US Army Corps of Engineers

Final Hydrology Report

Hydrologic Analyses
The Red River of the North Main Stem
Wahpeton/Breckenridge
To
Emerson, Manitoba

Prepared by:
U.S. Army Corps of Engineers
St. Paul District

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Summary Table of Discharge-Frequency Statistics
Red River of the North Main Stem Stations

Location	Mean Log	Standard Deviation	Adopted Skew	Discharge-Frequency (cfs) % Chance of Exceedance 10.0	2.0	1.0	0.2
Wahpeton	--	--	--	7,180	10,850	12,150	18,300
Fargo	--	--	--	10,300	22,300	29,300	50,000
Halstad	3.9470	0.3935	-0.2344	27,600	50,700	62,200	93,000
Grand Forks	4.1889	0.3903	-0.2247	47,700	87,600	108,000	161,000
Drayton	4.2688	0.3413	-0.0537	50,600	91,200	112,000	169,000
Emerson	4.3105	0.3302	-0.0376	54,000	95,900	117,000	176,000

Purpose

2. The purpose of this report is to present the hydrologic analyses for development of a consistent set of discharge-frequency relationships for the main stem of the Red River of the North from Wahpeton, North Dakota and Breckenridge, Minnesota through Emerson, Manitoba. These analyses were performed as part of updating Flood Insurance Studies (FIS) for communities and counties on the main stem of the Red River of the North.

Background

3. The discharge-frequency curves for the Red River of the North main stem have not been updated since the 1971 Regional Flood Analysis (Reference 1) and the 1977 Red River of the North Main Stem Hydrologic Data report (Reference 2). The U.S. Army Corps of Engineers and the U.S. Geological Survey formed an administrative agreement in 1979 that adopted the 1971 flow values for floodplain management. The flood of record and other large events have occurred since these curves were computed. Most of the discharge-frequency relationships were developed by methodology in Bulletins 15, 17 and 17A by the Interagency Committee on Water Data. The current accepted methodology is contained in Bulletin 17B (Reference 3). Revisions have occurred to some floodplain delineation maps and flood hazard boundaries based on flood reduction measures and detailed topographic mapping; however, the flood flow frequency values have not changed. Appendix A contains a summary table of effective main stem FIS flow values and includes notes on the origins of the data.

Coordination

4. This report was prepared in cooperation with technical experts from the Minnesota Department of Natural Resources, the North Dakota State Water Commission, the U.S. Geological Survey (North Dakota District), FEMA Region V (Chicago), FEMA Region VIII (Denver) and FEMA Headquarters (Washington, D.C.). These agencies are in concurrence with the results presented in this report. Public comments provided by a consulting firm representing basin interests were incorporated in the analyses for the discharge-frequency curves at Fargo and Grand Forks, and are attached as Appendix I. These comments were addressed at an interagency review committee meeting held on March 21 and 22, 2001, at the Minnesota Department of Natural Resources in St. Paul. All of the agencies listed above were in attendance. A memorandum for record about the meeting can be found in Appendix J. The results of the coordinated interagency review committee meeting were sent to the mayors of Fargo and Moorhead and to points of contact at Grand Forks and East Grand Forks. Public meetings were held in Moorhead and Grand Forks on July 17, 2001, to present the updated discharge-frequency curves and to answer questions. The Corps of Engineers would like to thank Neil Harden, Duane Kelln and Alf Warkentin of Manitoba Water Resources for their ongoing cooperation in providing data for Canadian river gages.

Drainage Area

5. The Red River of the North drainage basin is the remnant flat lakebed of the former glacial Lake Agassiz. See Figure 1 for a map of the basin. The basin is about as long as it is wide, with a central north-south axis that drains to the north. The river gradient varies from a little over 1 foot per mile at Wahpeton and Breckenridge to about 0.5 foot per mile in the vicinity of Grand Forks and about 0.2 foot per mile at the Canadian border. The slope is less than that in Canada. The meander bends of the main channel cause the effective channel length to be about twice the length of the basin. The tributaries generally have slightly higher gradients than the main stem as the basin rises to its boundaries of ancient beach ridges, glacial moraines with prairie potholes and permanent lakes, and upland swamps.

6. The drainage areas used in this study are listed in Table 1. These drainage areas were obtained from several sources, including the East Grand Forks General Reevaluation Study by the Corps of Engineers (Reference 4), the Soil Conservation Service (now the Natural Resources Conservation Service) Minnesota Watershed Inventory (Reference 5), U.S. Geological Survey water resources data books and topographic maps. The drainage areas were divided into two parts: contributing (effective) and noncontributing (includes closed basins). The contributing drainage areas were further divided into primary and secondary areas. Primary contributing drainage areas have direct watercourses to the main stem of the river. Secondary drainage areas begin to contribute to main stem flow for flood events of about a 50-year frequency. Depression or flood control (reservoirs) storage and poor hydraulic connections to the main channels may cause this. The boundary between primary and secondary contributing drainage areas was determined by assuming the secondary contributing area to be enclosed by a 5-foot contour line on a 7.5-minute series topographic map (Reference 4). The noncontributing drainage area is that area which does not contribute to flow, and is similar to the term "closed area" as used by the U.S. Geological Survey. The noncontributing area was assumed to be enclosed by a 10-foot or more contour line on the 7.5-minute topographic map (Reference 4).

Factors That Affect Flooding

<u>General</u>

7. Most of the largest floods on the Red River of the North main stem are spring snowmelt events associated with a late rapid snowmelt and additional precipitation. The factors that have the greatest influence on flooding in the Red River basin can be divided into physical basin characteristics which are fairly constant and annually variable parameters which are influenced by climate and meteorology (LeFever, Bluemle and Waldkirch, Reference 6, and Bluemle, Reference 7). The two most important physical features of the basin with respect to flooding are: the direction of flow is to the north and the river gradient is very flat. The basin's spring snowmelt begins in the south (headwaters) before melting has begun in the north, causing floodwaters to move up the tributaries and promoting ice jams. This condition can cause the Red River stage to be high when the tributary flood peaks arrive. The flat gradient causes the river to drain very slowly. The single most important climatic factor to influence spring flooding is the

amount of winter snow accumulation. Other factors that affect flooding are drainage, land use, timing and rate of the thaw, timing of tributary runoff, spring precipitation, antecedent soil moisture, and frost depth. The worst floods occur when more than one factor contributes to spring runoff; however, climatic factors such as moisture input and spring melt patterns appear to be the most important variables associated with the largest spring floods in the Red River Valley.

Drainage and Land Use

8. Most of the public drainage systems in the Red River Valley were completed between 1900 and 1920 and can be reviewed in the 1922 report by Simons and King (Reference 8). The public drainage constructed by 1920 represents most of the major ditch systems in place today in the valley. Additions made to the system since then are mostly private laterals that tie into the public system. The majority of these additions were completed in the 1940's and 1950's. The drainage systems increased the effective drainage area of the basin, but the cumulative effects are difficult to quantify. Miller and Frink (Reference 9) attempted to define the causes of the increased flood magnitudes in the basin since about 1950, but were unable to definitively separate the drainage effects from observed increases in climatic moisture inputs, and suggested further study. Another contributing factor to increased runoff and peak flood flows may be the shift over time in land use from prairie and wetlands to agriculture. Land use in the basin is about 75 percent agricultural, with about 66 percent of the basin in cropland (Miller and Frink). Agricultural row crops are known to yield higher runoff than prairie and wetlands. The evaluation of changing drainage and land use effects on flood frequency is beyond the scope of this study; however, the impacts would be less for larger floods.

