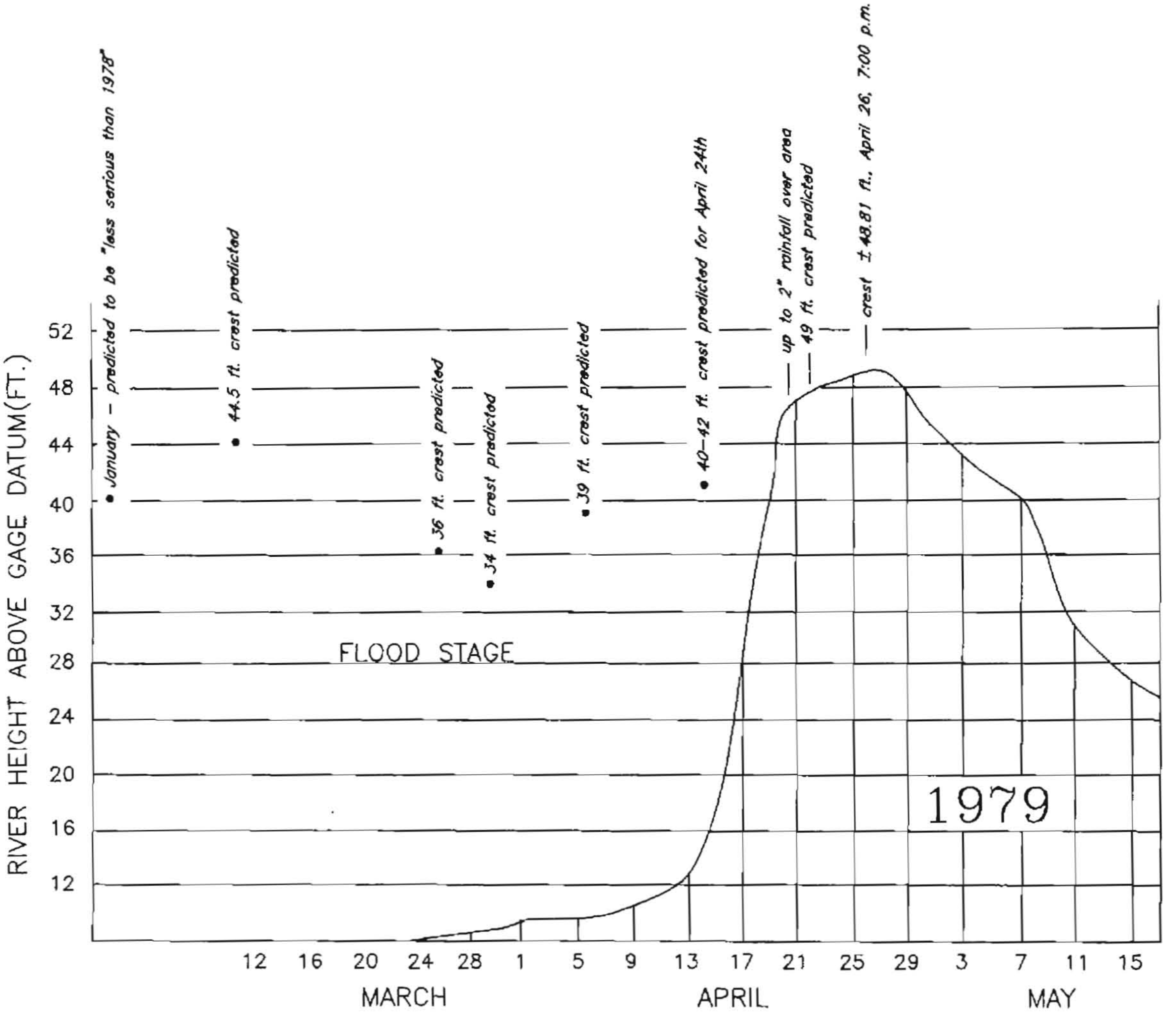


Figure 18. Hydrograph of the 1979 flood.

45 percent to farmstead properties such as buildings, machinery, and stored grains.

1978: Time to Prepare

Data on snowfall amounts, water content, soil temperature, and associated information collected during the winter of 1977-1978 led the National Weather Service to issue an initial flood outlook in mid-February indicating potentially serious flooding along the entire Red River and several of its major tributaries. This advance forecast gave federal, state, and local officials time to make emergency preparations before the flood, which spanned the period from March 24 to April 18. Several tributaries of the Red River were subject to flooding, and moderate flooding occurred along the Red River from Wahpeton-Breckenridge northward to Grand Forks. In the Grand Forks-East Grand Forks area, however, the flood was the highest of the century to that time (45.73 feet) and downstream at Oslo, Minnesota, the 1978 flood levels on the Red River were the highest ever recorded. North of Grand Forks-East Grand Forks, floodwaters spread out five miles wide, inundating farmland, roads, and rural homes. The agricultural levees on the Minnesota side were generally effective, but North Dakota levees were either breached, overtopped, or outflanked by floodwaters from the Red River tributaries on the North Dakota side. In the Red River drainage basin, a total of 553,000 acres of land were flooded. The 1978 spring snowmelt flood caused about $13,000,000 in damages ($32.4 million 1998 dollars). Approximately 80 percent of this was sustained by the agricultural segment of the economy. The flood also claimed two lives. Advance planning, accurate forecasting, and emergency protective measures helped to minimize flood losses in the urban areas.

1979: The Worst Yet

The soil throughout the Red River drainage area was reported to be low in subsurface moisture prior to the first snowfall in November 1978. This condition would normally have helped minimize flooding. However, several factors combined to more than offset this single favorable factor. The winter of 1978-79 was unusually long and unremitting, with above-normal snowfall and a very late thaw. Winter unofficially arrived on November 10, with snow and cold. Except for a few days in mid-December, temperatures were below freezing continually for about five months. The Grand Forks-East Grand Forks area received about 54 inches of snow, about 20 inches more than normal, during the winter. This was equivalent to about 5 inches of water in the snowpack when the melt began during the second week of April, about a month later than usual. Virtually all of the snow that fell through the winter was still on the ground when the spring thaw arrived. The base of the snowpack had been transformed into a layer of ice several inches thick. Finally, nearly two inches of rain accompanied the mid-April thaw and very little sunshine was available during the thaw to help evaporate snow and runoff.

When temperatures rose suddenly into the 50s and 60s on April 16, the snow cover melted rapidly. Apparently, much of the water from the melting snow flowed over the frozen ground and over the basal icepack so rapidly that almost none of it was absorbed by the supposedly dry subsoil. Furthermore, the very rapid melt immediately saturated the uppermost fraction of an inch of topsoil wherever ice was not present. This resulted in swelling of the clay-rich soil, forming an essentially impermeable seal at the top of the soil zone. The meltwater flowed over the sealed soil surface instead of replenishing

Figure 19. Belmont Road at the 1300 block. View south during the 1979 flood. (Photo by J. Bluemle)

the subsoil moisture supply. Had the melting been only slightly less rapid, the swelling of the surficial clay layer would have been much less effective in forming a seal. It would have dissociated and broken down, allowing a far greater percentage of the water to penetrate the soil zone. The soil did become saturated in areas where the runoff water accumulated, against the south and west sides of roads in the northeast corners of nearly all sections.

The April 1979 flood was characterized by an extremely rapid rise of the Red River (fig. 18). The crest of 48.81 feet came on April 26. Many farmsteads and communities, for example, Warren, Minnesota, and Emerado, North Dakota, were inundated by "flash" floods of runoff water from nearby fields, not by the river itself. In Grand Forks, the rapid runoff caused a severe flood on the English Coulee, a situation that few people anticipated.

Flooding in 1979 was severe in parts of Grand Forks that had not often been greatly affected by past Red River floods (area inundated by the 1979 flood is shown on figure 24). Parts of Belmont, Walnut, and Chestnut Streets at 15th Avenue South were flooded (fig. 19) when the lift station failed. Water backed up across South Forks Road (32nd Avenue South) near Schroeder School, flooding parts of the Terrace Drive area, the President's Park Trailer Court, and the Sleepy Hollow area.

The 1979 Red River flood resulted in damages of $91,000,000 ($203.7 million in 1998 dollars) in North Dakota and Minnesota. Damage to City of Grand Forks property was estimated at $1.2 million ($2.7 million in 1998 dollars). The flood drove an estimated 7,500 people from their homes in North Dakota alone; 6,000 North Dakota residences were damaged by the flood. Five million sandbags were used in the two cities during the flood and costs of fighting the flood totaled over two million dollars. Reimbursement to Grand Forks by the federal government for costs of repair and flood-fighting efforts amounted to approximately $1,300,000 ($2.9 million in 1998 dollars). Similar payments to East Grand Forks total about $1,000,000 ($2.2 million in 1998 dollars).

Other Floods

The English Coulee is an intermittent stream that enters Grand Forks from the southwest, flows through the University of North Dakota campus, and joins the Red River about a mile north of the State Mill and Elevator (fig. 20). Before the Grand Forks area was settled, the English Coulee drainage basin included the 115-square-mile area immediately southwest of Grand Forks. The English Coulee, along with other natural drainage ways in this area, trends generally northeastward or east-northeastward. However, the shape and characteristics of the original drainage basin have been altered by the addition of several drainage ditches and by the construction of roads.

Severe flooding occurred along the English Coulee in the southwestern portion of Grand Forks during the 1979 flood. Changes in the coulee's drainage basin were probably partly responsible for the anomalously high rates of flow observed. It is also possible that the overall section line road system acted as a barrier to the northeastward flow to such an extent that large flows of water were diverted far enough east so that they entered the English Coulee drainage basin. This is further accentuated with the road system, particularly U.S. Highway 2 and other east-west section line roads, that tend to divert water eastward, away from natural drainages that would normally (if the roads, ditches, etc. did not exist) flow northeastward past the city. Construction of several drainage ditches also modified the direction of flow, increasing flow in some areas and decreasing flow in others.

Additionally, changes in town also affected the way water flows into the English Coulee. Prior to the construction of Columbia Mall in 1978, 32nd Avenue South served as a dike, diverting north-flowing water eastward, away from the English Coulee and toward the Red River. With the construction of the mall, the road was widened and lowered several feet so that it no longer acts as a dike, permitting the northward flow of water.

The route of the northward flow of the English Coulee, once it reaches Grand Forks, is through culverts and beneath bridges that carry it past obstructions such as the railroad tracks, University Avenue, Sixth Avenue North, U.S. Highway 2, and other points. This flow, once it reaches a certain volume, is greatly impeded by these obstructions. The culverts and bridges that have been provided for the flow of the English Coulee through the city of Grand Forks are not sufficiently large to allow unimpeded flow of the increased volume of water during flooding, although they are sufficient for normal runoff.

The single most important obstruction to the flow of the English Coulee through Grand Forks during the April, 1979 flood was the culvert system beneath the railroad tracks at the south edge of the University of North Dakota campus (fig. 21). The two concrete culverts at that point measure about 6.5 x 10 feet each. These two culverts are large enough to allow an unimpeded flow of approximately 1,800 cubic feet of water per second; that is up to a stream flow of about 1,800 cfs, the railroad tracks would not cause much damming effect. However, during the flood, the flow on the Coulee was so great (greater than 5,000 cfs) that water backed up south of the railroad tracks. The resulting hydraulic head was sufficient to force about 3,500 cubic feet of water a second through the culverts.

Theoretically, a 22-foot diameter culvert would have allowed the English Coulee to flow beneath the

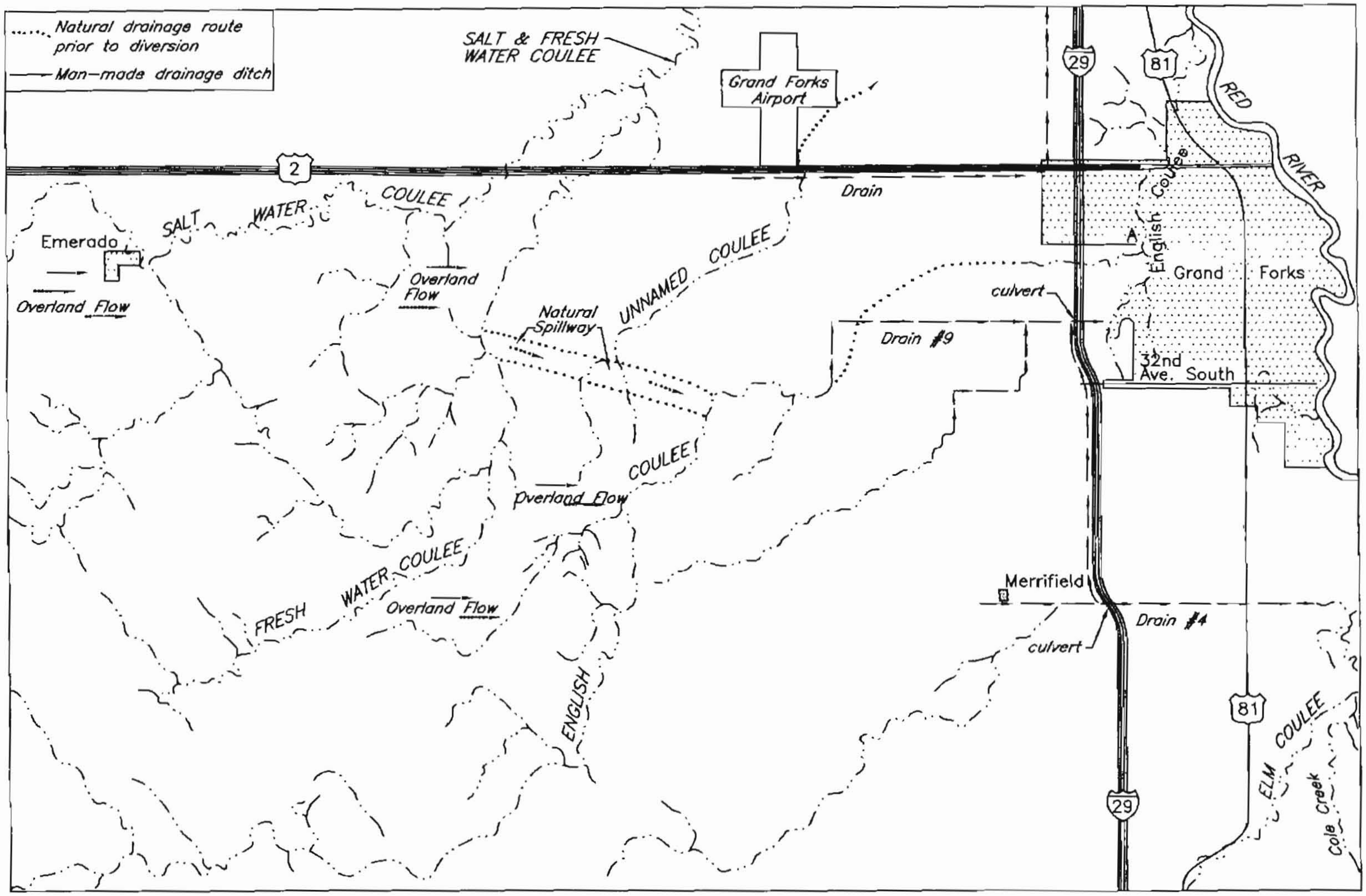


Figure 20. Map of the Grand Forks area showing English Coulee drainage and direction of water movement. Three drains are indicated on the map. Drain #4, that follows the section line road eastward from Merrifield, delivers water directly to Cole Creek and the Red River instead of the English Coulee. Drain #9 re-directs water along a westward extension of 17th Avenue South. Although this is a more southerly route than the natural channel, the flow results are the same. The water must still pass beneath the railroad tracks south of the University (point "A"). Finally the drainage ditch that follows U.S. Highway 2 delivers water to the coulee a half a mile south of where it normally would. The natural spillways are also indicated on the diagram. These natural spillways become active during situations of heavy, rapid runoff. Saltwater and Fresh Water Coulees are also shown, as are some of the areas of overland runoff during the 1979 spring flood. The dashed line shows the route prior to diversion by Drain 9. Point A is the culvert beneath the railroad tracks south of the University of North Dakota.

railroad tracks without backing up (a 22-foot culvert is approximately equivalent to eight 8-foot culverts); the existing system is equivalent to two 8-foot culverts. Of course, the English Coulee stream channel itself is not large enough to handle the flow through Grand Forks during a 100-year flood, and regardless of the size of the culverts and bridges provided, once a volume of water approaching the amount involved in the 1979 flood reaches the city, flooding is inevitable. It should also be pointed out that the area north of the railroad tracks would have experienced much more serious flooding if the culvert beneath the railroad tracks had been larger.

The three main reasons for the flooding by the English Coulee in southwest Grand Forks during the 1979 flood were 1) the presence of the rural road system, which diverted water eastward; 2) the insufficient size of the culverts in the city, which retarded the flow of the water from the flooded area; and 3) the overland water flows from the south, which prior to the reconstruction of 32nd Avenue South, would have been diverted away from the English Coulee.

A fourth point should be mentioned. Like all streams flowing over the glacial Lake Agassiz plain, the English Coulee occupies a shallow valley that is generally no more than 5 or 10 feet lower than the surrounding plain. Most of this area in Grand Forks was a cattail slough or marsh prior to the residential and commercial development during the mid and late 1970s. Much of this area was filled in during the course of construction.

This area would have been flooded during the April, 1979 English Coulee flood regardless of whether it had been developed, but the damage to the cattail slough would have been much less than it was to the houses that have been built in the former slough. In hindsight we know that the area should never have been developed. Our previous flood report, Bluemle and Harrison (1980), suggested that some form of corrective measures should be constructed to prevent future flooding along the English Coulee in this area. In the early 1980's, the U.S. Army Corps of Engineers constructed a dry dam/diversion project to prevent the flooding of this area by the English Coulee. This project was partly successful during the 1997 flood.

1997: Time to Leave

Examination of the flooding of Grand Forks-East Grand Forks in the spring of 1997 has to start with the fall and winter of 1996. The Red River Valley experienced above-normal precipitation during the months of September and October 1996 (Osborne, 1997). This rainfall left the soil-moisture content well above average, which decreased the surface-holding capacity, the first step towards a significant spring flood.

Winter, paying no attention to the calendar, started in November with the first blasts of arctic air; temperatures reported for the month were 9.4° F degrees below normal. The September and October pattern of above average precipitation continued into November, 1996 with an early blizzard occurring on the weekend of November 16 and 17. The Grand Forks Herald, in an attempt to make the winter a bit more bearable, started naming each of the blizzards (table 4). Blizzard "Andy" dumped 12 inches (13.6 accumulated inches) throughout the region. This was the start of a very long and harsh winter.

The cold and the storms continued into December and January. Temperatures were below average, with no mid-winter thaw. Six more blizzards pounded the region before April, 1997. In this time period, the Fargo area and regions to the south experienced one additional blizzard that missed the cities of Grand Forks-East Grand Forks. However, this blizzard added to the high snow levels already present in the headwaters of the Red River.

Concerns regarding flooding began towards the end of February, 1997, when snow melt water equivalents were reported to be 5 to 7 inches south of Fargo and 3 to 5 inches north of Fargo. The National Weather Service (NWS) issued its first flood outlook on February 14. At that time, NWS stated that a severe spring snowmelt flood potential existed for the Red River from Wahpeton to the Canadian border. Severe potential meant the river might be higher than the 1979 crest of 48.8 ft in Grand Forks-East Grand Forks. The first official flood forecast of 47.5 to 49 feet was issued by the National Weather Service on February 28.