Climate

9. The climate in the Red River Valley is characterized by wide variations in temperature and moderate precipitation. Precipitation generally increases from northwest to southeast, and the annual average is about 20 inches over the basin. It has been observed on a regional basis in areas such as Devils Lake and the upper Mississippi River Valley that annual moisture inputs have increased since about 1940, and may be similar to the pattern of the 1800's. The years from about 1900 to about 1940 represent a time of less moisture input. See Table 2 for a listing of temperature and precipitation 30-year normal values for 1961-1990, as presented in Climatography of the United States No. 81 (Reference 10). See Table 3 for a listing of the 20 largest floods based on flow for various locations in the basin. Note that these events are all in the 1800's and after 1940 and that the ranks for each event are different at the different locations.

Streamflow Records

Observed Flow Data

10. The U.S. Geological Survey (U.S.G.S.) maintains several continuous streamflow recording gages on the main stem of the Red River of the North. Gaged streamflow data used for this study included stations at Wahpeton, North Dakota (U.S.G.S. Gage No. 05051500, water years

1897, 1942-2001), Fargo, North Dakota (U.S.G.S. Gage No. 05054000, water years 1882, 1897, 1902-2001), Halstad, Minnesota (U.S.G.S. Gage No. 05064500, water years 1936-2001), Grand Forks, North Dakota (U.S.G.S. Gage No. 05082500, water years 1882-2001), Drayton, North Dakota (U.S.G.S. Gage No. 05092000, water years 1936-2001), and the international gaging station at Emerson, Manitoba (U.S.G.S. Gage No. 05102500, water years 1913-2001). Additional flow data was obtained for the Emerson location from Manitoba Water Resources (Reference 11) for the years 1875 through 1912. These flows were developed by correlation with the Winnipeg and Grand Forks gage records, and were used in this study. Tables of the data used in the discharge-frequency analyses in this study can be found in Appendix B.

11. It should be noted that the North Dakota District of the U.S. Geological Survey has recommended using an annual peak flow value of 114,000 cfs for the 1997 flood at the Grand Forks gage as stated in Open File Report 00-344 (Reference 12). The U.S. Geological Survey estimated the 1997 peak flow to have been 137,000 cfs based on gaging measurements, but concluded that the flow was short-lived and was caused by unusual hydraulic conditions. The interagency review committee adopted 114,000 cfs for all of the analyses in this study.

Historic Floods

12. Historic floods that occurred before the period of systematic records were investigated for Grand Forks and Emerson. The historic floods of 1826, 1852 and 1861 were documented in letters, journals, and railroad records with specific information regarding maximum water levels and flood durations. Publications by the U.S. Geological Survey, the Manitoba Department of Mines and Natural Resources (R. H. Clark) and the University of Winnipeg (W. F. Rannie) present useful portions of these historic documents and discussions of historic floods (References 13, 14 and 15). Prior studies have estimated Red River discharges downstream of the Assiniboine River at Winnipeg, Manitoba for the 1826, 1852 and 1861 floods to be 225,000 cfs, 165,000 cfs and 125,000 cfs, respectively. Additional analyses by the St. Paul District, Corps of Engineers in 1979 (Reference 16) used linear regression and drainage area-discharge relationships to transfer these historic flood flows from Winnipeg to Emerson, Manitoba and Grand Forks, North Dakota. The resulting peak discharges at Grand Forks were determined to be 135,000 cfs for 1826, 95,000 cfs for 1852, and 65,000 cfs for 1861. No flows were published for Emerson in the 1979 study. The analysis for Fargo used the published values by the U.S. Geological Survey of 20,000 and 25,000 cfs for the 1882 and 1897 floods, which occurred prior to the systematic record at that location.

13. An updated analysis on historic events was done for this report to incorporate additional years of record. The study was a least squares linear regression model similar in scope to the 1979 Corps analysis, but included additional data from 1980 through 1997. This study used the same assumptions as the 1979 study that adjusted the Winnipeg flows to be upstream of the Assiniboine River. This adjustment subtracted Assiniboine River flows from the Winnipeg flows for observed annual peaks and 30,000 cfs was subtracted from the three estimated historic flows at Winnipeg. This adjustment was made to keep the total drainage areas for Grand Forks and Winnipeg within reasonable limits for transferring the historic flows. The total drainage area of the Red River at

Grand Forks is 30,100 square miles, and the area at Winnipeg above the Assiniboine River is 48,490 square miles. The Assiniboine River has a drainage area of 62,510 miles, resulting in a total drainage area at Winnipeg below the Assiniboine of 111,000 square miles. See Table 1 for a complete listing of the drainage areas. Another factor considered in making the adjustment was that the runoff yield (cfs per square mile) of the Assiniboine River was only about 20 percent of the runoff yield from the Red River above the Assiniboine. Reference 16 cites a conference at the St. Paul District in May 1951, at which Mr. R. H. Clark of the Canadian Department of Natural Resources and Development stated that he believed the Assiniboine River would never discharge more than 30,000 cfs at its mouth. This was due to large overbank diversions at high flow conditions. Mr. A. A. Warkentin of the Manitoba Department of Natural Resources recently adopted a value of 26,000 cfs for major flood events based on observed conditions in 1974 (Reference 17), so 30,000 cfs is considered to be a reasonable estimate for the historic events.

14. The resulting updated estimates of the historic flows at Grand Forks were determined to be 123,000 cfs for 1826, 85,000 cfs for 1852, and 59,000 cfs for 1861. The regression plots with equations for transferring flow from Winnipeg to Emerson and Emerson to Grand Forks can be found in Appendix C, along with tabular output from the computations. The 1979 Corps study (Reference 16) can be found in Appendix D. The resulting historic flows at Emerson from the new analysis were 151,000 cfs, 104,000 cfs and 73,000 cfs for the 1826, 1852 and 1861 events, respectively. The available literature leaves no doubt that large floods occurred during those years. Exact values of the flood flows are not certain, but the magnitudes presented here are reasonable.

15. The North Dakota District of the U.S. Geological Survey also evaluated the 1826, 1852 and 1861 historic events in the Red River Valley (Reference 18). A series of regression models were developed for relating log-transformed peak flows at Winnipeg, Grand Forks, Fargo and Wahpeton, given known historical peak flows at Winnipeg. The historic flood values estimated for Grand Forks were 164,000 cfs, 108,600 cfs and 76,300 cfs for the 1826, 1852 and 1861 floods, respectively. The historic flood values estimated for Emerson were 196,000 cfs, 131,000 cfs and 92,000 cfs for the 1826, 1852 and 1861 floods, respectively.