After Blizzard "Gust" on March 4, temperatures slowly began to rise in the typical spring thaw fashion, cold days occurring sporadically in an overall warming trend. This warming cycle ended abruptly on April 4. This particular Saturday morning, residents of Grand Forks-East Grand Forks woke up to freezing rain. By midday, travel throughout the region was hazardous because of the thick layer of ice that had formed on everything. By evening, the weather had worsened with the rain turning to snow. Conditions deteriorated further when the wind started late Saturday. High winds associated with the cold temperatures made the valley a land of extremes. In addition, power outages occurred throughout the region as the ice-laden power poles were snapped by the wind. It was estimated that 2,000 power poles were broken and that 300,000 people lost power throughout the region. This also hampered flood-fighting efforts in the Breckenridge-Wahpeton area, where the Otter Tail and the Bois de Sioux (the headwaters of the Red River of the North) were in flood stage.

The valley suffered through the worst blizzard of the winter on April 4 to April 6, Blizzard "Hannah."

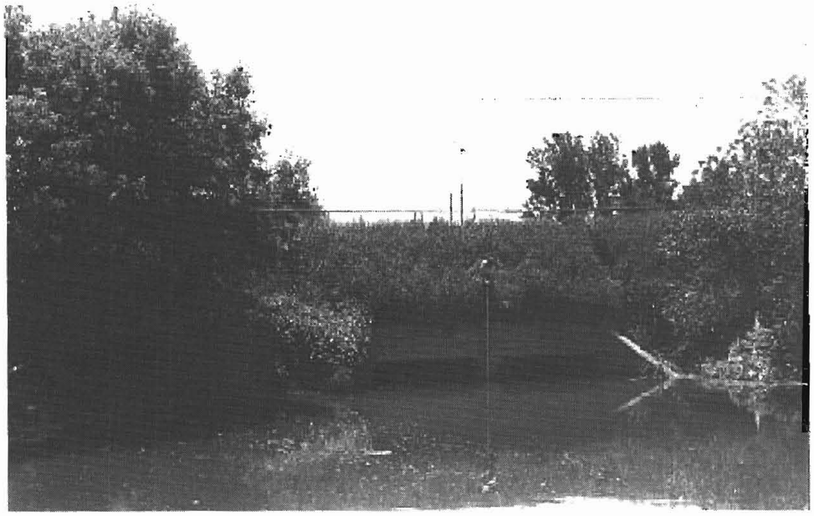


Figure 21. Culverts beneath the Burlington Northern Railroad tracks at the south edge of the University of North Dakota campus. Each culvert has a cross-sectional end area of 130 square feet (6.5x10 feet). A culvert system this size can handle a maximum flow of approximately 1,875 cu ft/sec before water starts backing up. (Photo by J. Bluemle)

"Hannah" was ranked as the highest category blizzard with wind speeds in excess of 80 mph (Osborne, 1997). Temperatures were well below freezing with deadly wind chills. A total of 6.3 inches of new snow fell on the Grand Forks-East Grand Forks area from this storm. The Grand Forks-East Grand Forks area now had a new snowfall record of 98.6 inches. Grand Forks-East Grand Forks wasn't the only city to have new records, Fargo also set a new record with 117 inches of snow, shattering the previous record of 89 inches, and most of North Dakota recorded all-time record snow fall during the winter of 1996-97.

Preparation for potential flooding in Grand Forks began prior to the last snowstorm. The Federal Emergency Management Agency (FEMA) implemented an ad campaign a month prior to the flood to encourage the purchase of flood insurance throughout the region. The National Weather Service (NWS) issued their second flood forecast on March 28, again for 47.5 to 49 feet. The North Dakota National Guard began dusting the Red River with sand on March 31 in an attempt to speed up the melting process and prevent ice jams. The City of Grand Forks started sandbagging and dike-building operations on April 3. The Red River was in flood stage by April 4 and the NWS was still predicting a 49-foot flood. The crest was projected to occur during the week of April 20 to 27. The City of East Grand Forks followed Grand Forks on April 10 calling for sandbaggers. The dikes around town were raised to 52 feet.

It was becoming apparent that all of these preparations were going to fall short of what was needed. Temperatures continued to rise - the Grand Forks Herald stated that the average temperature rose from 9° F on April 9 to 58° F on April 18. The National Weather Service issued a revised forecast of 50 feet on April 14; by then the Red River was currently at 44.43 feet. Severe flooding was occurring through the headwaters of the Red River, south of Grand Forks-East Grand Forks. Each major city along the river was fighting its own flood battle against the Red or its tributaries. First was Breckenridge-Wahpeton, then Fargo-Moorhead and many small towns in between. Additionally, lake levels at Lake Traverse and Orwell reservoirs were at their maximum when the U.S. Army Corps of Engineers announced on April 15 that they had increased the discharge from the two reservoirs, thereby adding more water to an already-full system.

Flood forecasts issued by the National Weather Service (NWS) started to change more quickly. During the 5 days immediately prior to the crest date, the NWS revised its forecast for the river five times (fig. 22). The flood fight was lost on April 18 at 8:00 am, when the temporary dike at the corner of Belmont Road and Lincoln Drive failed. Water quickly flowed north and west down streets and storm sewers and east into the Lincoln Drive area. In East Grand Forks, a dike holding back the Red Lake River failed, flooding the Point area at 3:30 pm.

Once the river had breached the dikes, floodwater continued filling in lows along the river's edge. The Central Park (GF), Sherlock Park (EGF), downtown Grand Forks, Griggs Park (EGF), downtown East Grand Forks, and Riverside Park (GF) areas were flooded one after another as the river water headed north (table 5). Residents were evacuated from the advancing floodwaters with little or no notice. The river started to spread out by Saturday afternoon as it crossed South Washington Street at 13th Avenue South (fig. 23). At this point, the water had spread out over a mile to the west of its channel (Grand Forks Herald, 1997).

TABLE 4. The eight blizzards that hit Grand Forks-East Grand Forks during the winter of 1996-1997 (from Grand Forks Herald, 1997). This snowfall was in addition to the above normal accumulation from winter storms. The Grand Forks-East Grand Forks area received a record snowfall of 98.6 ft for the winter of 1996-97.

Blizzards	Date	Snowfall
Andy	November 16-17	12 inches
Betty	December 16-18	8.7 inches
Christopher	December 20	4.2 inches
Doris	January 9-11	8.8 inches
Elmo	January 14-16	0.4 inches
Franzi	January 22-23	8.6 inches
Gust	March 4	0.2 inches
Hannah	April 4-6	6.3 inches

Note: A blizzard has weather conditions that include wind speeds of 35 mph or more, considerable falling and/ or drifting snow, and visibility near zero.

On the northwestern side of town, the flood fight was different. Flooding from the English Coulee in 1979 was from the southwest. The flooding in 1979 resulted from overland flow into the city. This flow pooled and flooded the south end of town when it backed up at the Burlington Northern Railroad tracks due to restricted flow at a culvert. The English Coulee flooding was different in 1997 (fig. 24). As the river levels rose on the Red River, the English Coulee started to back up from its confluence to the north. Low-level flooding was apparent throughout the area west of Columbia Road Thursday through Friday afternoon. By Friday noon, the river exceeded 51.5 feet and the diversion ceased to work. Without the diversion to remove excess water, the coulee backed up along its main channel and its many, normally dry, tributaries (fig. 25). The direction of flow in English Coulee at this time was to the south (Plate I). Sandbagging efforts through Saturday were focused around the low-lying areas, such as Boyd Drive, Stanford Road, and Shakespeare Road and on the University campus (fig. 26). Most of these efforts failed as the river continued to rise and combined with the coulee to flood the north end of town.

Southward flow of the English Coulee was once again restricted by the culverts at the Burlington Northern Railroad tracks; ponding occurred on the north side of the tracks this time opposite to what happened in 1979 (fig. 24). Water flowing south through the culvert combined with the river water coming from the east to pool and flood the same low-lying areas previously flooded in 1979. The areal extent of this flooding was slightly greater in the area immediately south of the tracks (DeMers Avenue to 13th Avenue South) for the 1997 flood than in 1979. Beyond that area, the flooding for the two floods was identical. The diversion had delayed the flooding, but not prevented it.

Evacuations had been ordered for different sections of town at various stages of the flood. By Sunday, remaining areas that were undergoing flooding were ordered to evacuate. It is estimated that 55,000 people left the Grand Forks-East Grand Forks area. Prior to the crest, the river had set a new record - an instantaneous peak discharge of 136,900 cubic feet per second (52.2 feet) was measured by the U.S. Geological Survey on April 18 while the river was still confined within its dikes. During the morning of April 22 the river crested at 54.35 feet, again setting new records.

As the river started to recede, sections of town were re-opened and residents were allowed to return to their damaged houses and businesses. Eleven thousand homes and businesses were damaged in Grand Forks and all but 27 homes in East Grand Forks were damaged. Estimates of damages included $300 million in personal property and $800 million in damages to residential and commercial buildings (Grand Forks Herald, 1997). Revised damage estimates are almost 2 billion (City of Grand Forks, 1999). The day of the crest, $500 million in flood relief was promised to the cities of Grand Forks-East Grand Forks by the federal government. Federal and state monies provided for disaster relief are presented in table 6; these figures are only for disaster recovery. Expenditures for future flood control are not included in these figures.

The cities slowly returned to normal with the re-openings of the Kennedy (April 28) and Point (May 11) bridges. As the residents returned to the cities, clean-up operations went into full swing. Flooded remains of personal property were placed on the parkways around town to be removed to the landfill. It is estimated that 60,000 tons of debris was moved and deposited in the Grand Forks landfill (City of Grand Forks, 1999). Additionally, the 3.5 million sandbags used to fight the flood had to be hauled away. All of this debris removal was contracted by the U.S. Army Corps of Engineers.

THE LOCAL FLOOD HAZARD

Although the Red River officially reaches flood stage at a gage reading of 28 feet, little damage is done in Grand Forks-East Grand Forks until a river height of 35 feet is surpassed. At levels above 40 feet, damage may be considerable, necessitating sandbagging and evacuation of some residential areas. This involves considerable expense to the community, the federal government, and a few unfortunate individuals. It is important, therefore, to know how often floods of a certain magnitude can be expected, how fast the floodwaters will rise, what areas will be flooded and for how long, and what effects future floods will have on public transportation and utilities. These problems will be discussed in the following pages.

Magnitude of Past Floods

The magnitude of the peak annual floods from 1882 to 1998 is shown in figure 27 (also see Appendices 1A and 1B). The ten worst floods are summarized on table 7. The highest known flood in this area, which occurred in 1997, crested at 54.35 feet above gage datum.

The graph (fig. 27) indicates that the magnitude of floods is somewhat cyclic. Periods of lower-than-average flooding occurred during the late 1880s, about 1900, 1911, middle 1920s, middle 1930s, and early 1960s and early 1990s. These lows probably correspond to periods of less precipitation, especially the low-flood period of the 1930s. The peaks of the high-flood cycles are separated by periods ranging from 10 to 30 years, though the common interval is about 12 years. These flood cycles probably reflect similar cycles in the average annual precipitation, the ultimate control of which remains poorly understood.

Rate of Rise of Floodwater

The rate at which the river rises during flooding is dependent upon the flood factors discussed previously. The rate of rise of the Red River at Grand Forks-East Grand Forks during past floods is shown on figure 28.

The rate of rise generally decreases as the river height increases. This is due to the rapid spreading of the river over the floodplain once its banks are overtopped. As a result of this widening of the channel, a greater volume

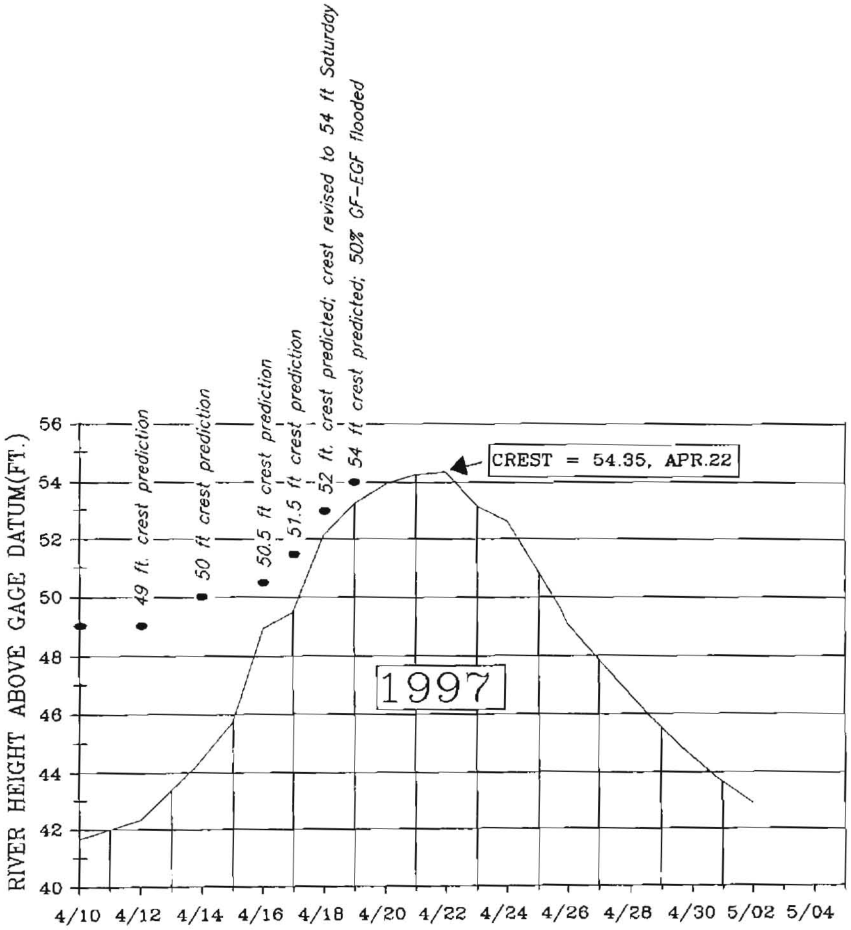


Figure 22. Hydrograph of the 1997 flood.

of water is needed to increase the river height from 25 to 30 feet (for example) than from 20 to 25 feet. The relationship can easily be seen on the discharge-river height curve for the Red River at Grand Forks-East Grand Forks (fig. 29).

According to the discharge-river height curve, an increase in discharge of 5,000 cubic feet per second is needed to raise the river from 20 to 25 feet, whereas a 6,000 cubic feet per second increase in discharge is required to raise it from 30 to 35 feet. To raise the river from 45 to 50 feet requires an increase in discharge of about 36,000 cubic feet per second (at 45 feet, flow is 48,000 cfs; at 50 feet it is about 84,000 cfs). Note that the slope of the curve is much more gentle above the 28-foot height than below it. The 28-foot height corresponds to flood stage--the height at which water begins to overflow the banks of the river and greatly increases the width of the channel; at this height, the river is flowing at 16,000 cfs. The same relationship is verified by the graph (fig. 30) showing the increase in width of the Red River at Riverside Park as the water rises.

In some areas of the United States, especially the arid portions, flash floods are a hazard. In these areas, the length of time between the river's flood stage and its flood crest is usually short, perhaps only a few hours. In the Red River Valley, however, flash floods are usually not a problem, except on smaller streams. Overland flows resulting from rapid melting of snow cover or from heavy rainfall can result in flood situations such as those in several small towns and rural areas during the 1979 melt. The rapid rise on the English Coulee in south Grand Forks in 1979 is probably the nearest thing to a "flash flood" likely in this area.

Usually, several days elapse between the time the Red River tops its banks and when it reaches its crest. This is especially true of the larger floods, those over 40 feet. The flood-to-peak time interval for several of the

TABLE 5. Chronology of events during the flood of 1997 (Grand Forks Herald, 1997; U.S. Geological Survey Water Resources Division <http://wwwdndbmk.cr.usgs.gov>; U.S. Department of Commerce, 1998).

Date	Event
Feb 6	First airborne snow survey of the Red River of the North (seven surveys were conducted in 1997).
Feb 14	National Weather Service (NWS) issues first outlook. Potential for spring flooding is characterized as severe. River may exceed the 1979 crest of 48.8 ft.
Feb 27	NWS snowmelt outlook updated. River crest predicted at 47.5 (with no additional precipitation) or 49 ft. (with normal precipitation).
Mar 27	NWS snowmelt outlook updated. River crest predicted at 47.5 or 49 ft.
Apr 3	Grand Forks starts sandbagging operations.
Apr 4	Red River at 28 ft. (flood stage). NWS outlook predicts a 49 ft. flood given normal precipitation.
Apr 5	Severe blizzard (Hannah) with one to three inches of precipitation.
Apr 9	Airborne snow survey.
Apr 10	East Grand Forks calls for sandbaggers.
Apr 11	NWS predicts the crest will be during the week of April 20-27.
Apr 14	Red River at 43.7 ft. NWS raises flood forecast to 50 ft. First non-outlook crest forecast (operational crest forecast).
Apr 15	Point Bridge closes in East Grand Forks. East Grand Forks warns of possible evacuation. Red River at 45.71 ft. Lake Traverse and Orwell Reservoir increase releases because lake levels are at a maximum.
Apr 16	NWS changes flood forecast to 50.5 ft. Grand Forks warns of possible evacuation.
Apr 17	Red River at 49.91 ft. NWS changes flood forecast to 51.5 ft. Corps field construction personnel instructed to increase levees to handle a 52.0 to 54.0 ft. flood.
Apr 18	City orders evacuation of Lincoln Park, Central Park and Riverside areas in Grand Forks. Water breaks through temporary dike at Belmont Rd. and Lincoln Drive flooding the Lincoln Drive area. Red River at 52.04 ft. NWS revises crest forecast to 53 ft. Sandbag levee is breached and the Point area, East Grand Forks, is evacuated and flooded. Murray bridge closes. Red River at 52.62 ft. NWS revises crest forecast again to 54 ft. on Saturday. Kennedy Bridge closes.
Apr 19	Griggs Park and downtown area of both cities are flooded. Red River at 52.89 ft. By noon, 50% of Grand Forks and virtually all of East Grand Forks are flooded. Riverside Park flooded. By afternoon, the area east of Columbia Road is evacuated. Fire in Security Building downtown Grand Forks. By early evening, 90% of East Grand Fork's residents have evacuated.
Apr 20	By 8 pm, 75% of Grand Forks' residents are evacuated. Red River at 53.99 ft.
Apr 22	Red River crests at 54.35 ft.