16. The interagency review committee discussed the various historic events included in the discharge-frequency analyses for the Fargo, Grand Forks and Emerson gages at the March 21-22, 2001 meeting. The consensus for the Fargo discharge-frequency curve was to use the 1882 and 1897 flows presented in the published U.S.G.S. data and not change the current analysis because the effective Flood Insurance Study discharge-frequency curve was adopted in place of the current analysis at the meeting. If the Fargo analysis is done again in the future, dropping the 1882 event may be considered at that time. The use of the historic events for 1826 and 1852 at Grand Forks and Emerson was determined to be acceptable. The 1861 event was dropped from the derivation of each discharge-frequency curve because there may have been a larger flood prior to the start of the systematic records (1882 at Grand Forks and 1913 at Emerson). It should be noted that the recorded peak stage at Emerson for 1861 was 2.6 feet higher than the peak stage in 1997. The committee decided to take an average of the new Corps of Engineers and U.S.G.S. values for estimates of the 1826 and 1852 flood peaks to be used for the computation of the

discharge-frequency curves. The resulting historic flow values for Grand Forks were 144,000 and 97,000 cfs for the 1826 and 1852 floods, respectively. The resulting historic flow values for Emerson were 174,000 and 118,000 cfs for the 1826 and 1852 floods, respectively.

17. Estimates of the 1826, 1852 and 1861 floods were not made in this study for locations upstream of Grand Forks because they were too far removed from Winnipeg in size of drainage area and geographic proximity. In addition, the main stem locations from White Rock Dam to Fargo are now affected by Traverse and Orwell Reservoirs, which were not in place when the historic events occurred.

Discharge-Frequency Analyses

General

18. Development of discharge-frequency probability relationships along the Red River of the North main stem was accomplished by fitting the annual instantaneous peak flows at the gage locations to a log-Pearson Type III distribution using the computer program HEC-FFA, Flood Frequency Analysis (Reference 19). Additional hydrologic techniques consistent with Bulletin 17B were used as necessary for specific locations as described in the following paragraphs. All of the analytical discharge-frequency curves represent computed probability without the expected probability adjustment and median plotting positions. This is consistent with current Corps of Engineers criteria for hydrologic investigations.

Methodology

19. The methodology used for this study is in accordance with the general guidelines for discharge-frequency analyses as provided by the Federal Emergency Management Agency (FEMA) in "Guidelines and Specifications for Study Contractors" for flood insurance studies, FEMA Publication No. 37, dated January 1995 (Reference 20). The methods used are also in accordance with Bulletin No. 17B, "Guidelines for Determining Flood Flow Frequency," of the Interagency Advisory Committee on Water Data, dated March 1982. The Corps of Engineers Hydrologic Engineering Center (HEC), Davis, California, provided specific guidance.

Discharge-Frequency for the Wahpeton/Breckenridge Area

20. The St. Paul District, Corps of Engineers has recently completed the hydrologic and hydraulic analyses for Wahpeton and Breckenridge (Reference 21). It was determined that backwater from channel ice had significantly affected half of the observed annual peak stages, requiring an ice-affected mixed population stage-frequency analysis. See Table 4 for a listing of the frequency data for Wahpeton and Breckenridge. Note that the peak flows shown on the table are for open water and will not yield the stages shown on the table if used with an open water rating curve. Paragraphs 21 through 34 describe the discharge and elevation frequency analyses for Wahpeton and Breckenridge and are taken from Reference 21.

21. Discharge-probability distributions through the Breckenridge/Wahpeton study area are affected by the upstream flood control reservoirs at White Rock Dam and Orwell Dam, an upstream breakout flow area near County Ditch No. 55 and State Highway 127, and ice conditions in the form of ice cover and/or ice jams on the Red River of the North. Analysis of the historical operation of the upstream reservoirs indicates that they have been regulated so as to not contribute significantly to peak flows at the Wahpeton gage. With the exception of the 1997 flood event, all peak flows from 1942 through 2001 are considered to be representative of the local drainage area (1,020 square miles) between the dams and the Wahpeton streamflow gage. The annual instantaneous peak flow measured at Wahpeton in 1997 was 12,800 cfs on April 15. Breakout flows from the Bois de Sioux River across State Highway 127 were observed for the first time during the 1997 flood of record when a peak discharge of 2,200 cfs was estimated to have broken out of the Bois de Sioux River upstream of the Wahpeton gage. Without the existence of the breakout area, a peak flow as large as 15,000 cfs could have potentially been observed at the gaging station. Inspection of reservoir releases indicates that the maximum local peak flow at the gage was approximately 10,000 cfs on April 6.

22. Because of the complexity due to reservoirs, breakout flows and ice conditions, of developing frequency distributions within the study area, it was determined to initially establish a natural condition discharge–frequency curve that would serve as a maximum envelope for developing the upper end of the frequency relationships for discharge and stage. To estimate reasonable maximum discharges for natural conditions, a graphical drainage area-discharge ratio method was employed using computed discharge-frequency relationships for inflows to Lake Traverse and for gaging stations at Wahpeton (local drainage area flow), Fargo and Grand Forks based on period of record flows. To determine values for the large recurrence interval peak discharges, the total drainage area at Wahpeton/Breckenridge was assumed to be a maximum of 2,425 square miles, which includes the contributing drainage area upstream of the reservoirs. A peak discharge-frequency relationship at Wahpeton was established for the local contributing drainage area based on period of record flows at the Wahpeton streamflow gage. To reflect increases in flow for the larger floods due to reservoir releases, adjustments were then made to this local area frequency curve with consideration given to the upper limit of the previously determined natural condition frequency curve. Breakout flows were then subtracted from this frequency curve based on a split flow analysis conducted for the breakout area.

Red River of the North at Wahpeton/Breckenridge

23. Prior to the 1997 flood event, annual peak discharges observed at the Wahpeton gage for the entire period of record were unaffected by upstream reservoir releases and breakout flows across State Highway 127. Based upon streamflows measured at the Wahpeton gage and known outflows from White Rock Dam and Orwell Dam, the local peak flow for 1997 at Wahpeton occurred on April 6 and had an estimated discharge of 12,000 cfs (which includes estimated breakout flows at County Ditch No. 55/State Highway 127). Using an estimated local peak discharge of 12,000 cfs for the 1997 flood, an annual instantaneous peak discharge-frequency curve was developed for the local drainage area of 1,020 square miles based on period of record flows from 1942 through 2001 using computer program HEC-FFA with 1997 considered the

largest event in the historic period dating back to 1897. Minor adjustments in flow values were also made for the years 1958, 1963, 1964, 1975, 1976, 1991 and 1996 for slight effects from reservoir releases (actually represented insignificant increases but adjustments were made for technical accuracy). This local drainage area discharge-frequency curve represents only the local drainage contributions, as it does not account for reductions in flow due to upstream breakouts and increases in flow from reservoir contributions known to occur for large flood events such as 1997. A sensitivity analysis was done to determine if two-station comparison methodology would improve the frequency relationship by adjusting the statistics of the local flow at the Wahpeton station on the basis of regression analysis with the longer record available at the Fargo gaging station. The two-station methodology was not adopted since it produced a local area all season discharge–frequency curve that was considered unreasonable due to flow values that were lower than the local area open water subpopulation frequency curve discussed in detail in Paragraph 31.

24. To establish the discharge-frequency curve at Wahpeton with impacts from the upstream reservoirs, the general relations methodology of drainage area-peak discharge was employed. As previously discussed, a logarithmic plot of drainage area versus discharge was established for flood events of several recurrence intervals based on adopted annual peak discharges for the Red River at Grand Forks, Fargo and Wahpeton and peak inflow to the Lake Traverse Reservoir Project (1,160 square miles). Using a maximum contributing drainage area of 2,425 square miles (maximum contributing drainage upstream of reservoirs), the logarithmic plot of drainage area-discharge was used to establish an upper limit boundary for the discharge-probability relationship at the Wahpeton gage. The median plotting position value for the 1997 peak flood event was used as a guide for graphically shaping the upper end of the curve. The median plotting position value is 0.66 percent based on the 1997 flood being the largest known flood event since the historical flood of 1897. The 1997 peak flood discharge value was plotted as 15,000 cfs, which represents the estimated total flow at Wahpeton without breakout flow impacts. To further aid in defining the upper end of the frequency curve, increasingly larger drainage areas were used within the general relation's methodology so as to represent the increase in contributing drainage from those areas upstream of the reservoirs for progressively larger flood events. The increase in contributing drainage area for the larger flood events is discussed in more detail in Paragraphs 23 and 26. The resulting discharge-frequency relationship for the Red River of the North at Wahpeton is shown as the higher curve on Figure 2 and represents local drainage along with contributions from the upstream reservoir areas for the larger, less frequent floods. This frequency curve does not include reductions due to the breakout flow area.

25. To include the impacts from upstream breakout flows on the frequency curve, a HEC-RAS analysis ("Hydrologic Engineering Center - River Analysis System", Reference 22) was conducted to determine a split-flow relationship at the breakout area near County Ditch No. 55 and State Highway 127. Results of this analysis were used to apply holdouts to the previously developed discharge-frequency curve to account for the breakout flows that never reach the Wahpeton gage for the larger flood events. The resulting annual peak discharge-frequency relationship, shown as the lower curve on Figure 2, represents local drainage along with contributions from the upstream reservoirs and reduction impacts from the upstream breakout

area. For the purpose of performing risk-based analysis, the discharge-frequency relationship at Wahpeton was extrapolated for determining flow values for the 0.10% and 0.15% frequencies.

Bois de Sioux River at Wahpeton/Breckenridge

26. The annual instantaneous peak discharge-frequency curve was developed for the Bois de Sioux River above the Otter Tail River based on the previously developed logarithmic plot of drainage area versus peak discharge. For the larger flood events, increasingly larger drainage areas were used to represent the increase in contributing drainage from that area upstream of White Rock Dam. The increase in contributing drainage area was estimated from a log-probability relationship developed for the total storage required at White Rock Dam for complete control of upstream inflow of various exceedance frequencies. This relationship was based on routing large synthetic flood events through White Rock Dam. The amount of storage required for complete control of any specific runoff event was computed in acre-feet per square mile of drainage area and plotted on a log-probability graph. As a means for determining the increase in uncontrolled upstream drainage area for the larger floods, the available storage at White Rock Dam was computed as a percentage of that required for complete control of any specific flood event. That percentage was then applied to the total upstream drainage area for estimating that portion which would be controlled by the dam. The residual drainage was then combined with the local 807 square miles as an estimation of the total square miles contributing to the peak flow for the Bois de Sioux River at Doran.

27. The peak discharge for the Bois de Sioux River was assumed to coincide with the peak discharge for the Red River at Wahpeton. This assumption was verified by analysis of peak discharges for the 9 years of record available at the Doran streamflow gage. The graphical-based frequency curve for the Bois de Sioux River was consistent with that for the Red River at Wahpeton for all flood flow frequencies including the larger, less frequent events that result from an increase in upstream uncontrolled drainage area.

28. Holdouts were then applied to the graphical-based frequency curve for the Bois de Sioux River to account for the upstream breakout area near County Ditch No. 55 and State Highway 127. The adopted annual instantaneous peak discharge-frequency curve for the Bois de Sioux River above the Otter Tail River represents impacts from the upstream breakout area and White Rock Dam contributions. The resulting adopted annual instantaneous peak discharge-frequency relationship for the Bois de Sioux River at Wahpeton and Breckenridge is shown as the lower (dashed) curve on Figure 3 and is tabulated in Table 4. This curve represents local drainage along with contributions from the upstream reservoirs and reduction impacts from the upstream breakout area.

Otter Tail River at Breckenridge

29. The logarithmic plots of drainage area versus discharge were also used to develop an annual instantaneous peak discharge-frequency relationship for the Otter Tail River at the mouth. Peak discharges for the Otter Tail River are affected by Orwell Dam for the more significant flood

events. Similar to what was done for the analyses for the Red River of the North at Wahpeton and the Bois de Sioux River, increasingly larger drainage areas were used for progressively larger flood events to represent the increase in contributing drainage from that area upstream of Orwell Dam. The increase in drainage area was based on the log-probability plot of reservoir storage per square mile of runoff required for complete control of the upstream drainage area. The adjusted contributing drainage area value was then used in conjunction with the drainage area-discharge relationship for graphical development of the peak discharge frequency relationship. The resulting adopted annual instantaneous peak discharge-frequency relationship for the Otter Tail River at Breckenridge is shown as the upper (solid) curve on Figure 4 and is tabulated in Table 4.

Elevation–Frequency for Wahpeton/Breckenridge

General

30. Of the 60 years of available gaged streamflow records (1942-2001) for the Red River of the North at Wahpeton, 29 years of annual peak stages were ice-affected and 31 years of annual peak stages were associated with open water discharges. River discharges during ice-affected conditions are typically lower than discharges during open water conditions. The formation of an ice cover or ice jam on a river can result in a significantly larger wetted perimeter. The additional resistance to flow, combined with the reduction in flow area caused by ice, results in higher stages than a comparable open water discharge would produce. Due to the significant number of ice-affected flood stages for the Wahpeton/Breckenridge study area, flood frequency analysis based on peak annual instantaneous discharges is not considered appropriate. Consequently, an elevation-frequency analysis was conducted to account for the large number of ice-induced flood events that have historically been known to occur in the study area.

31. For determining elevation-frequency relationships in the study location that includes several ice-affected flood events, the analysis considered the mixed populations of annual peak ice-affected stages and annual peak open water stages. A combined-population frequency analysis was conducted by deriving an annual elevation-frequency curve from two frequency curves developed from separate subpopulations. These two subpopulations were separated according to the season (ice-affected versus open water) and not arbitrary calendar months. A combined-population frequency curve (P_c) was then developed by combining independent annual frequency curves for the two subpopulations of ice-affected elevations and open water elevations, where P_c is defined as:

$$P_c = P_1 + P_2 - (P_1)(P_2)$$

where

P_c = probability of a selected elevation being equaled or exceeded from either an ice-affected flood event or an open water flood event

P_1 = probability of the same selected elevation being equaled or exceeded from an ice-affected flood event

P_2 = probability of the same selected elevation being equaled or exceeded from an open water flood event

Ice-Affected Subpopulation

32. An independent ice-affected elevation-frequency curve was developed at the U.S.G.S. gage on the Red River of the North at Wahpeton based on 59 years of stage data available from gaged records. Annual peak ice-affected elevations were graphically plotted using median plotting positions. The 1997 peak ice-affected elevation of 962.4 feet was plotted as the highest flood elevation since the historic spring flood of 1897 (peak elevation of 960 feet) and has a median plotting position of 0.66 percent based on a 105-year historic period from 1897 to 2001. A curve was graphically fitted to the 59 years of plotted peak elevations to produce an annual series peak ice-affected elevation-frequency relationship for the Red River of the North at the Wahpeton U.S.G.S. streamflow gage. An ice-affected elevation-discharge rating curve was used to determine the corresponding ice-affected discharge-frequency relationship at the gage. The discharge-probability curve was then extrapolated beyond the 0.66 percent event to determine the discharges and corresponding elevations associated with the 0.5 percent and 0.2 percent ice-affected flood events.