Figure 23A

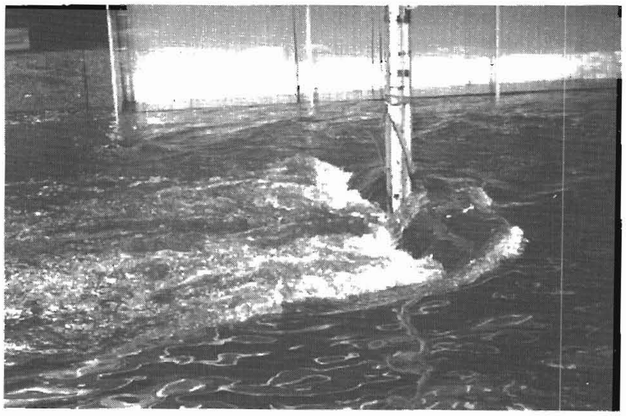


Figure 23B

Figure 23C

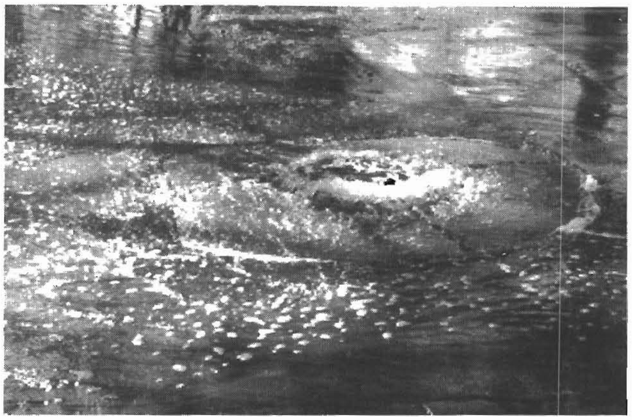


Figure 23D

Figure 23. A) Flood waters in downtown Grand Forks looking east towards the DeMers Avenue (Sorlie) Bridge. B) Floodwaters flowing north in front of the First Bank Building, downtown Grand Forks. C) Floodwaters crossed South Washington Street on Saturday, April 20 as the river spreads out. D) Floodwaters bubble-up from a storm sewer lifting the manhole cover. The storm sewer system acted as a perfect delivery system, quickly filling in low lying areas with floodwaters long before the areas were reached by floodwater. (Photos by J. Fischer)

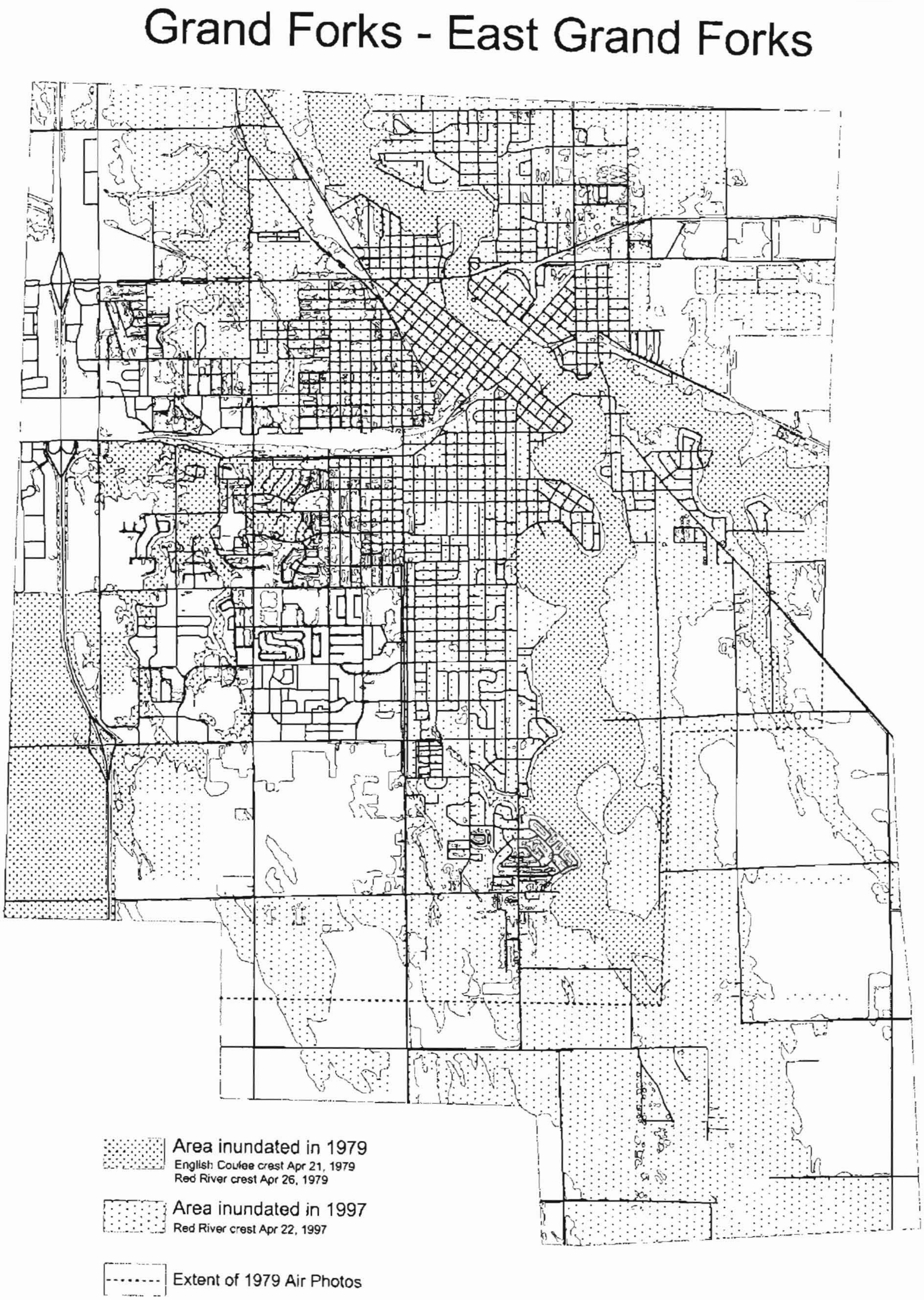


Figure 24. Map showing the extent of the 1979 flood compared to the 1997 flood. The extent of the 1997 flood is as of April 21, 1997.

Figure 25A

Figure 25B

Figure 25. Floodwaters backed up normally dry tributaries to the English Coulee when the height of the river exceeded the capacity of the diversion. A) Floodwaters flow south from the English Coulee into University Heights subdivision along 13th Avenue North, Saturday, April 19. B) The English Coulee is shown out of its banks covering the bike trail, Friday, April 18. (Photos by J. LeFever)

larger floods in the two-city area has ranged from 6 to 22 days; in 1997 it was 22 days.

Flood Frequency

One useful relationship that can be derived from flood records is that of flood magnitude (height or volume of flow) to flood frequency (Dalrymple, 1960). The rank and height of each flood since 1882 is shown on Appendix 1B. A flood-frequency graph (fig. 31), based on rank and recurrence interval of all known floods was derived from these records.

The flood-frequency graph (fig. 31) is an approximation, based on the rank and recurrence interval of known floods since 1882. Recurrence interval is calculated using the Weibull method: years of record + 1 divided by rank of flood equals recurrence interval. The Grand Forks-East Grand Forks flood record goes back 117 years; so, for example, the 1979 flood, which is the third highest-ranking flood, has a recurrence interval of (117+1)/3 or 39 years. Therefore, it falls at the 39-year point on the curve. Similarly, according to the graph a 44-foot flood should have a recurrence interval of about 10 years. We see that the 10th ranking flood, in 1893, crested at 45.50 and the recurrence interval for a flood of that level can be calculated: (117+1)/10=11.7 or approximately every 12 years.

The flood-frequency curve (fig. 31) shows that a crest above flood stage can be expected to occur, on the average, about every two years. Floods of less than 40 feet, however, do little damage in this area. A flood 40 feet high or higher can be expected to occur on the average about once every 5½ years. This does not mean that 5½ years must separate each of these floods, but that over a 60-year period, about 10 floods of this magnitude or greater may be expected.

Graphs like the one shown on figure 31 have some interest, but they should not be taken too seriously. It is especially important to keep in mind that the recurrence interval is merely a statistical description that has no bearing whatsoever on what may happen during any given year. Floods are much more diverse and complex than any statistical method used to describe them (Baker, 1994). The flood data for these statistical analyses may be assumed to be representative of the phenomenon but may actually exclude data critical to a particular flood or may result in the use of information not representative of the flood in question.

Using the statistical method just described, it can be seen that the chance of a flood over 45 feet high occurring in any one year is about 1 in 12. A 45-foot flood, such as the flood in 1979, costs hundreds of thousands of dollars for flood protection and damage in Grand Forks-East Grand Forks.

Relying on the same statistical method, it can be seen that a flood 50 feet high or higher can be expected about once in every 50 years (the chance that it will occur in any given year is about 1 in 55). Prior to 1997, a flood of this magnitude had not occurred in Grand Forks since 1897. The recurrence interval of floods greater than 54 feet high cannot be statistically predicted based on historical flood records.

Estimating future floods is a chancy undertaking, at best. The highest flood that might be expected once every hundred years on the average is defined as the Intermediate Regional Flood (IRF). That is, although such a flood could occur during any year, it has a one percent chance of occurring in any given year. The peak flow and height of this flood have been developed from statistical analyses of streamflow and precipitation records, as well as runoff characteristics for the river and its tributaries.

Figure 26A

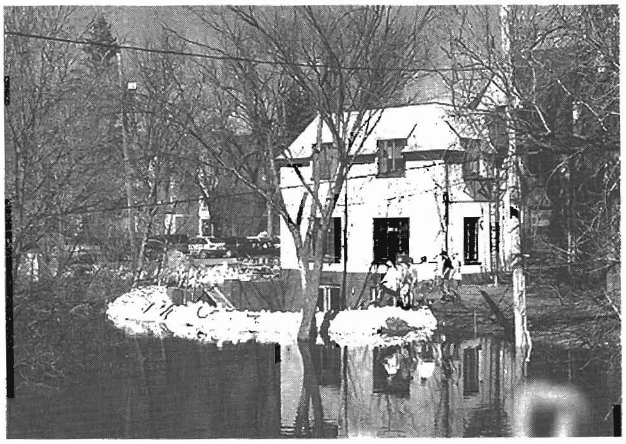


Figure 26B

Figure 26C

Figure 26D

Figure 26. The English Coulee backed up from its confluence with the Red River when the capacity of the diversion channel was exceeded. Sandbagging efforts were focused around low lying areas along the coulee. A) Houses adjacent to the coulee are sandbagged as water gets high enough to flow over the culvert under 6th Avenue North (Friday, April 18). Water was flowing south. B) Sandbaggers attempt to keep water out of the basement to the Gamma Phi Beta Sorority on the University of North Dakota campus (Friday, April 18). C) Water covers the bridge leading to the Hughes Fine Arts Center (Friday, April 18). The top tier of the fountain (middle right) is still above the water level at this time. D) Floodwaters cover Campus Road near the Hughes Fine Arts Center as water backs up from the culvert at the Burlington Northern Railroad Tracks (Friday, April 18). (Photos by J. LeFever)

TABLE 6. FEMA, SBA, State of North Dakota disaster aid <http://www.fema.gov/>.

North Dakota Residents Registered for Assistance	36,494 (4/7/98-8/6/98)
Grant Totals	
FEMA Housing Grants (24,031)	$51,149,169
Disaster Recovery Centers	24,031 individuals
ND Dept. of Labor-Unemployment Claims (6,633)	$ 4,412,357
Dept. of Emergency Management (9,152 Individual and Family)	$12,163,093
FEMA Infrastructure Grants	$65,720,442
FEMA/State of ND-Hazard Mitigation Grants (Property Acquisition)	$27.3 million
Crisis Counseling Grants	$ 2.5 million
FEMA Funding for Federal Agencies (Disaster Relief)	$29,882,919
FEMA Water Treatment Plant Grant (90%)	$ 2,245,512
FEMA Sewer Clean-up (90%)	$ 2,276,226
Loans	
SBA Disaster Loans (6,686 total) (4,967 Homeowners/Renters; 906 Businesses)	$162,933,800
	$360.58 million total

The Intermediate Regional Flood is one with a discharge of about 110,000 cfs and a gage reading of 52.5 feet (table 8).

The 500-year flood represents a reasonable upper limit of expected flooding in the Grand Forks-East Grand Forks area. It can be defined as the major flood that can be expected to occur once in 500 years on the average, again, although it could occur in any year. Such a flood would occur as a result of the combination of the most severe meteorological and hydrological conditions considered to be reasonably possible in the Red River of the North drainage basin. In other words, it is the volume of flow that would be expected, assuming all flood-producing factors are at their worst. The estimate of this flood is expressed as a river discharge of 240,000 cfs (table 7). The river height-discharge curve (fig. 29) was extended mathematically to give a rough estimate of the height of the maximum probable (500-year) flood. It is calculated it would be about 61 feet above gage level.

While frequency can be statistically defined for each flood of the past and, within limits, projected for the future, it should be emphasized that the period of record for the Red River of the North at Grand Forks-East Grand Forks is relatively so short (117 years), that it is not possible to accurately assign a frequency figure for a large flood that has not yet been experienced. Thus, the frequency derived for a 500-year flood reflects the best judgment of hydrologists who are familiar with the area and with its hydrological and meteorological characteristics. Floods greater than the 500-year flood can occur in any year, although the combination of factors necessary to produce such large flows would be extremely rare. Flood-frequency estimates assume present climatic and land-use conditions. Climatic conditions can change substantially within periods of time less than 500 years.

While ingrained in the literature, flood frequency values must be regarded as approximate since they are recalculated every time a significant flood occurs. These values should not be used in connection with any planning of floodplain use. For a more accurate view, city planning should be based on the areas inundated by known river elevations rather than a value that changes with each significant flood (Plate II).

Effects of Flooding

Some of the effects of both past and hypothetical

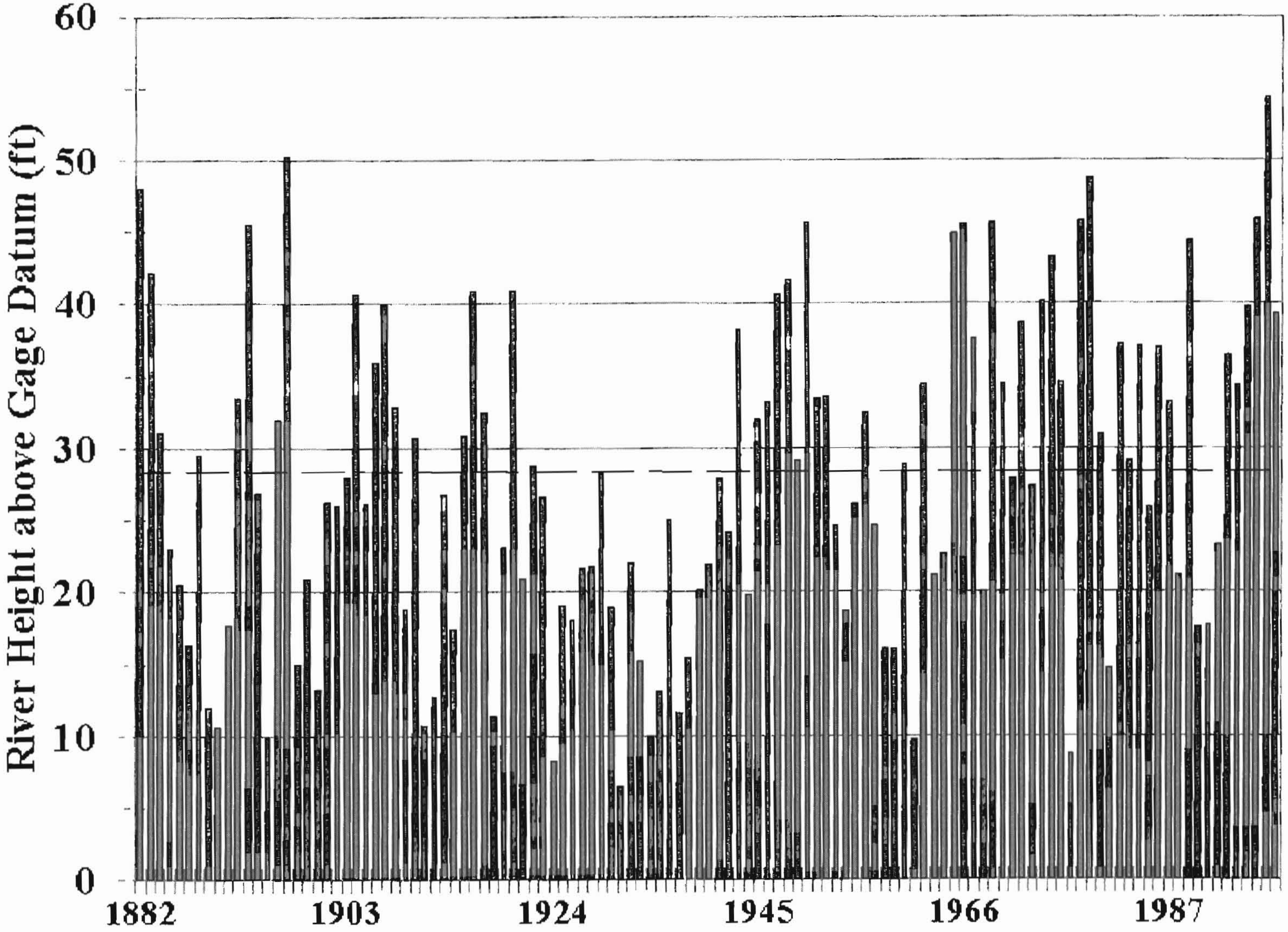


Figure 27. Magnitude of past floods at Grand Forks-East Grand Forks (based on U.S. Geological Survey records). Flood stage indicated by horizontal dashed line.

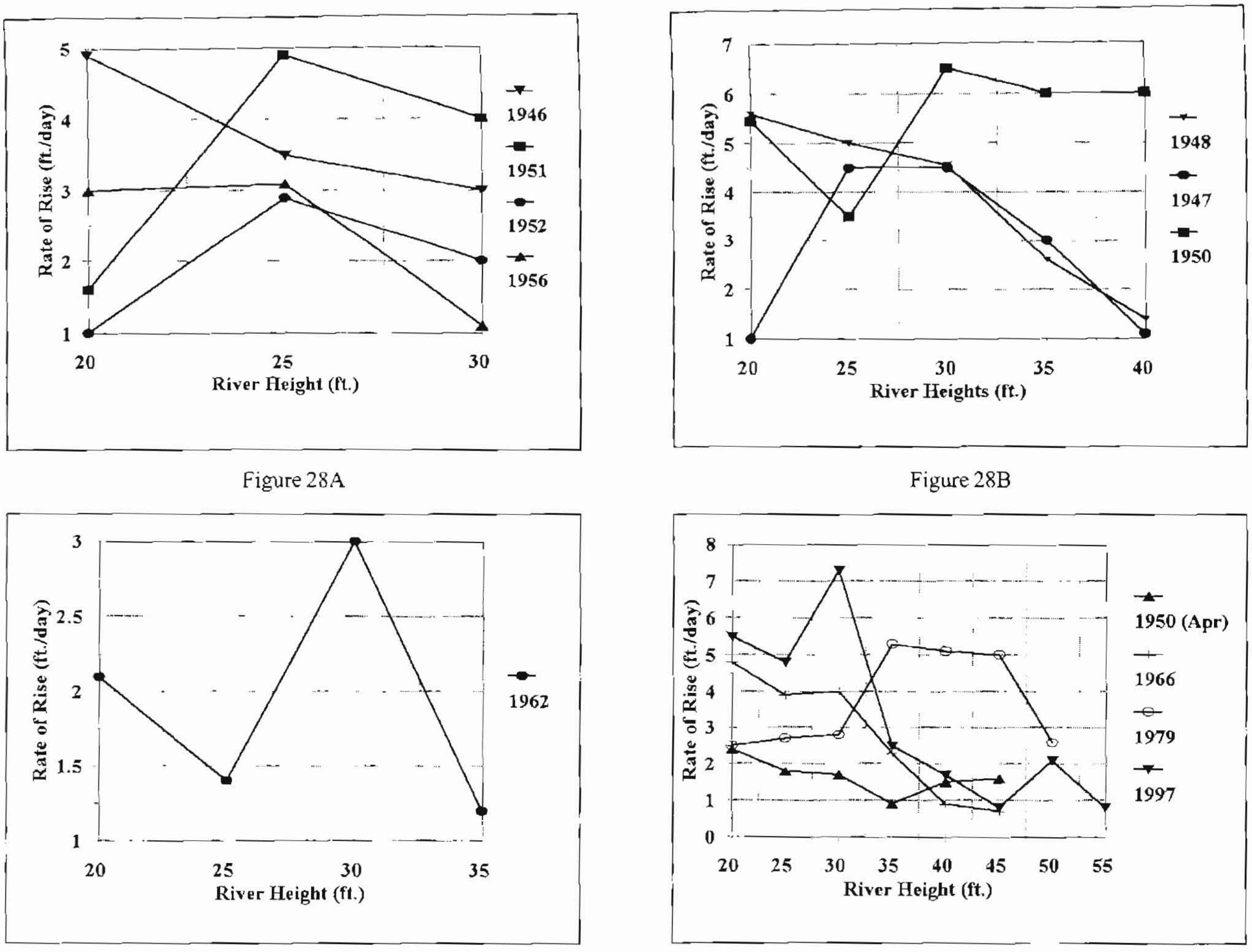


Figure 28A

Figure 28B

Figure 28C

Figure 28D

Figure 28. Rate of rise of the river during floods of various heights. A. 30-34 ft. crests; B. 35-39 ft. crests; C. 40-44 ft. crests; D. 45-55 ft. crests.

floods are listed on table 9. These effects were determined from historical records, flood maps, and information from the U.S. Army Corps of Engineers. Only the more important effects are listed, with emphasis being given to the relationship of flood heights to transportation, public utilities, large residential areas, and flood-protection dikes.