Open Water Subpopulation

33. An independent annual peak open water elevation-frequency curve was also developed at the U.S.G.S. gage on the Red River of the North at Wahpeton. This open water elevation-frequency curve was based on an annual series peak open water discharge-frequency curve developed from 60 years of available gaged streamflow records. These open water discharges were considered hydrologically independent from the ice-affected stages used for deriving the annual peak ice-affected elevation-frequency relationship. A few of the annual open water discharges were adjusted so as to be representative of conditions with no breakout flows. Since the flows do not represent an annual mixed population, no regional skew was used within the HEC-FFA analysis. Also, two-station comparison methodology could not be utilized since a separate subpopulation of open water flows was not readily available for any long-term gaging station. Similar to what was done for the annual all season discharge-probability relationship, adjustments were then made to the open water local area curve to include impacts due to upstream breakout flows and contributions from the upstream reservoir drainage areas for the larger floods. An open water elevation-discharge rating curve was developed at the U.S.G.S. gage and used in combination with the adopted open water discharge-frequency curve to graphically develop an annual peak open water elevation-frequency curve.

Combined Population

34. Using the probability of union, as discussed in Paragraph 31, a combined population elevation-frequency curve was developed at the gage by combining the independent frequency curves for the two subpopulations of ice-affected elevations and open water elevations. As previously discussed, the upper end of the frequency curve (0.2% exceedance frequency elevation) was defined from the annual all-season peak discharge-frequency curve. This was based on the assumption that these remote flood events would occur under open water conditions due to expected ice instability at high discharges. The adopted combined-population elevation-frequency curve for the Red River of the North at the U.S.G.S. gage is shown on Figure 5 along with the subpopulation frequency curves for ice-affected elevations and open water elevations as described in Paragraphs 32 and 33. Table 4 provides a summary of flow and elevation for selected frequencies for the combined population for the Red River of the North at the U.S.G.S. gage, the Bois de Sioux River upstream of the Otter Tail River and the Bois de Sioux River upstream of the breakout flow.

Red River of the North at Fargo/Moorhead

General

35. The discharge-frequency relationship for the Red River of the North at Fargo/Moorhead is based on the period of record flows available for the Fargo continuous streamflow gaging station. The available annual peaks of the systematic record were 1902 through 1997 and historic events in 1882 and 1897. The recorded peak flows at the Fargo gage have been affected by reservoir regulation since 1942 by the White Rock Dam on the Bois de Sioux River at Lake Traverse and also by the Orwell Dam on the Otter Tail River at Orwell Reservoir since 1953. The regulation effects caused by the dams require a special discharge-frequency analysis described in the following paragraphs. The basic procedure was to develop a set of natural conditions annual peak flows to simulate the basin conditions without the two dams in place. This was accomplished with a reservoir routing model, computed reservoir inflows and observed gage data. Data prior to 1942 was used as published without modification. This natural conditions data was used to develop an analytical discharge-frequency curve which was then adjusted for the impacts of the dams. The adjustments were made based on a linear regression curve for the "with" and "without" dams data for 1942 through 1997. A volume-frequency analysis was then performed with the reservoir routing model using computed mean daily reservoir inflows and mean daily observed flows at the U.S.G.S. gages to determine if the resulting discharge-frequency curve was reasonable, especially for the 500-year flood. The methodology used to derive the Fargo discharge-frequency curve was in compliance with guidance provided by the U.S. Army Corps of Engineers Hydrologic Engineering Center (Reference 23). This is documented in a memorandum by Dr. David Goldman included in Appendix J.

Fargo Discharge-Frequency

36. The Red River of the North at Fargo, North Dakota is measured by a U.S. Geological Survey continuous recording gage (Gage No. 05054000). It has 101 years of systematic record and 120 years of historic record (1882, 1897, 1902-2001). The 1997 event is estimated to be the largest flood known to occur since 1882. The 1969 event is estimated as the second largest event known to occur since 1882. Because both of these events are part of the systematic record, they are considered to be high outliers. The 1897 event is the third largest event of record. Because it was not part of the systematic record, it is treated as a historic event. The 1882 event is the fifth largest flood on record and the eighth largest adjusted natural flow and is considered to be part of the systematic record.

37. Flows at Fargo are affected by regulation from two upstream U.S. Army Corps of Engineers reservoirs with dams: Orwell on the Otter Tail River (Orwell Dam) and Lake Traverse on the Bois de Sioux River (Reservation Dam and White Rock Dam). Flows have been affected since 1942 when White Rock Dam began operation. Orwell Dam became operational in 1953. Orwell provides a relatively small amount of storage for flood control (approximately 13,100 acre-feet of effective storage). The flood control storage at Orwell Dam primarily benefits agricultural interests adjacent to the Otter Tail River, upstream of the Red River. The main function of the Orwell project is for downstream water supply during low flow periods. Lake Traverse provides 137,000 acre-feet of flood storage.

38. A natural condition discharge-frequency curve was determined for the without dams conditions so that the entire period of record is homogeneous. The regulated flows since 1942 were modified to reflect natural conditions without the dams in place. The U.S. Army Corps of Engineers HEC-5 reservoir simulation computer program (Reference 24) was used to route the flows from 1942 to 1997. Reservoir inflows were computed for the period of record by using the outflows and change in reservoir elevation (storage) for daily data. Table 5 shows the without dams flows, which include actual recorded flows for 1882, 1897, and 1902-41 and adjusted flows for 1942-97. The U.S. Army Corps of Engineers discharge-frequency computer program HEC-FFA, which follows U.S. Water Resources Council Guidelines, Bulletin 17B, was then applied to obtain an analytical curve.

39. The computed station skew for the Red River at Fargo (+0.0325) was compared to the adopted skews at the other gaging stations on the main stem of the Red River, which included Wahpeton (-0.3756), Halstad (-0.2344), Grand Forks (-0.2247) and Emerson (-0.0376). The skew for the Fargo station was not consistent with these stations even when weighted with the regional skew value of -0.25 as per the Minnesota U.S. Geological Survey skew study (Reference 25). An examination of the fit of the log-Pearson Type III distribution to the annual plotting positions indicated that the lower portion of the distribution may be contributing to a poor fit on the upper end of the analytical curve. To obtain a better fit, the skew for the stations on the Red River was plotted vs. mean log. A regression line was then drawn to smooth the skew at Fargo. The skew from this relationship was approximately -0.2. After further consideration, this skew was averaged with the station skew because of the long length of record at Fargo, resulting in an

adopted skew value of -0.1. This skew was approved by interagency consensus after extensive technical review of the procedures described above (Reference 26). Figure 6 shows the natural condition discharge-frequency curve.

40. To obtain the existing condition, with dams, discharge-frequency curve, a linear regression relationship between the observed and HEC-5 simulated values since 1942 was developed with the observed values as the independent variable (X-axis). This analysis resulted in a correlation (R) of 0.99 and standard error of 11%. Results of the regression analysis are shown on the graph and table in Appendix E. The equation for the regression line is

$$Y = 0.8358X + 377.23.$$

The analytical values for the natural condition discharge-frequency curve were then adjusted downward to reflect the with-dams regulated condition using this relationship. Table 6 shows the with-dams regulated flows, which include adjusted flows for 1882, 1897, and 1902-41, and actual recorded flows for 1942-97. Figure 7 shows the with-dams (circles) and without-dams (triangles) regulation frequency curves. A summary of the various Fargo discharge-frequency relationships is shown in Table 7.

41. The linear regression relationship in Appendix E was used to adjust flows up to the 100-year return period. Because the 500-year event is beyond the range of flows shown in the regression relationship, and because for the higher discharges the reservoir impacts downstream may diminish due to limited flood control storage, an HEC-5 simulation was made for this event for with and without dams. Flood volume frequencies were developed for the inflow to Orwell and Lake Traverse as well as the intervening incremental local flow for Wahpeton and Fargo. Using these flood volume-duration relationships, balanced 500-year hydrographs were derived using the U.S. Army Corps of Engineers HEC-1 flood hydrograph computer program (Reference 27). The hydrographs were then routed and combined at Fargo using HEC-5 for with and without dams in place.

42. The volume-frequencies were derived from the available period of record from 1942 to 1997. The recurrence interval for this event at Fargo plots at approximately a 670-year event for the natural condition frequency curve because this period had higher flows compared to 1902 to 1941. Because this event is near the 500-year event, differences in the peak magnitudes were also applied to the 500-year flood based on the linear regression analysis in Appendix E. The resulting discharge of 57,400 cfs for the 500-year flood anchors the regulated with dams, graphically drawn, curve at the upper end as shown on Figure 7 and in Table 7. A more detailed description of the volume-frequency analysis can be found in Paragraphs 44 through 51 below.

43. The interagency hydrologic review committee felt that there were a number of uncertainties in the data and assumptions of the Fargo discharge-frequency analysis. The uncertainties involved the reservoir routing model, values of historic floods and adjusted station skew. In addition, the confidence limit test prescribed by FEMA showed that the effective flood insurance study discharge-frequency curve was within both the estimated 90- and 50-percent confidence

intervals of the new curve. This condition allows the existing effective curve to remain as the adopted discharge-frequency relationship for that location. As a result, the majority of the interagency review committee participants decided to retain the effective flood insurance study discharge-frequency curve for the Fargo gage. The effective 100-year (1 percent chance of exceedance) discharge for Fargo and Moorhead will remain 29,300 cfs. A summary of the various discharge-frequency curves for the Fargo gage can be found in Table 7. The adopted curve is shown on Figure 7 as the lowest of the three lines plotted. The March 21-22, 2001 interagency hydrologic review committee meeting discussion can be reviewed in a memorandum for record in Appendix J.

Traverse, Orwell and Fargo Volume-Frequency Analysis

44. The annual instantaneous peak discharge-frequency relationship for the Red River of the North at Fargo/Moorhead is based on the period of record flows available at the Fargo continuous streamflow gaging station. The available annual peaks of the systematic record were 1902 through 1997 and historic events in 1882 and 1897. The Lake Traverse reservoir project (White Rock Dam, 1,160 square miles of contributing drainage area) began operation in 1942, and Orwell Dam became operational in 1953 (245 square miles of contributing drainage area). Orwell Reservoir provides a relatively small amount of flood storage. All peak flows from 1942 through 1996 are considered to be representative of the local drainage area downstream of the reservoirs (3,220 square miles). Had the dams not been in place, there would have been significant increases in the peak flows at Wahpeton and Fargo.

45. A reservoir routing model was developed for White Rock and Orwell Dams using the HEC-5 computer program and was used for several different types of analyses for the Fargo gage. The natural, or without-dams, simulated flows were required at Fargo for 1942 through 1997 to complete the discharge-frequency analysis, as previously discussed. The volume-frequency analysis was needed to compute a balanced synthetic 500-year hydrograph to have a more physically data-based approach to incorporate actual basin conditions in the estimate of the 500-year flood. Reservoir inflows were computed for the period of record by using the outflows and change in reservoir elevation (storage) for daily data.

46. The 1997 event was analyzed with the HEC-5 model, with channel routings calibrated to the 1997 flood. The actual releases from White Rock and Orwell Dams were used for the calibration as well as observed travel times. It was determined that the local incremental flow downstream of the reservoirs was 23,000 cfs of the 28,000 cfs peak. Thus, reservoir outflow accounted for 5,000 cfs of the peak flow at the Fargo gage in 1997. The 1997 flood value of 23,000 cfs can be included with the period 1942 through 1996 to get a homogeneous data set of annual peak flows for 1942 through 1997. Orwell Dam was not in operation until 1953, but it does not have much impact on the peak flows at Fargo because it has only 13,100 acre-feet of effective storage. The flood control storage at Orwell Dam primarily benefits agricultural interests adjacent to the Otter Tail River, upstream of the Red River. The main function of the Orwell project is for downstream water supply during low flow periods. Lake Traverse provides 137,000 acre-feet of flood storage.

47. The reservoir routings of inflows for Lake Traverse Reservoir (through Reservation and White Rock Dams) and Orwell Reservoir (through Orwell Dam) are governed by established regulation plans for each reservoir to balance reservoir elevation (storage), downstream channel capacity and a target flood stage at Wahpeton. With the exception of 1997, Traverse and Orwell reservoirs have not contributed significant flows to the peak at Fargo for all their years of operation. The established operating plans for the dams were incorporated into the HEC-5 input. The target elevation is defined as when the U.S. Geological Survey gage at Wahpeton reaches the specified stage, at which time the outflow structures of both dams are completely closed until the stage at Wahpeton drops below the target or the maximum allowable pool elevations are reached. The target elevation for Wahpeton is determined each year based on the basin average snow water content in late February. The target stage at Wahpeton is 10.0 feet if the snow water content is 3 inches or less, and 12.0 feet if it is greater than 3 inches. The published channel capacities downstream of the dams are 1,100 cfs for White Rock and 900 cfs for Orwell. These capacities can be exceeded regardless of the stage at Wahpeton if the pool stages and inflows require greater releases to lower the pool in an emergency to prevent damage to the structure. The HEC-5 model was then used to compute what the annual peaks at Fargo would have been without the reservoirs in place for 1942 through 1997.

48. The total drainage area above the Fargo gage is 6,800 square miles, but 590 square miles of the Wild Rice River (North Dakota) are non-contributing and 1,585 square miles of the Otter Tail River above Orwell Dam do not contribute flow until weeks after the peak at Fargo. This is caused by the large volume of lake storage in the Otter Tail basin, and can be seen in the reservoir inflow hydrographs for almost all non-drought years. It should also be noted that the peaks at Fargo without dams for 1969 and 1997 would have been 31,700 and 31,000 cfs, respectively. The observed flood peaks for 1969 and 1997 were 25,300 and 28,000 cfs, respectively. These storage effects were more pronounced for Wahpeton and Breckenridge and dampen out downstream of Fargo as the effective drainage area of the basin increases.

49. The differences between the 1969 and 1997 floods at Fargo for the "with" and "without" dams conditions also show that the local area downstream of the reservoirs can contribute significantly different amounts for different flood events. Examination of the gage records for the Wild Rice River at Abercrombie showed that this river had nearly the same peak flow for 1969 and 1997 floods, but different timing with respect to the peak at Fargo. Timing of the hydrographs from the main contributing areas is critical to the peak at Fargo, and is variable for different floods.