Table 9 shows that relatively little damage is done by floods less than 40 feet high, which occur, on the average, during one year in five. At a river height of about 40 feet, many downtown merchants experience basement seepage and find it necessary to use sump pumps, and in some instances, to remove their stock.

At a river height of 42 feet, most of Riverside, Central, and Lincoln Parks are inundated and several residences require protection in the form of sandbag dikes. At about 45 feet, the approach to the Minnesota Point bridge becomes flooded. The DeMers Avenue (Sorlie) Bridge becomes impassable when the water reaches 48 feet. Also, at 48.9 feet, the river is level with the top of the emergency East Grand Forks dikes.

All railroad bridges become impassable at river heights over 50 feet though this has happened only twice, in 1897 and 1997. In their 1980 report, Harrison and Bluemle estimated that the river would reach a height of 55 feet during the "500 year flood event." They noted that, at this height, a large portion of both cities would be inundated by shallow water. In 1997, this proved to be true when the river crested at 54.35 (although statistically not a "500 year flood" event) and two-thirds of the area in the two cities was inundated.

Drastic, emergency sandbagging efforts were not effective in the 1997 flood. Shallow water covered the area east of South Washington and north of 17th Avenue South. Water movement was restricted along the southern portion of South Washington street where the roadbed was elevated. The area west of this portion remained dry

TABLE 7. Historic floods (since 1882–when the gage was installed).

Rank	Height	Year	Peak Discharge[a] cubic feet/second (cfs)
1	54.35	1997	136,900[b]
2	50.20	1897	85,000[c]
3	48.81	1979	82,000
4	48.00	1882	75,000
5	45.90	1996	58,400
6	45.73	1978	54,200
7	45.69	1969	53,500
8	45.61	1950	54,000
9	45.55	1966	55,000
10	45.50	1893	53,300

[a] Cubic feet per second (cfs) is a measure of the rate of flow past a specific point within a given time period (one cfs for a duration of one day would amount to water one foot deep over two acres of land). The floodwaters from the April 26, 1979 flow had a discharge of 82,000 cfs at Grand Forks-East Grand Forks. The floodwaters for just that day would have covered 164,000 acres to a depth of 1 foot (or a single section–640 acres–of land to a depth of 250 feet).

[b] The instantaneous peak flow discharge for the 1997 flood occurred during the rising stage of the river prior to dike failure (April 18, 1997). The discharge volume equates to a stage height of 52.21 feet.

[c] The peak discharge figure for April 10, 1897, is simply an estimate based on known discharge figures for the 1997 flood. The 1897 flood was previously estimated at 80,000 cfs, but this was based on known discharge figures for the 1950 flood as no discharge figures were calculated at the time of the 1897 flood. In 1979, this figure was revised to 100,000 cfs. It has been revised again to place it in context with the 1997 flood. Similarly, the 1882 discharge figure is also an estimate.

The 50.2 foot gage reading for the 1897 flood is probably correct. All eyewitness accounts attest to a higher level for the river in 1897 than in 1979. For example, farmers living east of Buxton report that the river extended nearly three miles farther west over farmland in 1897 than during the 1979 flood. This is just about what would be expected if the river level were a foot higher.

to flooding except for storm sewer backup (Plate I). If the roadbed had not been elevated, that portion of town would also have been inundated by the river.

Extent of Floods

The extent of inundation of the April 1997 flood for Grand Forks-East Grand Forks is shown on Plate I. The previous report, Bluemle and Harrison, included a map showing the extent of floods having a recurrence interval of 10 years, 100 years and the estimated extent of the maximum probable flood (500 year; 55 ft.). At that time, the areas that would be inundated by each of these hypothetical floods were determined by tracing the elevation of each flood, beginning at the gaging station and working upstream. An increase in river height of about one foot was allowed between the gage and the south end of Grand Forks.

Although a conservative value was used for the gradient of the river, the 1979 map proved to be remarkably accurate in predicting the 1997 flood. The 1997 flood crest approached the elevation previously determined to be the maximum probable flood. Apparent discrepancies in 1997 between the actual location of flood waters and the projected map location were due to changes in flood control after the 1979 flood. For example, inundation of the area by Columbia Mall by the English Coulee was prevented by the construction of a dry earthen dam west of town. The earthen dam prevented overland flow from the coulee into the southwestern portion of town. On the north end of town, backwater effects along the coulee were diminished, but not entirely mitigated, by a diversion project.

The exact gradient of the river in this area during floods varies somewhat with each flood. The Grand Forks City Engineers' Office reports a drop in the river level of three feet between the gage and the south end of Grand

Forks for the flood of 1997 (A. Grasser, written communication).

We used a Geographic Information System (GIS) program called ARC/Info to create Plate I and Plate II. Plate I shows the area inundated by surface water. This area was derived from aerial photography obtained on April 21, 1997. By using GIS software and manual air photo interpretation, the image was split into three categories on Plate I. The first category, colored green, shows areas that were not covered by surface water. Although not "wet" these areas would tend to have a high soil moisture content. The light blue fill shows the areas that were covered by surface water either from the Red River, Red Lake River, English Coulee, from miscellaneous drainage, or overland flow. The areas shown as shaded with light blue diagonal lines represent land that was determined to be highly saturated. This saturation could have been caused by melting snow and/or high groundwater and many of these areas contained standing pools of water, however, these areas were not flooded.

Plate II shows the areas that would be inundated at certain water elevations. The base map elevations were derived from United States Geological Survey 7.5 Minute Topographic Quadrangle Maps compiled in 1963, prior to much of the construction in the south end of Grand Forks. Contours in this area are mapped at 5-foot intervals. Elevations between the 5-foot contour interval were interpolated by using the GIS software ARC/Info. The lines were then checked against a digital version of the base map.

Water elevations are also based on the average mean pool elevation of 779 feet above Mean Sea Level (M.S.L.) at the downtown gaging station. The three gage levels used are 45, 50, and 55 feet (elevations of 824, 829, and 834 feet, respectively). The three gage levels are indicated by different shades of blue: dark blue (45 ft), medium blue (50 ft), and light blue (55 ft). The map also includes the location of the existing city streets and pre-flood levee system. A value of one foot per mile was used for the gradient of the river based on the information obtained from the Grand Forks City Engineer. Elevations for the various flood levels indicated by the colors on the map were adjusted to take into account the gradient of the river. The resulting river levels are drawn strictly based on elevation and gradient and are not affected by the pre-existing levee system.

The dark blue color on Plate II shows the area inundated by the river when the gage reads 45 feet. This area is not constrained by the existing dikes or flood protection. The water is well above the banks of the rivers and spreads over the floodplain producing a river width ranging from about 800 feet at DeMers Avenue to about 2,300 feet in the vicinity of the Lincoln Park Golf Course. The constriction of the river near DeMers Avenue causes a pooling (backwater) during floods and hence tends to increase the height of the river upstream from that point. Dikes, such as those located at Lincoln Park and throughout East Grand Forks, have the same effect; they constrain the river and increase the height of the river upstream.

Flooding at the 45-foot level includes low-lying areas adjacent to the river, including a portion of the Central Park and Lincoln Drive areas (protected by existing dikes), Lincoln Park Golf Course, and low-lying areas in the East Lake and Shady Ridge Estates. The map also shows that, when the Red River is at 45 feet, water starts to back up the English, Heartsville (Bygland), and Belmont coulees. The English Coulee diversion project constructed in the early 1980's prevents backwater from the Red to a river elevation of 51.5 feet. Flooding from the coulee would have been more extensive without this diversion.

The additional large areas inundated by the 50-foot flood (medium blue on Plate II) are in the vicinity of 15th Avenue South and Belmont Road, Central Park, downtown Grand Forks, Belmont Coulee (near Schroeder Jr. High School), the Minnesota Point area of East Grand Forks, and the general area just north of the two cities. With the exception of the 15th Avenue South and Belmont Road areas, most of this zone lies at or below the confluence of the two rivers, indicating a broader floodplain downtown.

The 55-foot flood level covers most of both cities with shallow water. Only areas lying above 833 feet on the north end of town and above 835 feet on the south end escape inundation at that level. Few areas are this high, however. Most of the upland along the river in this area lies between 832 and 833 feet above sea level.

The 1997 flood (54.35 ft gage elevation) followed this inundation pattern. There is a 3½-foot elevation change along the river between the gage and the south end of town. Therefore, a 54-foot flood at the gage actually measures 57 feet at the south end of town when the gradient of the river is taken into account. Part of this discrepancy in elevation may also be related to the pooling or backwater effect of the river.

Flood waters would have inundated the south end of town as predicted, had they not been restricted in their westward flow by the raised roadbed of South Washington Street. The area south of 13th Avenue South and west of South Washington Street was dry to flow from the river. The area west of Columbia Road was dry as a result of the English Coulee dry dam and diversion. However, these areas were dry only because of the conditions of this flood. If the river had remained high for a longer period of time (for example: due to an ice jam) or if

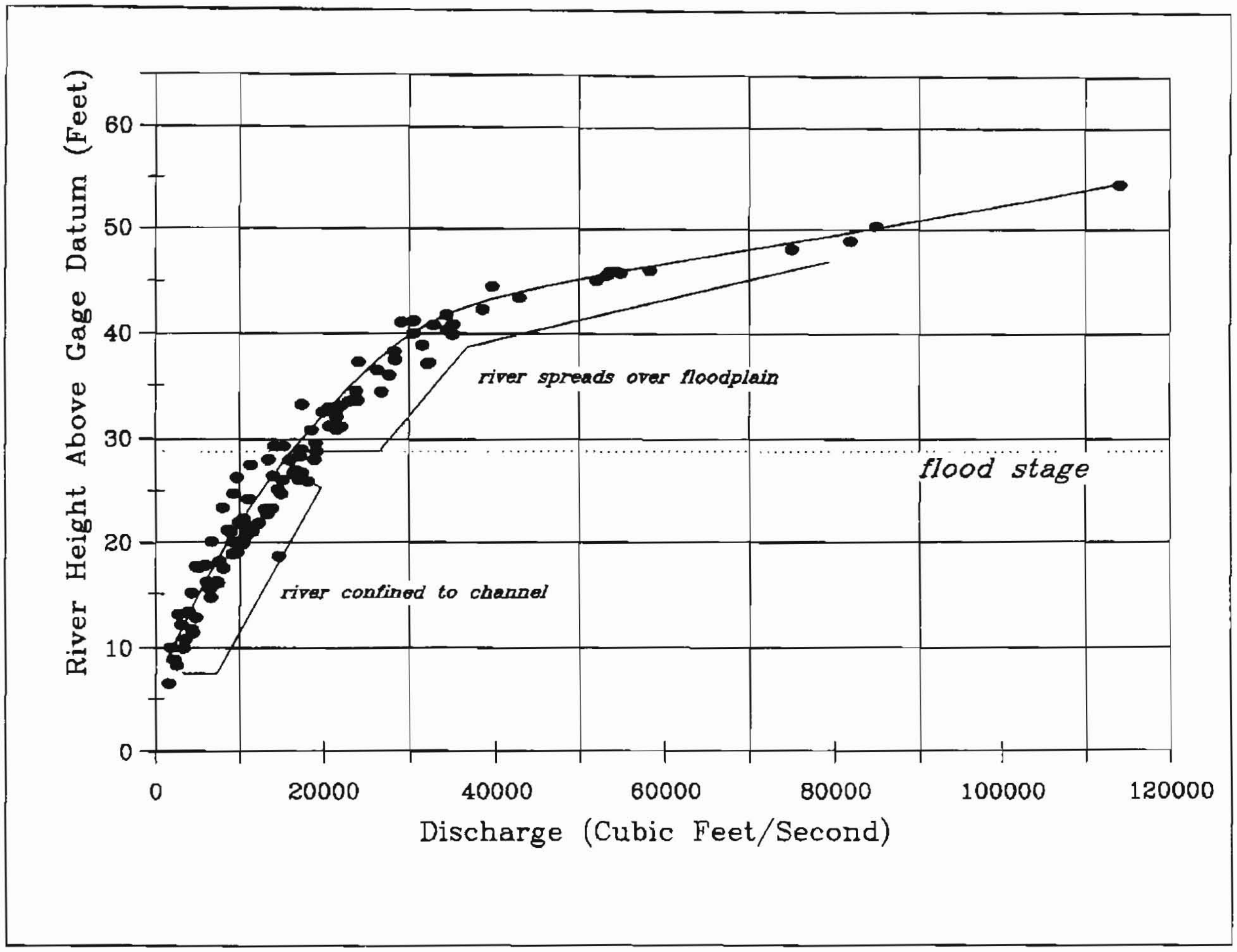


Figure 29. River height-discharge curve for the Red River at Grand Forks-East Grand Forks. Instantaneous peak flow discharge for the 1997 flood occurred during the rising stage of the river prior to dike failure. Crest height (54.35) corresponds to a lower discharge volume.

there had been additional precipitation, the entire south end of town would have been flooded. The favorable weather and lack of ice on the river worked to the advantage of the south end of Grand Forks.

Two profiles, one drawn through Riverside Park and the other through Central Park, are shown on figure 32. The locations of these profiles are shown on the map by lines A-A' and B-B'. The extent of inundation in these areas in indicated for gage readings of 30, 45, 50, and 55 feet.

It should be apparent that, when the river is "artificially" confined by the construction of permanent or temporary dikes, the size of the channel is diminished (fig. 33). For this reason, dikes tend to raise the river level, both upstream from the dikes and at the point the dikes are built. They also tend to increase the flow velocity of the river and its destructiveness. Further evidence for this increase in flow velocity was exhibited by the1997 flood, when the instantaneous peak flow for the river was measured at 136,900 cfs prior to the topping of the dikes. After the dikes were topped, the flow velocity diminished quickly as the river spread out.

Obviously, dikes are necessary to protect already-developed areas, but they will always be an expensive, stop-gap measure in areas that would be better left undeveloped, except as parks, etc., to flood without interference and undue expense and damage. These areas should remain as free of obstructions as possible to facilitate free flow.

FLOOD FORECASTING

Forecasts of flood crest allow time for precautions to be taken to reduce flood damage. The prediction of flood crests for the Red and Red Lake Rivers involves evaluation of all the flood-producing factors discussed earlier. These include: (1) slope, size, and shape of the drainage basin, (2) condition of the soil, depth of frost,

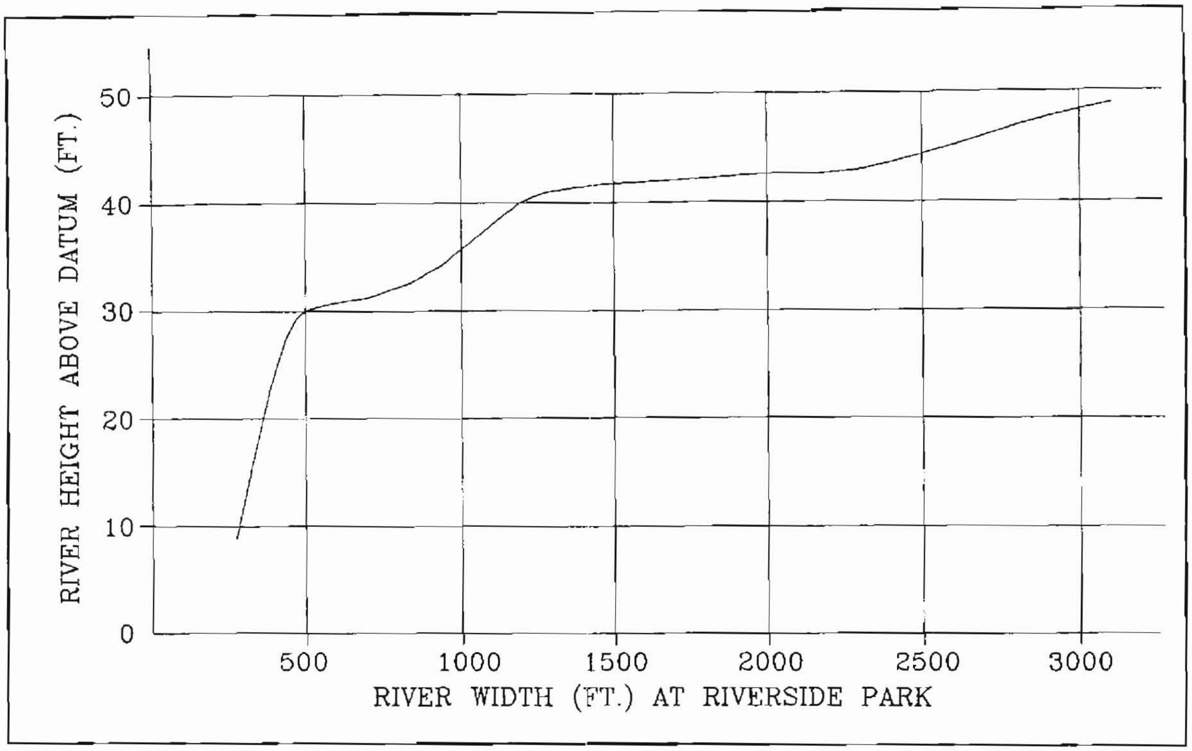


Figure 30. River width at various heights at Riverside Park.

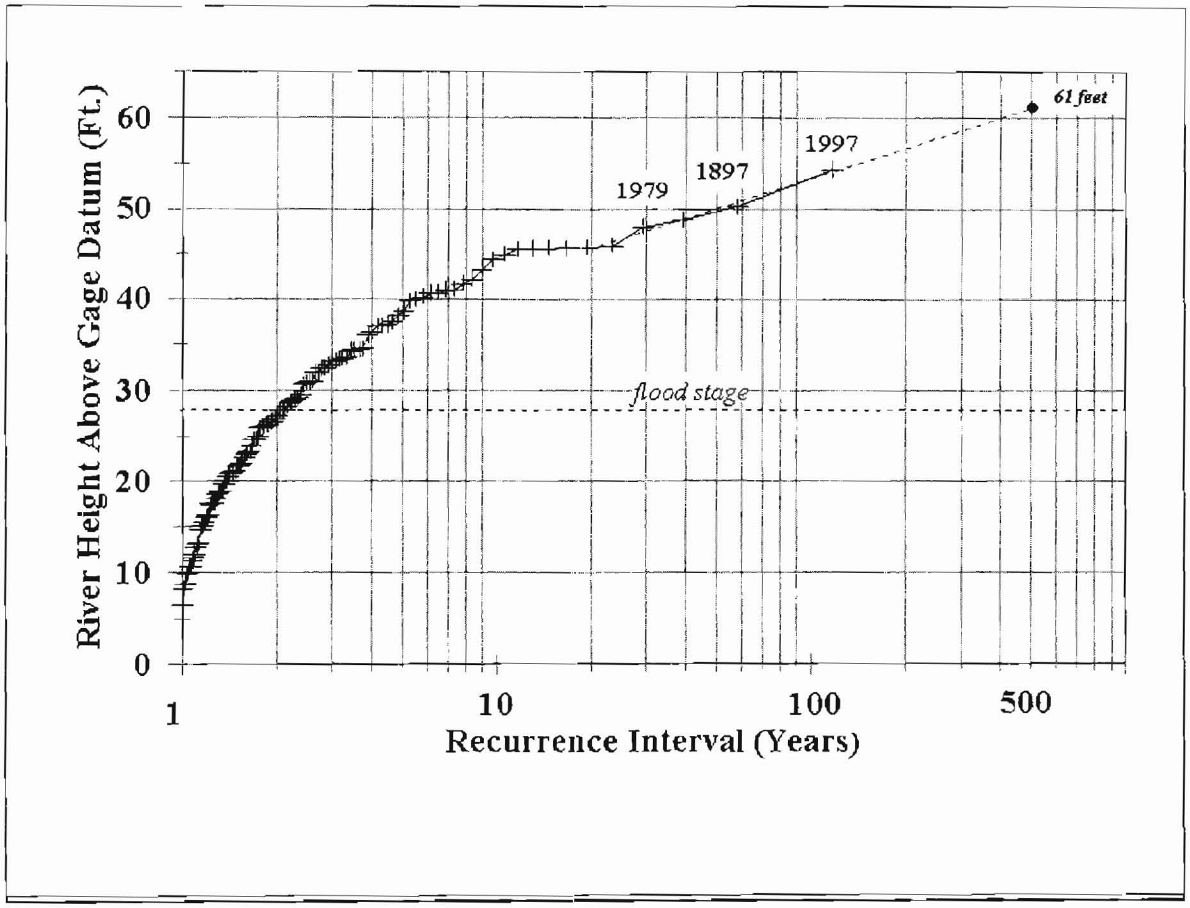


Figure 31. Flood frequency graph of the Red River at Grand Forks-East Grand Forks.

and ice thickness on the river, and (3) snow accumulation, spring precipitation, and time and rate of spring thaw. Past flood records are used to develop the predictions.

Flood forecasting is based on the relationship of the river stage to flow volume rate. Flow volume rate (discharge) is required by the computer models for their calculations. However, the forecast information is presented to the public in terms of river stages or crests. This relationship between river stages or crests and flow volume rate (expressed as volume per unit time) is plotted in a graph called a rating curve (figs. 29 and 34).

Forecasting is dependent on the rating curve, but there are inherent problems in using the curve. This is, in part, because there is not a linear correlation between stage and discharge. Discharge may vary depending on whether the river is rising or falling. Discharge is also highly variable in mildly sloping rivers where, for a variety of reasons, a significant backwater effect may occur. Additionally, this backwater effect may change from year to year based on ice conditions within the river, debris accumulation, the volume of runoff and other factors. Therefore, small changes in discharge may result in large changes in stage (U.S. Department of Commerce, 1998). Problems with the rating curve also arise when the event has a greater magnitude than past events. At that point, the curve has to be extended by extrapolation using one of three methods: linear extrapolation, logarithmic extrapolation, or hydraulic extension. These extensions work reasonably well unless the river has significant backwater effects, as does the Red River.

For the Grand Forks-East Grand Forks area, official outlooks and flood predictions are issued by the North Central River Forecast Center in Chanhassen, Minnesota. The forecasts are then sent to the regional office of the National Weather Service (NWS) for release to the public. An "outlook" that extends 60 days into the future is issued first, prior to spring runoff. The outlook is based on actual current conditions prior to spring melt. It includes the amount of snowcover (determined from airborne surveys), soil moisture, frost conditions, river ice, and base flows. These factors are modeled using two scenarios, one with no precipitation and one with normal precipitation. The values generated are then considered to be a minimum and a maximum, not a range, and have a high degree of uncertainty. In the assessment of the 1997 flood of the Red River of the North by the National Weather Service of the U.S. Department of Commerce (1998), it was stated that the "zero precipitation model has a high likelihood of being exceeded" (in fact, in all but one of the years examined by the Service the zero condition has been exceeded). The second scenario, assuming normal precipitation, is considered by the National Weather Service to be the median. The NWS stated that there is a 50% chance of that outlook being equaled or exceeded.

The National Weather Service issues a three-day stage forecast when the river starts to respond. This is a transition from the flood outlook to the flood forecast. At this point, the outlook is used to determine the projected crest.

The flood forecast is an attempt to predict a specific crest and crest date based on variable weather conditions. The computer modeling technique uses: 1) the amount of soil moisture at time of freezing, 2) depth of frost, 3) water content of snow cover before spring runoff, 4) stream flow, and 5) ice in streams with a northerly flow. It assumes "normal" or "typical" weather conditions between the time the prediction is made and the projected

TABLE 8. Maximum discharge and elevation comparisons (theoretical predictions).

Flood at Grand Forks-East Grand Forks	Discharge (cfs)	Elevation (ft)	River Reading (ft)
500-year flood	240,000	840.0	61.0
1997 flood	136,000[a]	833.5	54.4
Intermediate Regional Flood (100 year flood)	110,000	831.5	52.5
1979 flood	82,500	827.5	48.8

[a] The maximum discharge for the 1997 flood occurred four days prior to the actual crest during the rising stage of the flood when the river stood at a height of 52.21. The actual discharge associated with the 54.4 ft crest elevation was 114,100 cfs.

TABLE 9. Effects of various flood heights on residential and business areas, public utilities, and transportation. Rationale for mobilization by the City of Grand Forks (1998, U.S. Army Corp of Engineers <http://www.mvp-wc.usace.army.mil>).

Gage Reading	Elevation	Effects
0.0	779.0	Gage datum
28.0	807.0	Flood stage – Red River begins to overflow banks. Mobilization of the City of Grand Forks. Start the pumping station at Lincoln Park and close gate wells.
34.0	813.0	Water over roof of Red River water pump house.
35.0	814.0	Raw sewage from treatment plant enters the river.
40.0	819.0	Seepage in business district basements.
42.0	821.0	Riverside, Central, and most of Lincoln Parks flooded in Grand Forks.
45.0	824.0	Belmont Road at 15th Ave. requires diking to protect homes.
47.0	826.0	Waterworks becomes inoperative.
48.0	827.0	Top of levee in Riverside Park area. DeMers Ave. Bridge impassable.
48.9	827.9	Top of emergency levee in East Grand Forks.
50.0	829.0	Railroad bridges become inoperative.
51.9	830.9	Top of permanent levee/flood wall at Lincoln Park.
55.0	834.0	Most of both cities inundated by shallow water.

crest date. The model considers a 24-hour precipitation forecast and the projected high and low temperatures for the next five days.

Soil moisture, water content of the snow, and frost depth can be measured accurately throughout the drainage basin well in advance of the flood. While it is possible to measure all three of these items, the water content of the snow cannot be measured very far in advance of the flood. Late winter storms may add a significant amount of snow and water content to spring runoff. The additional precipitation may result in a serious flood even when no previous threat existed.

Precipitation and temperature patterns during the spring runoff, however, can only be predicted by extended weather forecasts. By considering a range of possible temperature and precipitation conditions during the spring runoff, a range of expected flood crests can be made several days or weeks in advance of the flood. Ice action may cause last-minute fluctuations of one to three feet (or even more). For instance following the March blizzard, in 1966, a prediction was made for a 48- to 51-foot crest more than one month before the actual crest occurred. This advance warning provided ample time for extensive protective measures to be taken. After the advance prediction was made, the range of the expected crest heights was decreased every few days as fluctuations in temperature and precipitation warranted.

On the other hand, in 1979, flood crest predictions were erratic due to changing weather conditions and the unusually late thaw. The National Weather Service issued its first "outlook" in January of 1979. At that time, flooding was expected to be less serious than in 1978. In early March, the Service predicted a crest of 44.5 feet, assuming normal temperatures and precipitation. On March 25, the prediction was revised downward to 36 feet and on April 1 it was revised downward again to 34 feet.

However, on April 6, the National Weather Service predicted a 39-foot crest on the Red River at Grand Forks-East Grand Forks. Then, on April 13, the Service predicted a 40- to 42-foot crest to occur on April 24. A revised forecast of 49.5 feet was issued April 19. At this time, the river was already at 41.9 feet. This forecast included one inch of rain above Grand Forks, which did occur. A week later, on April 22, the Service, again, predicted a 49-foot crest for April 23 (by that time the river was already over 48 feet). The actual crest at Grand Forks occurred on April 26 reaching 48.8 feet.

The inaccuracy of flood forecasting is illustrated by the hydrograph of the 1979 flood (fig. 18). Ideally, the "prediction curve" should be a relatively smooth line that predicts the crest date early and accurately. However, this is usually not the case. Changing weather conditions, such as prolonged cold or additional precipitation, necessitate drastic, periodic revisions to the forecast.

Forecasting the 1997 Flood

After the 1997 flood disaster, many people attempted to place the blame on the National Weather Service for erring in their flood forecast. The following discussion examines the series of events and problems that led to the less than ideal forecast by the Service.

As previously discussed, the winter of 1997 was one of extremes. At the beginning of winter, there was heavy precipitation resulting in high soil moisture. Over the winter, the Red River Valley received two to three times the normal annual snowfall (the area received approximately ten inches of snow-water equivalent). Finally, an April blizzard added two to three inches of moisture while also delaying the melt due to cold temperatures. Temperatures rose suddenly on April 17 to above normal and did not drop below freezing overnight.

After the flood, the National Weather Service conducted an assessment of their services provided during the flood of 1997 (U.S. Department of Commerce, 1998). This was done in an effort to determine what had caused the discrepancy between the flood forecast and the actual crest. The intent of the Service was to correct the situation and prevent it from happening again in the future. In this analysis, all of the factors that contributed to the forecast error were reviewed.

The initial "outlook" issued by the National Weather Service in February, 1997 was characterized as "severe" with the potential for the river to exceed the 1979 crest of 48.8 feet (table 5). The public paid little attention to this warning. Despite repeated advertisements by FEMA urging people to buy flood insurance, few policies were written. By February 27, the Service had issued the actual "outlook forecast" stating that the river would crest at 47.5 or 49 feet. This "outlook" remained in effect until a second full assessment was done approximately one week after the April blizzard, "Hannah." This prediction called for a crest of 50 feet. The public expected to hear an increase in the predicted crest height immediately after the storm. However, the lack of increase and the repetition of the forecast, even after "Hannah," gave the impression that the original forecast was precise. Since the cities of Grand Forks-East Grand Forks were already prepared for a flood of 52 feet, three feet above the forecast of 49 feet, there was a sense of complacency.

The forecasts started to change on April 14 as the data from the final storm was compiled. From that point on, the crest forecast increased rapidly, almost every day (fig. 22). As previously stated, the crest forecast more closely represents the median, not the maximum height. What was left unsaid by the National Weather Service was that there is a two to ten percent uncertainty in the forecast amount. It was possible to have a two to ten percent increase (or decrease) over the predicted amount. Ultimately, the river crested within the allotted ten percent. New flood records were set all along the Red River and its tributaries, but none of the other forecasts were five feet off. The amount of error was the greatest at Grand Forks-East Grand Forks. The reasons for this will be discussed in the following paragraphs.

Four separate items that were responsible for the error in the forecast were discussed by the U.S. Department of Commerce (1998). The item responsible for the largest increase in crest height was the rating curve, which, as previously mentioned, is critical to forecasting. The U.S. Geological Survey measures the streamflow in the river and provides discharge and rating-curve information to the National Weather Service (NWS). This information contains only the actual flow for the river; the U.S. Geological Survey does not extend the curves. If the flooding event is larger than previously recorded, the NWS mathematically extends the curve (log-log extrapolation was used for the 1997 flood). These extensions generally work well, but not in areas that have a significant potential for backwater (due to low stream gradient), as in the Red River. In areas affected by backwater, the instantaneous peak discharge may not correspond with the crest. This is what happened in Grand Forks during the 1997 flood - the NWS extended the curve, but missed the peak discharge, which occurred during the rising stage of the river (fig. 34). Thus, the backwater effect was missed. The slowing of the discharge related to the inability of the river to drain rapidly caused the river to rise an additional 2.4 feet.

According to the U.S. Department of Commerce (1998), additional increases in river stage were due in part to the presence of the bridges in downtown Grand Forks-East Grand Forks. The cross-sectional flow area of the channel is less than the natural channel when a bridge is present. This channel restriction usually raises the height of the river during flood stage. The height of the river increases even more when it impinges on the bridge deck. After the flood, the U.S. Department of Commerce (1998) modeled all four of the bridges. It was ascertained that the most critical causes for raising the water levels were the DeMers Avenue (Sorlie) Bridge (which raised the gage level 0.44 feet) and the Foot Bridge (which raised it 0.25 feet). It was found that the Burlington Railroad and Kennedy bridges had minimal effect on the gage level. It follows that the Burlington Railroad Bridge should not cause a measured increase in the river height since it is upstream of the gage.

Aerial photographs taken April 21, 1997, the afternoon before the crest, show a 45-foot wide area of increased surface turbulence on the upstream side of the Burlington Railroad Bridge. The presence of this turbulence indicates obstruction of flow, and suggests that the river height was increased upstream of the bridge. Similar turbulence was not observed on the same photographs for any of the other bridges in question.

Another flood effect that was not modeled was breakout flow ("transbasin flow") from the Red River of the North to the Red Lake River. Breakout flow results when the volume of water is so great it exceeds the capacity of the river, causing it to break out from the main channel. Water may flow across areas where it has not been observed to flow before. The route is usually more direct, as in overland flow in the low points between two streams (this is exhibited frequently by the lake between East Lake Estates and the L&S Subdivision in the south end of Grand Forks and rarely by the Heartsville (Bygland) Coulee on Plate I and fig. 35; U.S. Department of Commerce, 1998).

According to the National Weather Service (NWS), the expected discharge for the Red River at the Grand Forks-East Grand Forks gage should have been approximately the sum of the gages at Halstad, MN (Red River of the North) and Crookston, MN (Red Lake River; U.S. Department of Commerce, 1998). The breakout flow from the Red River to the Red Lake River occurred just north of the Thompson bridge, delivering water to the Heartsville (Bygland) Coulee and another unnamed coulee (fig.35). These two coulees provide a more direct route for the water by having straighter channels, than the Red River. It is argued that the two coulees delivered water faster to the Red Lake River, increasing its flow and the measured discharge at the gage in Grand Forks-East Grand Forks. The NWS discounts the influence of the breakout flow on the gage, stating a need for a source of water not included in the upstream gages at Halstad and Crookston. However, it seems unlikely that there wasn't a significant amount of additional water entering the Red River in the 78 river miles between Halstad and Grand Forks. The same holds true for the 52 river miles between Crookston and Grand Forks.

In summary, the analysis of the 1997 flood shows how difficult it is to accurately predict the amount of flooding likely to occur or to account for the flooding that took place, after the fact. A large number of factors must be accounted for in the computer models. These variables may or may not change, but, when they do, the resulting effects can often be catastrophic. As previously discussed, conditions were right for flooding in 1997; there was a tremendous amount of water in the river system (3.79 million acre-feet of water was discharged at East Grand Forks over 30 days of flooding; Yorke and Harkness, 1997). This was a 45% increase in the volume of water over the previous big flood (1979). Additionally, record floods were recorded at 21 of the 34 forecast points along the Red River and its tributaries (1998, National Weather Service, <http://www.chr.noaa.gov/fgf/floodrec.htm>). It is hard to imagine how the situation could have been worse, but that would have been entirely possible. Grand Forks-East Grand Forks was lucky that there was no additional precipitation or significant ice jams to add to the crest height.

FLOOD DAMAGE REDUCTION

The solution to the flood problem is not to simply remove all structures from the floodplains and prohibit any future development (fig. 36). There are many definite advantages for developing floodplains, despite the flood hazard (Murphy, 1958). The problem, however, is that once individuals have developed the floodplain, they subject the local community to the potential for considerable financial loss. If the individuals bore the entire flood-damage loss themselves, flood-plain development would be of little concern to the government--except as a moral responsibility to the individual who suffers due to his own disregard for the flood hazard. However, the individual is rarely willing to accept full responsibility. Governmental units usually bear the expense of flood fighting, evacuation, damage to private property, and repair of public utilities. Heavy public investment often must therefore follow private investment on floodplains. These developed areas are a potential permanent drain on the economies of cities. Intelligent planning and regulating of development in these floodplain areas is imperative, therefore, if damage from flooding is to be reduced.

Possible Means of Reducing Flood Loss

The following methods are usually employed to reduce flood losses (Murphy, 1958).

1. Engineering works: levees, reservoirs, channel

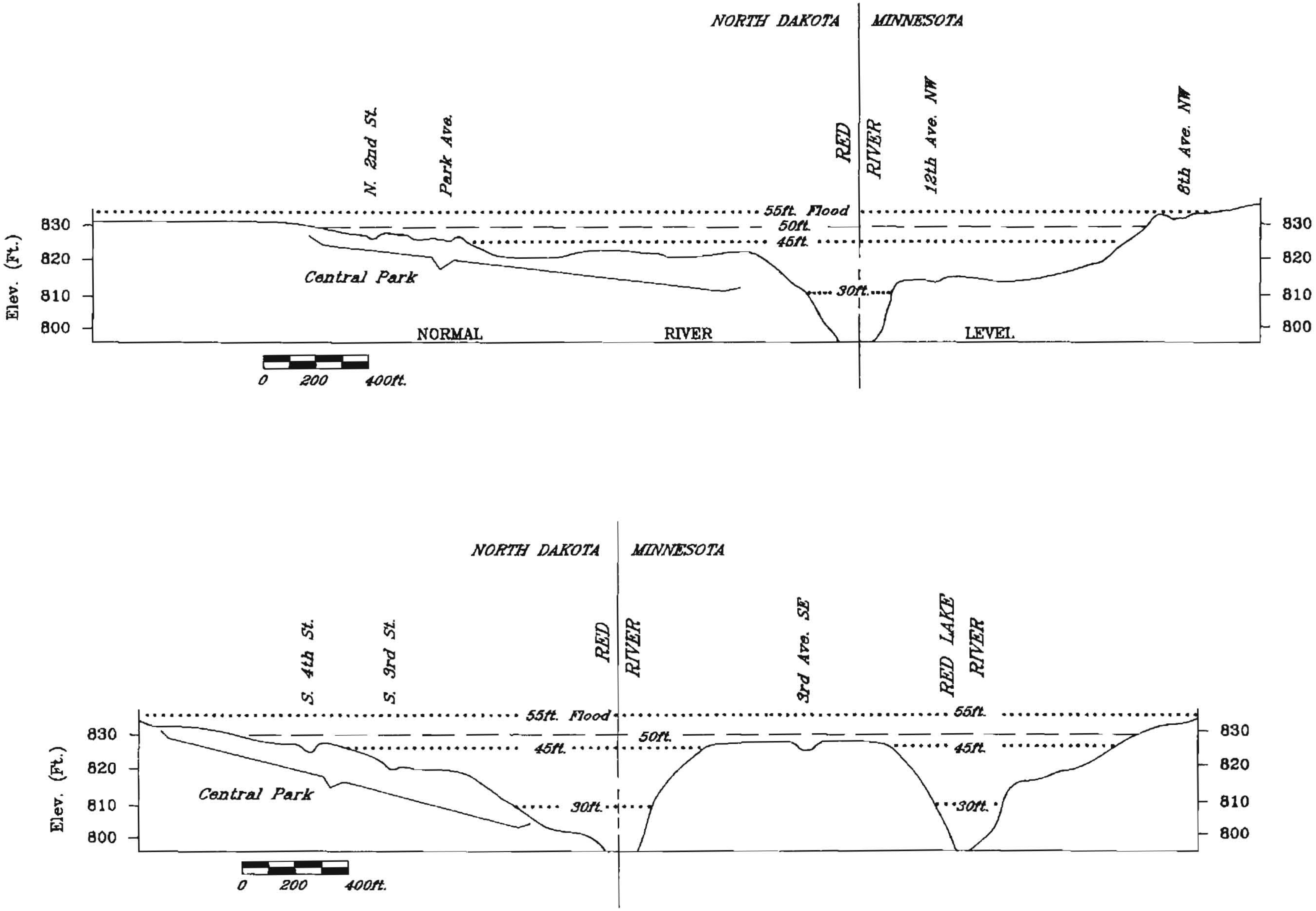


Figure 32. Profiles of the flood-hazard areas in the Riverside vicinity (A-A', above) and in the Central Park vicinity (B-B', below), both in Grand Forks.