50. A reservoir analysis with the HEC-5 computer program was required to define the upper end of the discharge-frequency curve because available reservoir storage can attenuate reservoir outflows and the magnitude of the 500-year flood was beyond the reasonable range of the other graphical analysis methods. This analysis involved the derivation of inflow volume-duration curves for White Rock and Orwell Dams and flow volume-duration curves for Fargo from mean daily flows. Daily inflows for Traverse and Orwell Reservoirs from 1942 through 1997 were computed from observed outflows and change in reservoir elevations. The elevations were first

smoothed by taking a 5-day centered moving average (CMA) of each daily value to eliminate wind effects. The computed daily inflows were used to derive the 1-, 3-, 7-, 10-, 30-, 60-, and 90-day annual maximum inflows for each year by again using the CMA method. Inflow-frequency curves were computed for both reservoirs and a flow-frequency curve was computed for Fargo for each duration with the HEC-FFA computer program. These curves can be found on Figures 8, 9 and 10.

51. The volume-duration relationships from the inflow-frequency curves were then put into the HEC-1 computer program with 1997 observed hydrographs at each location to use as a pattern to compute balanced synthetic 100-, 200-, and 500-year hydrographs. The pattern of the 1997 flood was similar to other high flow events, especially 1969, when plotted together. However, the use of a different flood year to derive the pattern hydrograph could give somewhat different results for the routing of the synthetic events. The synthetic hydrographs were then routed with the HEC-5 model previously calibrated to the 1997 flood. These flows begin to depart from the analytical curve between the 100- and 500-year events. This process provided an approximate value for the 500-year flow of 60,000 cfs, and appeared to be reasonable when compared to the discharge-frequency analysis and the reservoir contribution observed for the 1997 flood (5,000 cfs).

<u>Red River of the North at Halstad</u>

52. The annual instantaneous peak discharge-frequency curve for the Red River of the North at Halstad is based on the period of record flows available at the Halstad continuous streamflow gaging station. The available annual peaks of the systematic record were 1936, 1937 and 1942 through 2001. A two-station comparison was done as described in Bulletin 17B, Appendix 7, with the longer record station at Grand Forks to adjust the mean and standard deviation. The historically adjusted mean and standard deviation were used for Grand Forks to transfer some of the benefit of the historic information to the short record station. The Beard Equation was used to compute the adjusted standard deviation, as described in "Hydrologic Frequency Analysis" by the Corps of Engineers (Reference 28). The Beard Equation is a simplified version of Equation 7-10 in Appendix 7 of Bulletin 17B. The results indicated that the adjusted statistics were improved to 107 years of equivalent record. The adjusted statistics were put into the HEC-FFA computer program to compute the analytical discharge-frequency curve. Pertinent equations and results of the two-station comparison can be found in Appendix F, and the curve along with adopted statistics is shown on Figure 11 and tabulated in Table 8.

<u>Red River of the North at Grand Forks/East Grand Forks</u>

53. The annual instantaneous peak discharge-frequency curve for the Red River of the North at Grand Forks was based upon 121 systematic events from the period of record flows for 1882 through 2001 available for the Grand Forks continuous record gaging station. The historic period for the Grand Forks gage is 176 years (1826 through 2001). Historic events were estimated for the 1826, 1852 and 1861 flood events. Derivation of the discharge-frequency curve used the observed streamflows from 1882 through 2001 along with the historic flood values for 1826 and 1852 in the HEC-FFA computer program to compute the analytical discharge-frequency curve.

The 1826 and 1852 events were used as historic events, and the 1861 event was not included, as was determined appropriate by the interagency hydrologic review committee at a meeting on March 21 and 22, 2001. A summary of the interagency discussion can be found in Appendix J as a memorandum for record. The use of the historic events for 1826 and 1852 at Grand Forks was determined to be acceptable. The 1861 event was dropped from the derivation of the discharge-frequency curve because there may have been a larger flood prior to the start of the systematic record (1882 at Grand Forks). The committee decided to take an average of the new Corps of Engineers and U.S.G.S. values for estimates of the 1826 and 1852 flood peaks to be used for the computation of the discharge-frequency curves. The resulting historic flow values for Grand Forks were 144,000 and 97,000 cfs for the 1826 and 1852 floods, respectively. The value of the 1997 flood peak was reduced from 137,000 to 114,000 cfs as recommended by the North Dakota office of the U.S. Geological Survey. The value of 137,000 cfs was determined to have taken place, but it was not considered appropriate for use in discharge-frequency analyses (Reference 12) because of unusual conditions of occurrence. The 1997 flood was determined to be a high outlier by the FFA computer program. The curve along with the adopted statistics is shown on Figure 12 and tabulated in Table 8.

Red River of the North at Drayton

54. The annual instantaneous peak discharge-frequency curve for the Red River of the North at Drayton is based on the period of record flows available at the Drayton continuous streamflow gaging station. The available annual peaks of the systematic record were 1936-1937 and 1941 through 2001. A two-station comparison was done as described in Bulletin 17B, Appendix 7, with the longer record station at Grand Forks to adjust the mean and standard deviation. The historically adjusted mean and standard deviation were used for Grand Forks to transfer some of the benefit of the historic information to the short record station. The Beard Equation was used to compute the adjusted standard deviation, as described in "Hydrologic Frequency Analysis" by the Corps of Engineers. The Beard Equation is a simplified version of Equation 7-10 in Appendix 7 of Bulletin 17B. The results indicated that the adjusted statistics were improved to 114 years of equivalent record. Pertinent equations and results of the two-station comparison can be found in Appendix F. The adjusted statistics were put into the HEC-FFA computer program to compute the analytical discharge-frequency curve, which is shown as the solid line on Figure 13.

55. Note that the values of the analytical discharge-frequency curve are less than the values for Grand Forks for the 100- and 500-year floods even though the drainage area at Drayton is larger. This is caused by the large negative skew of the Drayton data (-0.4424) relative to the skews at Grand Forks (-0.2247) and Emerson (-0.0376). The large floodplain storage volume and flow splits to the North and South Marais Rivers (in North Dakota) between Grand Forks and Drayton may contribute to this. Skew is also very sensitive to the period of record and extreme flood events. The systematic gage record at Drayton is from 1936 through 2001 with 1938 through 1940 missing, and thus does not contain most of the drought years from 1900 through 1940. This reduces the variance (standard deviation) of the discharge-frequency statistics compared to Grand Forks and Emerson. The two-station comparison adjustment did not entirely account for this.

The result is an analytical discharge-frequency curve that has less slope than the Grand Forks and Emerson curves, and crosses the Grand Forks curve at about 89,000 cfs. Therefore, the discharge-frequency curve for Drayton was adjusted to be regionally consistent with Grand Forks and Emerson using drainage area ratio transfer exponents computed for each recurrence interval. This curve is shown on Figure 13 as the dashed line, and fits within the confidence limits of the analytical curve.

56. The regionally adjusted curve was then used to develop mean log, standard deviation and skew using methodology in Appendix 5 of Bulletin 17B. This method uses the flows for the 2-, 10- and 100-year floods to compute station statistics. The approximated discharge-frequency values for the 2-, 10- and 100-year floods were 18,700, 51,000 and 112,000 cfs, respectively. The computed station statistics were then put into the HEC-FFA computer program along with the period of record of 63 years, and an analytical discharge-frequency curve with confidence limits was developed. The resulting discharge-frequency relationship was nearly identical to the regionally adjusted curve, so the computed curve was adopted. The adopted curve along with the computed statistics is shown on Figure 14 and tabulated in Table 8. The methodology and equations for computing the adjusted statistics are shown in Appendix G.