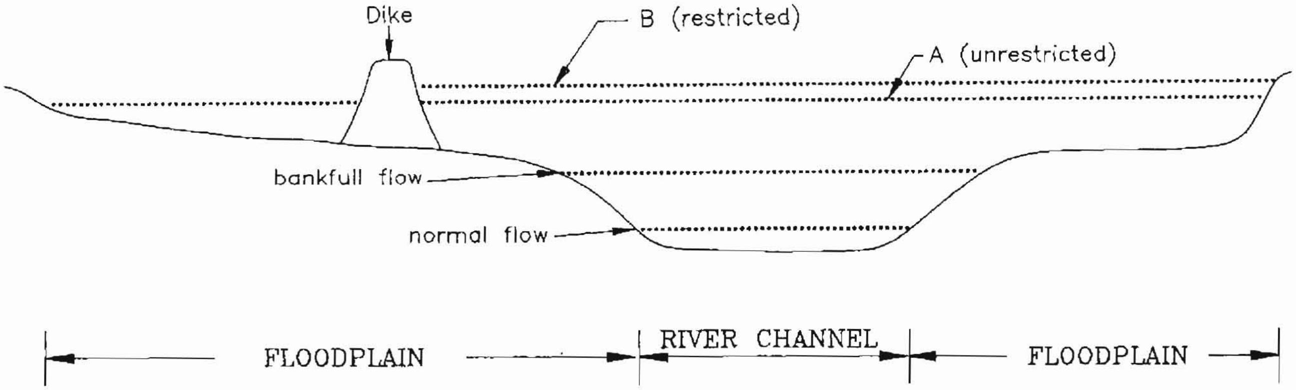


Figure 33. Diagram showing the effects of diking. This diagram shows that, without a dike, the river will flow at the level marked A (unrestricted). If a dike is built, that water which would have flooded the land protected by the dike is forced to flow within the dike. Most of this water contributes to raising the river to a new, higher level, B (restricted), although some of it helps to increase the river's velocity and some adds to flooding additional land upstream from the diked area.

enlargement and straightening, and channel bypasses. These are usually thought of as the best combination of solutions to flood problems. Experience has shown, however, that such protection is usually economically impractical.

2. Regulation of development: not necessarily prohibiting development, but defining the type of land use for the floodplain.

3. Adjustments in structures: including landfill, changing the design and layout of buildings, elevating equipment, water proofing structures, etc. This is generally referred to as flood-proofing.

4. Emergency measures: temporary evacuation of flooded areas and rescheduling of services, transport routes, etc.

5. Loss protection: flood insurance may sometimes be available from the federal government to distribute losses.

Only after careful study of the problem can the best, most economical solution for reducing flood losses be found. In most instances, a combination of all of the above methods is applied.

Grand Forks-East Grand Forks

Several strategies for dealing with future floods were considered by the U.S. Army Corps of Engineers for Grand Forks-East Grand Forks after the flood of 1997 (U.S. Army Corps of Engineers, 1998b). These include:

1) "No Action" Plan: there would be no flood-reduction project constructed in Grand Forks-East Grand Forks. The cities would continue to rely on the existing temporary levee system and emergency flood-fighting efforts. This would result in continued flood damage and the possible destruction of additional neighborhoods in the future. Also, a large portion of Grand Forks-East Grand Forks would be placed in the 100-year floodplain requiring flood insurance. It is estimated that, with the revision of the FEMA flood map, 15,000 structures will be included in the 100-year floodplain. Included in these are: residential, commercial, industrial, and public structures. The National Flood Insurance Program would also restrict building in certain areas within the two cities. The plan was considered to be socially unacceptable by the cities of Grand Forks and East Grand Forks.

2) "Nonstructural Measures": such as floodproofing to minimize flood damages, and evacuation and relocation of homes to place flood-prone structures outside the floodplain. This was considered not to be socially or economically acceptable by the cities of Grand Forks and East Grand Forks.

3) "Downstream and In-town Channel Modification Plans": to deepen, widen, or straighten the river and thereby reduce flood stages. These plans would not significantly reduce the flood stage of the river and were considered to be economically and/or environmentally unsound.

4) "Bridge Modifications": the raising or removal of bridges within the study area to reduce flood stages.

5) "Diversion Channel Plans": examination of several plans on both sides of the Red River to divert flood waters around the urban area.

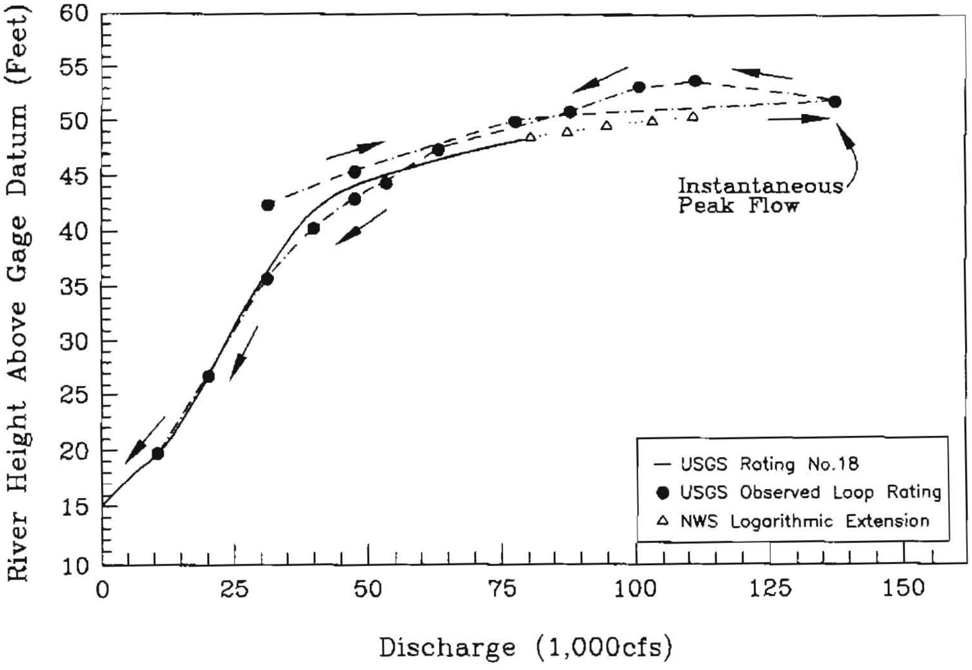


Figure 34. U.S. Geological Survey rating curve for the East Grand Forks gage for the flood of 1997. Gage datum is at 779 feet msl (modified from the U.S. Department of Commerce, 1998).

6) "Basin-Wide Reduction Methods": All of these plans were evaluated and considered by the U.S. Army Corps of Engineers not to be an effective primary method of flood control. Implementation of some of these procedures could provide a secondary method of flood damage reduction over the long range. Methods evaluated include plans for upper-basin storage and change in the operations at existing Federal reservoirs.

The U.S. Army Corps of Engineers recognizes a need for a permanent levee system (U.S. Army Corps of Engineers, 1998b). Engineering water-storage projects for the area upstream of Grand Forks-East Grand Forks is extremely difficult. In part, this is because the upstream drainage area is so large (30,100 square miles) and flat. Studies conducted by USACE on the Red Lake, Wild Rice, and Sheyenne Rivers show that implementation of major water-storage projects along these rivers would reduce the stage of a 100-year flood by only one foot. Such projects were considered to be infeasible from an economic, social, or environmental standpoint primarily because of the amount of affected riverine land and farmland.

Other federal storage projects examined by the U.S. Army Corps of Engineers (1998b) included Lake Traverse in northeastern-most South Dakota and western Minnesota. Assuming additional storage capacity for the reservoir, Lake Traverse has the potential to control runoff from only 6% of the drainage area upstream of Grand Forks. This would not normally reduce the flood stage at Grand Forks significantly. Twenty other projects upstream in Minnesota that were examined were determined to have the potential to reduce the flood stage at Grand Forks by only 0.11 foot (a reduction of 1%).

The U.S. Army Corps of Engineers (USACE) also examined another upstream storage plan. This plan, referred to as the "waffle plan," utilizes farmland to retain water until the flood threat is over. Calculations by the USACE determined the "waffle plan" would require 3 feet of water to be stored over 1,120 to 2,150 square miles of farmland. It would require a "well-coordinated operating plan with defined timed storage requirements" and maintenance system in order to be effective in flood reduction. According to the USACE, the other drawback with this proposal is that it would not improve federal floodplain delineations.

It was ultimately determined that none of these basin-wide programs were as effective as a primary flood-reduction mechanism. However, we believe that implementation of some or all of the plans could provide an additional layer of safety when applied in combination

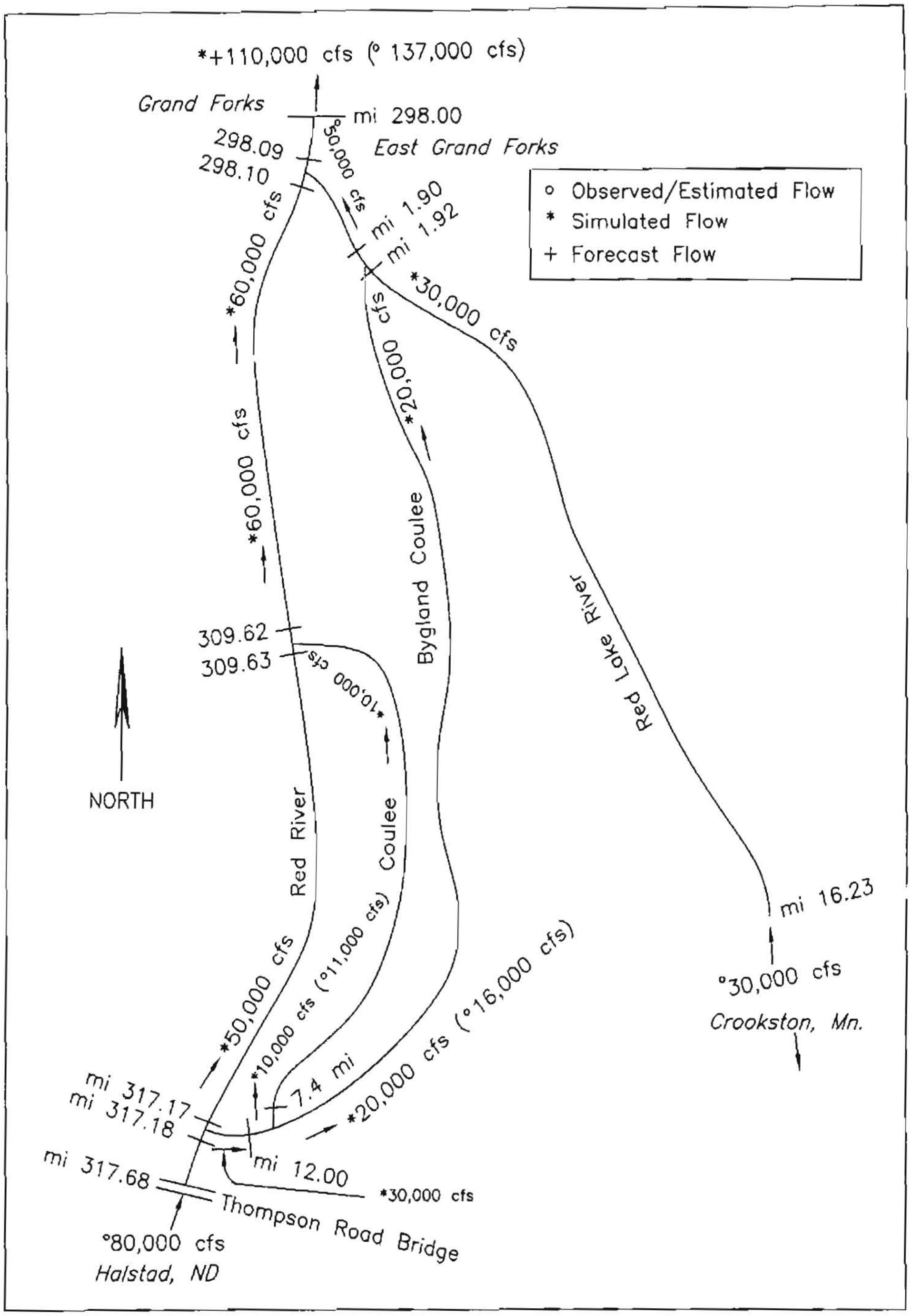


Figure 35. Schematic diagram of the breakout flow ("transbasinal flow") from the Red River of the North to the Red Lake River. Initial discharge measurements are taken from the gages at Halstad, Minnesota (Red River) and Crookston, Minnesota (Red Lake River; modified from the U.S. Department of Commerce, 1998).

with a permanent levee system.

7) "Permanent Levee/Floodwall Plans": plan for a permanent flood-control system. The system would involve set back from the river where practical to improve hydraulic efficiency. Greenway spaces would be added to the recreational features already present. The result would be a cost-effective flood reduction program.

Four plans were studied further by the U.S. Army Corps of Engineers in an attempt to develop a long-range flood-control plan. These are:

1) Minnesota Diversion: a large diversion on the Minnesota side of the river. An early evaluation of the plan, completed in July 1997, determined that it was not economically or socially feasible. The plan was withdrawn by the local sponsor.

2) Setback Levee/Floodwall System: levees were evaluated that would contain a 50-, 100-, and 210-year flood. It was determined that the 210-year levee of Levees/ Floodwall plans were the most cost-effective method of flood control. The cost of this plan, approximately $300 million, would be funded 50/50 between federal and non-federal entities. It would take 4 to 5 years to build and affect 350 additional structures. Included in this is an English Coulee closure plan that would prevent the Red River from backing up into the coulee. This plan would meet all of the requirements from a flood-insurance perspective.

This plan was considered to be one of the locally preferred plans, an economically feasible plan selected by the non-federal local sponsors. The Corps determined that the plan would have an 86% reliability against a 210-year flood event and would control a flow up to 136,900 cfs and a river stage of 58.5 feet. The Corps also stated that the Levee/Floodwall system would be a "solid foundation for future-flood fighting measures."

3) Minnesota Split-Flow: this plan includes a smaller diversion channel and lower-height levee system.

4) Western Split-Flow Diversion: would provide reliable flood control and an extra measure of safety with an in-town levee system and a large diversion on the North Dakota side of the river. The combined effect of this plan would provide protection up to a 500-year flood event (95% reliability of containing the event). It would contain an in-town flood to 51-foot river stage and a discharge to 136,900 cfs. The cost was calculated at $900 million with 4 to 5 years needed for construction of 100-year levees and ten years needed to construct the diversion channel. The cost/benefit ratio that determines the possibility of federal funding was low, suggesting that federal monies would not be available for the project.

The western split-flow diversion system was the other locally preferred plan. It provides an extra level of safety and reliability by providing more protection for larger floods without emergency flood-protection measures.

National Economic Development Plan

The National Economic Development Plan (NED) is determined by the U.S. Army Corps of Engineers as the plan that has the highest benefits for the cost (the NED must have a benefit-to-cost ratio of at least 1.0). Designs and costs for the permanent flood-control plan were evaluated for a 50-year, 100-year, and 210-year flood. The Corps determined that the 210-year plan had the highest benefits for the cost (1:1.2) designating it as the NED plan. This plan will require removal of 35 single family homes and four commercial buildings in East Grand Forks and 151 family homes and four commercial buildings in Grand Forks.

The Corps also examined the possibility of increasing the height of the levees. However, in order to increase the height, the levees would have to be set back farther from the river at a greater expense. The additional benefit from the higher levee did not justify the cost and would result in a greater number of social impacts.

There are problems on both sides of the river in dealing with the NED plan (fig. 37). These problems required additional dike-alignment studies. For example, the south-end alignment in Grand Forks was extended one mile from County Road 17 to the Merrifield Road (County Road 6). This happened because fill requirements and utility costs associated with the construction of the levees were lower at the Merrifield Road than at County Road 17.

Other problems with the NED plan involve the L&S Subdivision, Shady Ridge Estates, and East Lake Estates in Grand Forks County. In this area, the Corps evaluated three separate dike alignments (fig. 36). The alignment closest to the river, which includes all three subdivisions, is preferred by Grand Forks County, but would cause significant increases in river stages during flooding events. This plan is also the most costly. The Corps stated that the houses located in these subdivisions are largely outside of the existing 100-year floodplain and are not subject to frequent flooding, therefore, benefits for providing permanent flood protection features for these areas are low (U.S. Army Corps of Engineers, 1998b).

Numerous political problems exist with the placement of these houses on the "wet side" of the levee system. Some objections raised involve the decrease in property values of these homes and the inability for resale, increased potential for flooding in these neighborhoods from the Red River, Elm Coulee, and Cole Creek, ineligibility for future FEMA funding, and eligibility for flood insurance.

Two areas, one at the north end and one at the south end, in East Grand Forks were also studied for possible dike re-alignment (fig. 37). The re-alignment of the levees in these areas are considered betterments by the Corps and are not included in the existing plans, but could be pursued in the future.

Existing Flood Protection

Permanent Dikes in Place

Permanent flood protection in both cities consists entirely of flood levees, locally referred to as dikes. In 1958, the U.S. Army Corps of Engineers constructed a dike in the Lincoln Park area of Grand Forks. The dike consists of 5,160 feet of earthen levee and 770

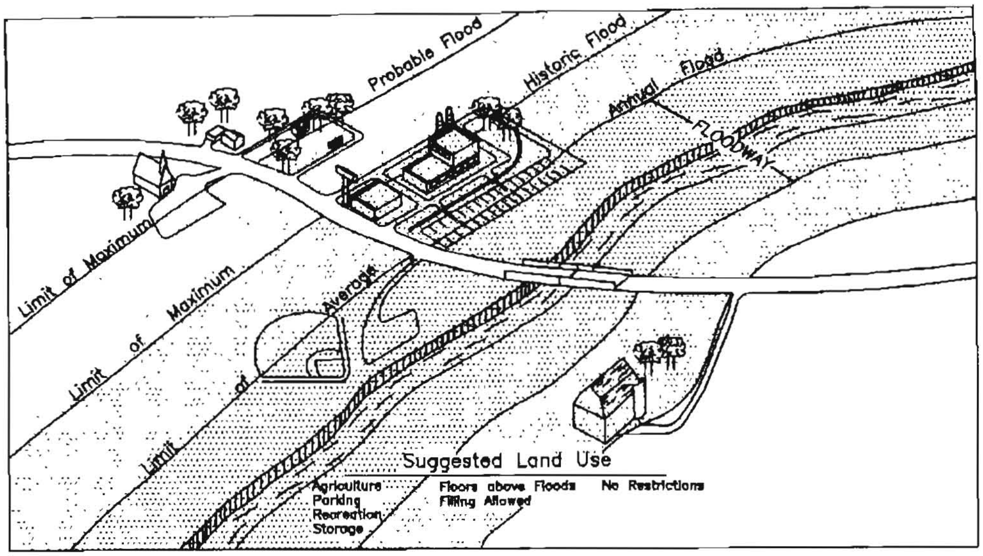


Figure 36. Proposed land-use categories for areas flooded at various river levels.

feet of concrete floodwall, as well as associated interior drainage works. The top of this dike is at an elevation of 832.0 feet at the north or downstream end, and 832.5 feet at the upstream end. The dike provides adequate protection from floods up to about 52 to 53 feet above gage datum. The area behind the Lincoln Park dike is protected from back-flooding through storm sewers by an emergency pumping system. The total cost of the Lincoln Park dike, including construction, relocation of homes, and land purchases, amounted to $1,307,000 ($7,349,048 in 1998 dollars), of which $940,000 ($5,285,467 in 1998 dollars) was paid by the federal government. Although adequate protection was provided by the Lincoln Park dike during the 1979 flood the dike was topped during the 1997 flood, resulting in extensive flooding.

Emergency levee works constructed during the 1975 flood remain at two locations in Grand Forks. A 1,500-foot-long earthen levee protects the Central Park area, and a 2,800-foot-long earthen levee plus a 650-foot-long wood plank floodwall protect the Riverside Park area. This levee was overtopped during the 1979 and 1997 floods.

Permanent dikes in East Grand Forks also total about 1 ½ miles in length (about 8,000 feet). Most of these dikes were constructed during 1966 in the few weeks prior to the flood that year. Because they were built as emergency dikes, most of the construction was covered by reimbursements from the Federal Office of Emergency Planning. Had they been constructed of conventional sandbags, rather than clay, they probably would not have been suitable as permanent dikes. The dikes were constructed to withstand floods from 47 to 48 feet high (Floan, written communication). This level was topped in 1979 and the dikes had to be raised with sandbags. These dikes were also topped during the 1997 flood.

East Grand Forks

At the time of this writing (July, 1999) East Grand Forks has progressed faster than Grand Forks with its new flood-control program. Most of the damaged houses and buildings have been removed. A combination of an 26 foot high earthen levee and an 880 foot long invisible floodwall has been constructed in East Grand Forks.

The floodwall consists of an elevated, reinforced concrete wall with vertical cement supports that is imbedded in the underlying strata. Horizontal, hollow aluminum planks with interlocking surfaces stack within the vertical supports. These planks are then secured by a horizontal locking device that is mounted to the vertical support beam. Diagonal braces add additional support to the wall.

The floodwall rises to a height of 14 feet above several street crossings and is set back from the previous earthen dikes allowing the river to have a slightly wider channel. The floodwall is tied into earthen dikes on both ends. Existing dikes will be re-aligned as the project progresses.

English Coulee

The English Coulee joins the Red River four miles downstream from the confluence between the Red River and the Red Lake River. There are 115 square miles of drainage in the English Coulee watershed (fig. 20). When floodwaters from the coulee significantly damaged the southwestern portion of Grand Forks during the 1979 flood (fig. 24), the U.S. Army Corps of Engineers devised a plan for flood reduction.

The U.S. Army Corps of Engineers constructed a dry dam to control the runoff for the uppermost portion of the English Coulee watershed (53.5 square miles) after the flood of 1979 (U.S. Army Corps of Engineers, 1998a). Downstream of the dam, a channel diverts the outflow from the dam. It also diverts the flow for an additional 8.7-square-mile area up to about 980 cfs. The remaining 29.3 square miles contributes the majority of the flow from the English Coulee.

A diversion channel was also constructed for the English Coulee to prevent backwater flooding from the Red River. The Red River floods the English Coulee by backing up due to its inability to drain away fast enough. It backs up not only in the main channel, but also along its tributaries. This backwater affects the English Coulee drainage basin. The Corps constructed a diversion channel that redirects the water that is backing up away from the north end of town to the dry dam. The channel was designed to be effective up to a river stage of 51.5 feet and, in fact, it was successful during the 1997 flood. Significant backwater did not occur along the English Coulee until the Red River exceeded 51.5 feet. The diversion delayed the southerly flow in the coulee through the culvert at the Burlington Northern Railroad tracks. This slowed the inundation rate and reduced the size of area that may have been flooded south of the Burlington Northern Railroad tracks.

Discussion of Future Flood-Loss Reduction

The 1979 Red River and English Coulee floods raised a great deal of controversy. The Grand Forks Herald, in May 1979, solicited suggestions for dealing with both the Red River and English Coulee flooding problems. Several people responded by suggesting dams, reservoirs, and additional, higher dikes to retain water during flooding situations. Dredging and channelization were proposed by some readers and others suggested that farmer-built dikes should be removed. It was suggested that the tributaries be shut off and one person proposed that the Red River be made to flow south instead of north.

Shelterbelts to collect snow and retard runoff were proposed by one reader. Another person suggested: "Take 100 feet from each side of the river and landscape the sides to channel a much larger waterway." A reader from Pisek offered what may be the most insightful suggestion: "The only way to get on top of this flood thing is to start controlling the snowmelt and water runoff at the upper reaches of any tributary--any river, stream, creek, coulee, drainage ditch, etc., that empties into the Red River. It will be necessary to have some means of controlling or regulating the flow of water in and from any and all of these, all up and down the Red River Valley, to benefit the entire area. Channelization... would definitely be the wrong way to go. It would only magnify the present problems. Building or raising dikes--while it may be the first thing to come to mind, especially during a crash effort in an emergency--is not the answer, except in a very few isolated cases. It would be rather impractical to try to dike tributaries very far back."

Clearly, no single solution will solve all of the flooding problems. It is interesting to note that, after the major flood of 1997, the same topics as those discussed in previous years are still under discussion, perhaps even stronger than before. Change is happening to Grand Forks-East Grand Forks whether it is welcome or not. The 1997 flood changed the landscape permanently. Neighborhoods that thrived no longer exist. Once again, the city is looking at removing the temporary dikes and constructing a permanent flood control system in their place. Neighborhoods that are in the dike alignment, on the "wet side" of the dike, and other concerned citizens are questioning the U.S. Army Corps of Engineers flood-reduction plan. Basin-wide water management is a topic that arises in most discussions on flood control. Although the ideas sound good, implementation of a solid basin-wide flood plan is difficult. Political, as well as economic issues work against, or at least delay, a basin-wide plan.

Grand Forks-East Grand Forks Flood Reduction Plan

Since the 1997 flood, the cities of Grand Forks and East Grand Forks have been working with the U.S. Army Corps of Engineers to develop a multi-purpose flood-reduction project for the Red River of the North and the Red Lake River. The final report for the proposed levee/floodwall plan was finished in the fall of 1998 (U.S. Army Corps of Engineers, 1998b). After examination of a variety of different proposals, the following discussion will detail the chosen National Economic Development Plan (the NED Plan). This is the plan that has the greatest net benefits and is the plan that the Federal Government is most supportive of constructing.

The NED plan will provide necessary flood reduction with a reliable foundation for emergency flood-fighting measures. Additionally, the plan includes diversion channels for the English and the Heartsville Coulees. It removes the pedestrian bridge (the old Great Northern Railway Bridge) and includes many recreational/greenway features with the construction of a new pedestrian bridge linking the two cities.

The plan includes a permanent levee and floodwall system that is designed to contain a 210-year flood (86% reliability). This equates to a river stage of 58.5 feet and a discharge event of 136,900 cfs. It would require approximately 735 acres of fee title real estate interests of unimproved and city-owned properties, the acquisition of 252 single-family residences, 95 apartment or condo units, and 16 businesses. It would require the

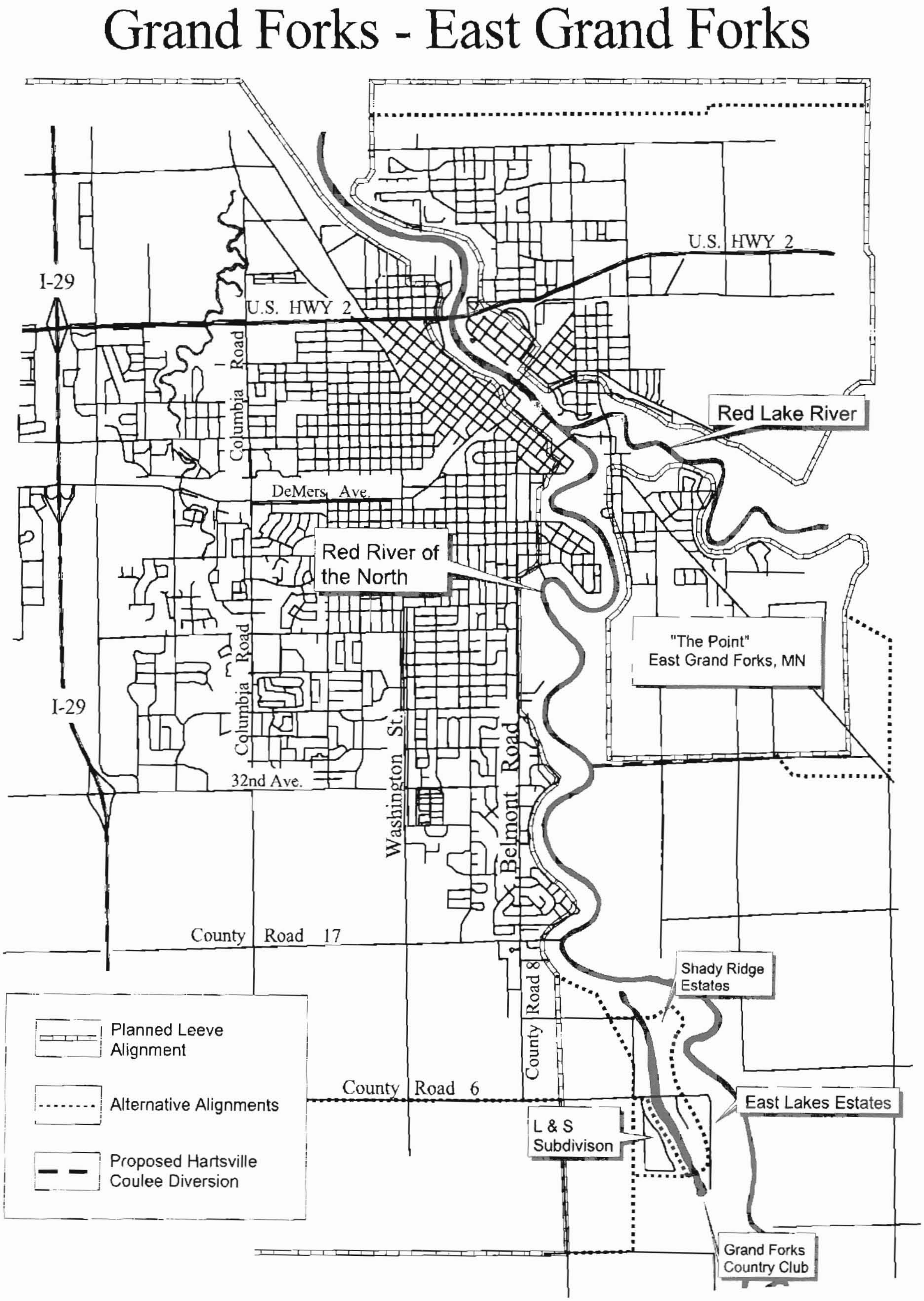


Figure 37. Proposed flood control project for Grand Forks-East Grand Forks showing the National Economic Development (NED) alignments and the possible alternative alignments of the levees and floodwalls (U.S. Army Corps of Engineers, 1998b). The location of the Heartsville (Bygland) Coulee diversion is also indicated.

relocation of numerous utilities, the removal of the existing pedestrian bridge and construction of a new replacement bridge.

Two main criteria were used in formulating the levee/floodwall plan (U.S. Army Corps of Engineers, 1998b). The alignment was based on the bank stability for the levee foundations and hydraulic capacity of the river channel. Secondary criteria included minimizing the cost with the least costly alignment being the best, avoiding historical and environmental resources, avoiding historic structures, maintaining the system integrity, and maintaining the infrastructure (insuring utilities and roads are designed into the alignments). The system integrity includes "minimizing levee height (maximum of 10 feet), constructing floodwalls where emergency dike construction can be easily accomplished, and accounting for potential river flow induced erosion, especially at sharp bends in the river."

The plan also addresses the problems associated with the coulees in Grand Forks-East Grand Forks. Diversion channels will be constructed for the English and Heartsville Coulees. Both of these channels will have gated control with a pumping station for the flow behind the closed gates and will be designed for 100-year flows during flood periods. A 3.5-mile-long extension will be added to the existing English Coulee diversion. The existing diversion will be expanded to intercept flow from the English Coulee and a smaller second coulee west of Grand Forks. A second diversion is to be constructed on the Heartsville (Bygland) Coulee. This will divert water westward to the Red River rather than allowing it to flow north into East Grand Forks. In addition to the diversions, a pumping station will be placed on Belmont Coulee.

The current estimated cost of the flood-reduction project for Grand Forks-East Grand Forks is $350,431,000 and has an overall cost-to-benefit ratio of 1:1.10. Additionally, Grand Forks-East Grand Forks will be responsible for the annual cost of operation and maintenance of $1,012,250 and another $346,750 for recreational features.

Several questions or concerns, in addition to those cited in the report, can be raised in reviewing the flood control plan for the cities of Grand Forks-East Grand Forks that has been proposed by the U.S. Army Corps of Engineers (U.S. Army Corps of Engineers, 1998b).

Examination of some of the alternate forms of flood control were stopped, almost before they started (example: the diversion of the Red Lake River at times of peak flood into its abandoned river channel, the Grand Marais Coulee). These plans were not evaluated for social or economic reasons. Other alternatives examined by the Corps, specifically the split-flow diversion channel and permanent levee plan, have higher degrees of safety. This would be preferential to the levees only plan, yet is not under consideration because it is too costly.

Justification for the flood control project (NED Plan) that is currently under consideration, is that it meets the benefit-to-cost ratio needed for federal funding. If one of the other plans were chosen, the cities of Grand Forks-East Grand Forks would have to incur all of the expenses instead of only half. Even though such a plan would provide a much greater measure of safety cannot be justified under the current method used by the Federal Government. In the long term it could prevent future disasters and their incurred expense and it would ultimately pay for itself. For example, after suffering heavy losses by the 1950 flood, the City of Winnipeg constructed a floodway. The floodway cost the City of Winnipeg and the Canadian government $63.2 million (estimated to cost $300 to 500 million in 1998 dollars) to build in the early 1960's, yet it has successfully protected the town 18 times and saved the city several billion dollars.

Examination of the NED plan raises several questions. The following discussion will attempt to answer some of the questions.

Why is the realiabiltiy of the flood-control project only 86%, when it supposedly protects to the 1997 flood level?

As part of the flood-reduction study for Grand Forks-East Grand Forks, a risk analysis was performed on the proposed project and alternative projects. Depending on the circumstances, there are multiple gage heights associated with any given river discharge. The risk analysis examines the probability distribution of the gage heights for each of the discharge values and, based on those values, determines the exceedence probabilities. This analysis determined that there was an 86% probability that the discharge equated to the 210-year flood (136,900 cfs) will be below the top of the levees for the project. In other words, there is a 1 in 7 chance that a flood with a discharge of 136,900 cfs (the 1997 peak flow) will top the levees.

Why is there a discrepancy between the measured discharge and the stage height reported by the Corps and used to determine the height of the future levees?

The U.S. Army Corps of Engineers (1998b) equates a river discharge of 136,900 cubic feet per second (cfs) to a stage height of 58.5 feet. They determined this to be equivalent to the 210-year flood and it is the basis for the permanent flood-protection plan. Examination of the actual 1997 flood shows that when the Red River reached this discharge it was still within the current levee/floodwall system. The river was at a stage of 52.2 feet. Later, when the actual crest arrived the discharge had decreased to 114,000 cfs. This decrease in discharge at the gage follows because the river had topped the levees, spread out over its floodplain, slowed down, and was starting to pool. The explanation for the discrepancy between the Corps calculations and what actually was observed is explained using the rating curve.

The Corps assumed that 136,900 cfs was anomalous because it was below the original rating curve; the 114,000 cfs value plotted on the original rating curve. Although the reason for the discrepancy is not completely understood, it was assumed to be related to availability of downstream storage, the timing of the flows through the area, breakout flow into the Heartsville Coulee, and the early April blizzard. The Corps is taking the conservative approach to the problem. The accommodation space and other factors that may have created the discharge may be unusual, but the discharge value was measured and should not be ignored. Since the crest plotted on the original rating curve and there is a range in gage heights for each discharge value, they adjusted the 136,900 cfs to the original curve and determined its corresponding stage height to be 58.5 feet.

What are the implications of the Heartsville (Bygland) Coulee diversion?

Another question arises when examining the NED plan for East Grand Forks. A diversion is planned for southern East Grand Forks along the Heartsville (Bygland) Coulee (fig. 37). This diversion will direct the northward flow of the coulee westward to the Red River. The diversion would come into effect when the discharge of the Red River was significant enough to have breakout flow from the Red River into the Heartsville (Bygland) Coulee, as in 1979 and 1997. When the flows are large enough to break out of the main channel, is it wise to divert that water west back to the Red River south of East Grand Forks? In one instance it protects East Grand Forks, yet in another instance it expedites the delivery back into the main stem Red River. Will this additional water moving at a faster rate cause a backwater effect when it reaches the dike system and the narrows (the confluence of the rivers), thereby increasing the stage height of the river upstream? The timing of flows and water movement will have to be modeled before these questions can be answered.

Is it necessary to remove the Great Northern Railroad Bridge?

Of historical concern to the community is the removal of the Great Northern Railroad Bridge. The question has been raised as to whether the slight increase in river stage justifies its removal. The bridge was determined to increase the stage height 0.6 ft at the gage and 0.2 ft at the south end of town.

What effect will the South End Drainway have on flooding and the south end of Grand Forks?

The South End Drainway crosses the southern portion of Grand Forks and was designed to prevent overland flooding. While it will prevent overland flooding during lesser floods, chances are it will act as a delivery system for the rivers to the southern portion of town during significant floods.

Future Remedial Actions

The potential exists that Grand Forks-East Grand Forks will eventually have a flood of greater magnitude than the 1997 flood. In addition to the levee/floodwall system, the U.S. Army Corps of Engineers (1998b) recommends that long-range strategies or measures be developed for Grand Forks and East Grand Forks to keep the town safe and dry. These long-term measures would include the design of local, county, and township roads and future highways as secondary lines of flood defense against potential future levee overtopping and/or failure (ex - South Washington Street). Also, as the bridges become obsolete, the replacement bridges should be designed so as not to obstruct the flow of the river. These new bridges can be designed as multi-purpose links that are strongly connected to the greenway. It would also be possible to reduce flood stage by elevating existing bridges.

Short-term flood-reduction measures include maintaining up-to-date emergency flood-fighting plans, requiring national flood insurance for flood-prone properties, revised floodplain management plans that accurately reflect changed physical conditions, and safety-related betterments, such as increasing the height of the proposed concrete floodwalls.

CONCLUSIONS

Grand Forks and East Grand Forks were built along the river because of the advantages of the location--the availability of river transportation, woodlands on the floodplain for construction and fuel, and a ready source of water. Many of these advantages have evolved into disadvantages--problems in maintaining an orderly pattern of growth given the constraints of the river and railroad and a repeated flooding problem. It is too late to move the cities and the already-developed residential areas on the floodplain, which probably should have been left to the river. It is, perhaps, an unfortunate fact that, even given the benefit of sound planning advice, city governments almost always tend to "cave in" to pressure from interests that stand to profit from ill-advised development.

In the opinion of the writers of this report, the best approach to alleviating the flooding problem in Grand Forks-East Grand Forks consists of adopting strict, informed, land-use controls for flood-plain development to reduce flood damage and flood-control effort. Areas that suffer repeated, severe flooding should be vacated to the river. The great initial expense of relocating homes and businesses will eventually be offset by reduced costs in combating future floods. The additional width returned to the river will help to lower future river crests and the city will benefit from the newly created parkland.

We want to stress that, except for placing structures in the path of floods, the flood problem in Grand Forks-East Grand Forks is not due entirely to human actions. Diking, road construction, increased sediment in the river channel from farmed land all tend to affect the flood situation in various ways. Regardless of what humans have done to the land or may do to alleviate the problem, whenever the weather refuses to cooperate, it produces a flood. Unofficial accounts of several eighteenth and nineteenth-century floods higher than any we have experienced this century are probably accurate; absolutely no responsibility can be assigned to man for any of these floods. We will continue to have severe floods and there is no reason to believe we've seen the last or the worst of the Red River. Our best recourse is to try to minimize the damage and then "get out of the way" when floods happen.

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APPENDIX 1A

ANNUAL FLOOD OF THE RED RIVER AT GRAND FORKS-EAST GRAND FORKS— HIGHEST LEVEL REACHED DURING EACH YEAR

APPENDIX 1B

RANK, HEIGHT, AND RECURRENCE INTERVAL OF FLOODS IN GRAND FORKS - EAST GRAND FORKS

APPENDIX 1A
ANNUAL FLOOD OF THE RED RIVER AT GRAND FORKS-EAST GRAND FORKS— HIGHEST LEVEL REACHED DURING EACH YEAR

Date	Level	Date	Level	Date	Level
1882	48.00	1921	20.90	1960	28.88
1883	42.20	1922	28.72	1961	9.75
1884	31.10	1923	26.60	1962	34.45
1885	23.10	1924	8.20	1963	21.23
1886	20.60	1925	19.00	1964	22.71
1887	16.30	1926	18.10	1965	44.92
1888	29.50	1927	21.70	1966	45.55
1889	12.00	1928	21.80	1967	37.50
1890	10.60	1929	28.30	1968	20.03
1891	17.70	1930	18.90	1969	45.69
1892	33.40	1931	6.48	1970	34.42
1893	45.50	1932	22.07	1971	27.86
1894	26.90	1933	15.18	1972	38.73
1895	9.90	1934	10.02	1973	27.32
1896	32.00	1935	13.07	1974	40.25
1897	50.20	1936	25.00	1975	43.30
1898	15.00	1937	11.57	1976	34.58
1899	20.90	1938	15.49	1977	8.71
1900	13.20	1939	20.13	1978	45.73
1901	26.30	1940	21.88	1979	48.81
1902	26.00	1941	27.86	1980	31.01
1903	28.00	1942	24.10	1981	14.68
1904	40.65	1943	38.16	1982	37.18
1905	26.11	1944	19.79	1983	29.17
1906	36.00	1945	32.00	1984	37.06
1907	39.95	1946	33.23	1985	25.90
1908	32.80	1947	40.71	1986	37.00
1909	18.80	1948	41.68	1987	33.19
1910	30.70	1949	29.11	1988	21.16
1911	10.70	1950	45.61	1989	44.37
1912	12.73	1951	33.52	1990	17.56
1913	26.70	1952	33.60	1991	17.63
1914	17.50	1953	24.63	1992	23.30
1915	30.80	1954	18.63	1993	36.39
1916	41.00	1955	26.17	1994	34.30
1917	32.50	1956	32.43	1995	39.80
1918	11.30	1957	24.67	1996	45.90
1919	23.20	1958	16.03	1997	54.35
1920	41.00	1959	16.10	1998	39.84

APPENDIX 1B
RANK, HEIGHT, AND RECURRENCE INTERVAL OF FLOODS IN GRAND FORKS - EAST GRAND FORKS

Rank	Date	Height	Interval
1	1997	54.35	118
2	1897	50.20	59
3	1979	48.81	39
4	1882	48.00	30
5	1996	45.90	24
6	1978	45.73	20
7	1969	45.69	17
8	1950	45.61	15
9	1966	45.55	13
10	1893	45.50	12
11	1965	44.92	11
12	1989	44.37	10
13	1975	43.30	9
14	1883	42.20	8
15	1948	41.68	8
16	1920	41.00	7
17	1916	41.00	7
18	1947	40.71	7
19	1904	40.65	6
20	1974	40.25	6
21	1907	39.95	6
22	1995	39.90	5
23	1998	39.84	5
24	1972	38.73	5
25	1943	38.16	5
26	1967	37.50	5
27	1982	37.18	4
28	1984	37.06	4
29	1986	37.00	4
30	1993	36.39	4
31	1906	36.00	4
32	1976	34.58	4
33	1962	34.45	4
34	1970	34.42	3
35	1994	34.30	3
36	1952	33.60	3
37	1951	33.52	3
38	1892	33.40	3
39	1987	33.19	3
40	1946	33.10	3
41	1908	32.80	3
42	1917	32.50	3
43	1956	32.43	3
44	1945	32.00	3
45	1896	32.00	3
46	1884	31.10	3
47	1980	31.01	3
48	1915	30.80	2
49	1910	30.70	2
50	1888	29.50	2
51	1983	29.17	2
52	1949	29.11	2
53	1960	28.88	2
54	1922	28.72	2
55	1929	28.30	2
56	1903	28.00	2
57	1941	27.86	2
58	1971	27.86	2
59	1973	27.32	2
60	1894	26.90	2
61	1913	26.70	2
62	1923	26.60	2
63	1901	26.30	2
64	1955	26.17	2
65	1905	26.11	2
66	1902	26.00	2
67	1985	25.90	2
68	1936	25.00	2
69	1957	24.67	2
70	1953	24.63	2
71	1942	24.10	2
72	1992	23.30	2
73	1919	23.20	2
74	1885	23.10	2

Rank	Year	Height	Interval
75	1964	22.71	2
76	1932	22.07	2
77	1940	21.88	2
78	1928	21.80	2
79	1927	21.70	1
80	1963	21.23	1
81	1988	21.16	1
82	1921	20.90	1
83	1899	20.90	1
84	1886	20.60	1
85	1939	20.13	1
86	1968	20.03	1
87	1944	19.79	1
88	1925	19.00	1
89	1930	18.90	1
90	1909	18.80	1
91	1954	18.63	1
92	1926	18.10	1
93	1891	17.70	1
94	1991	17.63	1
95	1990	17.56	1
96	1914	17.50	1
97	1887	16.30	1
98	1959	16.10	1
99	1958	16.03	1
100	1938	15.49	1
101	1933	15.18	1
102	1898	15.00	1
103	1981	14.68	1
104	1900	13.20	1
105	1935	13.07	1
106	1912	12.73	1
107	1889	12.00	1
108	1937	11.57	1
109	1918	11.30	1
110	1911	10.70	1
111	1890	10.60	1
112	1934	10.02	1
113	1895	9.90	1
114	1961	9.75	1
115	1977	8.71	1
116	1924	8.20	1
117	1931	6.48	1

$$\mathit{Recurrence Interval} = \frac{\mathit{years\ of\ record} + 1}{\mathit{rank\ of\ flood}}$$

Note: The values for the Maximum Gage Heights are given in feet above gage datum elevation. The values presented in this table differ from those in the previous flood report (Harrison and Bluemle, 1980). The values have been revised by the U.S. Geological Survey.

Industrial Commission of North Dakota

Edward T. Schafer
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ATTORNEY GENERAL

Roger Johnson
COMMISSIONER OF AGRICULTURE

North Dakota Geological Survey

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John P. Bluemle, *State Geologist*

Richard A. Baker, *Drafting Technician*
Randolph B. Burke, *Geologist*
Johnathan M. Campbell, *Paleontology Lab Technician*
Paul E. Diehl, *Geologist*
Sheilia J. Glaser, *Drafting Technician*
Karen M. Gutenkunst, *Business Manager*
Thomas J. Heck, *Geologist*
John W. Hoganson, *Paleontologist*
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Linda K. Johnson, *Information Processing Specialist*
Elroy L. Kadrmas, *Digital Conversion Technician*
Steve S. Kranich, *Drafting Technician*
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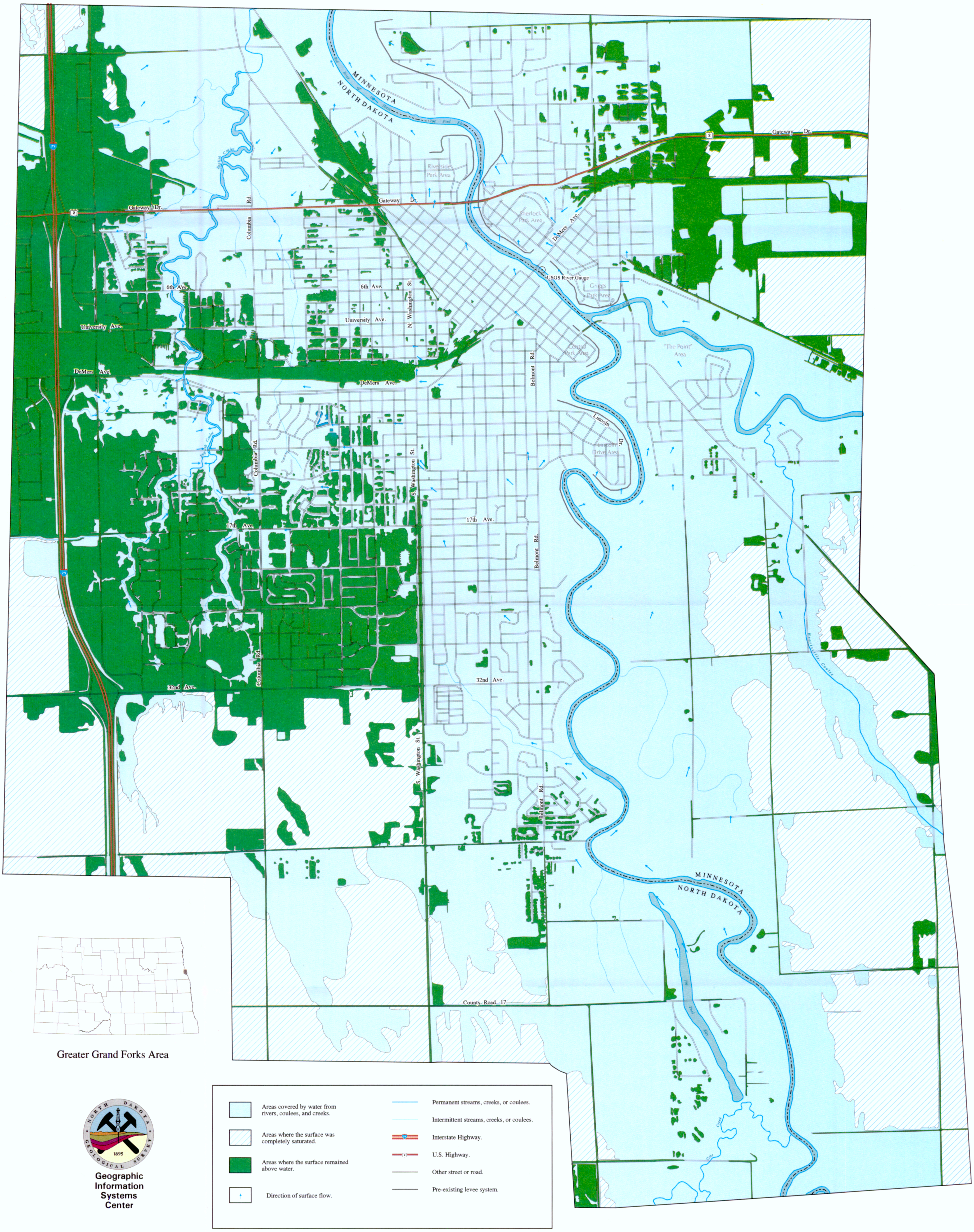
Karen J.R. Mitchell, *Geologist*
Edward C. Murphy, *Geologist*
Russell D. Prange, *Lab Technician*
Evie A. Roberson, *Administrative Officer*
Sheila K. Senger, *Receptionist/Publications*
Robert D. Shjeflo, *Drafting Technician*
Don H. Thom, *Drafting Technician*
Ryan P. Waldkirch, *Geographic Information Specialist*
Nita L. Wirtz, *Data Processing Coordinator II*

1999

Grand Forks, ND and East Grand Forks, MN - Area of Inundation

April 21st, 1997



Greater Grand Forks Area

🟦	Areas covered by water from rivers, coulees, and creeks.
▨	Areas where the surface was completely saturated.
🟩	Areas where the surface remained above water.
↑	Direction of surface flow.
—	Permanent streams, creeks, or coulees.
—	Intermittent streams, creeks, or coulees.
═	Interstate Highway.
—	U.S. Highway.
═	Other street or road.
—	Pre-existing levee system.

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The North Dakota Geological Survey compiled this map according to conventional cartographic standards, using what is thought to be the most reliable information available. The North Dakota Geological Survey does not guarantee freedom from errors or inaccuracies and disclaims any legal responsibility or liability for interpretations made from the map, or decisions based thereon.

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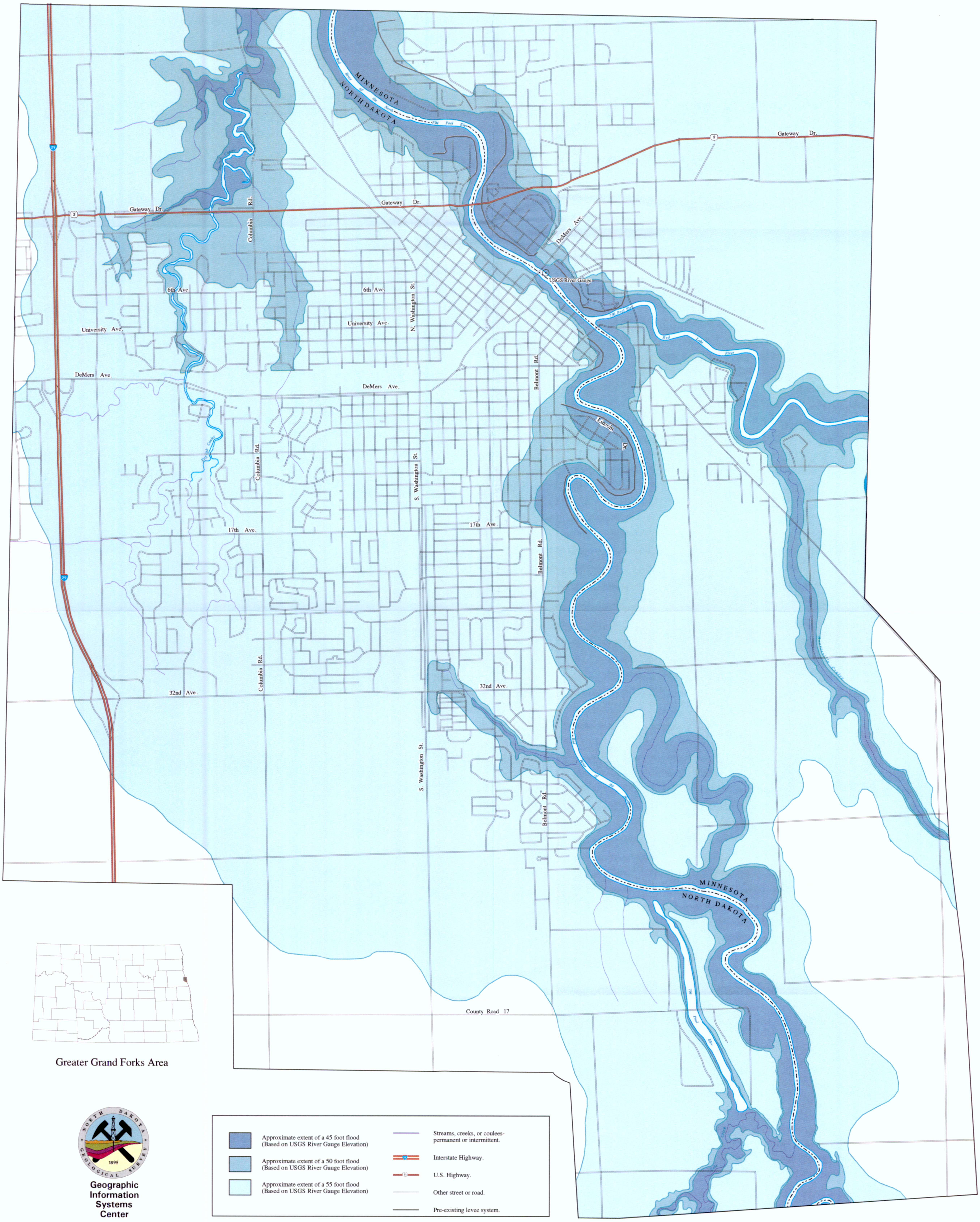
Universal Transverse Mercator Projection

This map was compiled from aerial photography taken on April 21st 1997. Two different sets of air photos were used, one color and one black and white. The scale of the airphoto is approximately 1:12,000. The direction of flow (shown by blue arrows) was determined from observation and interpolated from the airphotos. Arrow size does not indicate the speed or velocity of the moving water. The locations of the hydrologic features such as rivers, coulees, streams and creeks were taken from the USGS 1:24,000 scale Grand Forks Quadrangle map. The road network is modified 1995 US Census TIGER data set.

Approximate Flood - Extent Map

Grand Forks - East Grand Forks



▨	Approximate extent of a 45 foot flood (Based on USGS River Gauge Elevation)
▨	Approximate extent of a 50 foot flood (Based on USGS River Gauge Elevation)
▨	Approximate extent of a 55 foot flood (Based on USGS River Gauge Elevation)
—	Streams, creeks, or coulees-permanent or intermittent.
—	Interstate Highway.
—	U.S. Highway.
—	Other street or road.
—	Pre-existing levee system.

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Universal Transverse Mercator Projection

This is an approximate map. The extent of flooding shown on this map disregards the effects of pre-existing dikes. Detailed land surveys would be required to determine the precise effect of any given flood level at any given point. This map is based on the best- available aerial photography and U.S. Geological Survey topographic data, which is supplied at a five- foot contour interval. Detailed land surveys were not undertaken during the compilation of this map.