Red River of the North at Emerson, Manitoba

57. The annual instantaneous peak discharge-frequency curve for the Red River of the North at Emerson was based upon 89 systematic events from the period of record flows available for the Emerson continuous record gaging station and 37 estimated values from Manitoba Water Resources. Derivation of the discharge-frequency curve used the observed streamflows from 1913 through 2001 along with the estimated values for 1875-1878 and 1880-1912 and the historic flood values for 1826 and 1852 in the HEC-FFA computer program to compute the analytical discharge-frequency curve. The historic period for the Emerson gage is 176 years (1826 through 2001). The 1826 and 1852 events were used as historic events and the 1861 event was not included as was determined appropriate by the interagency hydrologic review committee at a meeting on March 21 and 22, 2001. A summary of the interagency discussion can be found in Appendix J as a memorandum for record. The use of the historic events for 1826 and 1852 at Emerson was determined to be acceptable. The 1861 event was dropped from the derivation of each discharge-frequency curve because there may have been a larger flood prior to the start of the systematic records (1913 at Emerson). It should be noted that the recorded peak stage at Emerson for 1861 was 2.6 feet higher than the peak stage in 1997. The committee decided to take an average of the new Corps of Engineers and U.S.G.S. values for estimates of the 1826 and 1852 flood peaks to be used for the computation of the discharge-frequency curves. The resulting historic flow values for Emerson were 174,000 and 118,000 cfs for the 1826 and 1852 floods, respectively. The estimated 1861 flood peak at Emerson was 83,000 cfs. The historic events developed in this study were derived in a consistent manner with the historic floods used for Grand Forks. The curve along with the adopted statistics is shown on Figure 15 and tabulated in Table 8.

Flows at Ungaged Main Stem Locations

58. Discharges were computed for selected main stem locations where gaging stations are not present. These locations were typically upstream and downstream of tributaries. The adopted discharge-frequency curves in this report at the U.S.G.S. gage locations on the main stem were used with the drainage area ratio method to compute the 10-, 50-, 100- and 500-year flows at the desired locations. Tables of these flows can be found in Appendix H. The contributing drainage areas were derived from the sources described in Paragraph 6 of this report. Flows for ungaged locations and the drainage area ratio exponents N are computed between gages 1 and 2. The following equation was used to compute the ungaged flows:

$$Q_U = Q_G \left(\frac{A_U}{A_G} \right)^N$$

where

$$N = \frac{Log\left(Q_1 / Q_2 \right)}{Log\left(A_1 / A_2 \right)}$$

Q_U = Flow at ungaged location
Q_G = Flow at gaged location
A_U = Contributing drainage area at ungaged location
A_G = Contributing drainage area at gaged location
Q_1 & Q_2 = Flows at gaged locations 1 and 2
A_1 & A_2 = Contributing drainage areas at gaged locations 1 and 2.

The values used for Q_G and A_G can be either pair of Q_1 and A_1 or Q_2 and A_2 once N has been determined.

Summary

59. This report was prepared in cooperation with technical experts from the Minnesota Department of Natural Resources, the North Dakota State Water Commission, the U.S. Geological Survey (North Dakota District), FEMA Region V (Chicago), FEMA Region VIII (Denver) and FEMA Headquarters (Washington, D.C.). Representatives of the listed agencies participated in this study from the development of the scope of work in April 1998, through various technical reviews and resolution of the public comments in March 2001. These agencies are in concurrence with the results presented in this report. Communities on the main stem of the Red River of the North had opportunities to review and comment on all components of the analyses through public meetings and written correspondence. Public comments provided by a consulting firm representing basin interests were incorporated in the analyses for the discharge-frequency curves at Fargo and Grand Forks, and are attached as Appendix I. These comments

were addressed at an interagency hydrologic review committee meeting held on March 21 and 22, 2001, at the Minnesota Department of Natural Resources in St. Paul. All of the agencies listed above were in attendance. A memorandum for record about the meeting can be found in Appendix J. Appendix J also contains other pertinent memoranda regarding this study. Appendix K contains correspondence. The results of the coordinated interagency review committee meeting were sent to the mayors of Fargo and Moorhead and to points of contact at Grand Forks and East Grand Forks. Public meetings were held in Moorhead and Grand Forks on July 17, 2001, to present the updated discharge-frequency curves and to answer questions.

60. This study was performed with streamflow records up to and including the spring flood of 2001. A summary of the discharge and elevation-frequency data for Wahpeton and Breckenridge can be found in Table 4 and is adopted from Reference 21. A summary of the adopted discharge-frequency curve data and gaging station statistics for the Red River main stem locations at Wahpeton/Breckenridge, Fargo/Moorhead, Halstad, Grand Forks/East Grand Forks, Drayton and Emerson can be found in Table 8. A plot of all the adopted main stem discharge-frequency curves can be found on Figure 16. Additional future studies that may provide greater insight into Red River of the North hydrology are: updated tributary discharge-frequency curves with coincident analyses of the main stem, and evaluation of changing climate, drainage and land use over time. Paleohydrologic studies may also provide useful information about rare flood events in the basin.

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26. Meeting at U.S. Army Corps of Engineers, St. Paul District, in conjunction with U.S. Geological Survey, ND, North Dakota State Water Commission, Minnesota Department of Natural Resources, and Federal Emergency Management Agency, Regions V and VIII, January 21, 2000.

27. U.S. Army Corps of Engineers, Hydrologic Engineering Center, HEC-1 Flood Hydrograph Package Computer Program, Version 4.1, June 1998.

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TABLES

Table 1
Red River of the North Main Stem Drainage Areas

	Drainage Area in Square Miles				
Location	Primary +	Secondary =	Effective	Non-Contributing	Total
Wahpeton/Breckenridge	1,020	1,405	2,425	1,585	4,010
Fargo/Moorhead	3,220	1,405	4,625	2,175	6,800
Halstad	12,785	2,420	15,205	6,595	21,800
Grand Forks	17,930	3,515	21,445	8,655	30,100
Oslo	19,005	3,515	22,520	8,680	31,200
Drayton	22,570	3,515	26,085	8,715	34,800
Emerson	26,390	5,055	31,445	8,755	40,200
Winnipeg (Upstream of the Assiniboine River)					48,490
Assiniboine River at Headingley (Winnipeg)					62,510
Winnipeg (Downstream of the Assiniboine River)					111,000

Table 2
Station Normal Temperature and Precipitation, 1961-1990

Station	Normal Annual Temperature (Degrees F) Max	Min	Normal Annual Precipitation (Inches)
Wahpeton 3 N	53.7	32.1	21.70
Fargo WSO AP	51.5	30.3	19.45
Grand Forks FAA AP	50.1	28.7	18.34
Grand Forks University	51.2	30.4	19.22
Pembina	48.6	25.2	17.78

Table 3
20 Largest Floods at Various Locations in the Red River Valley

Wahpeton		Fargo		Grand Forks		Emerson	
Year	Flow	Year	Flow	Year	Flow	Year	Flow
1997	15,000[1]	1997	28,000	1826	144,000[2]	1826	174,000[2]
1897	10,500	1969	25,300	1997	114,000[3]	1997	133,000
2001	9,220[4]	1897	25,000	1852	97,000[2]	1852	118,000[2]
1969	9,200	2001	20,300[4]	1897	85,000	1950	95,500
1989	8,370	1882	20,000	1979	82,000	1979	92,700
1952	7,130	1989	18,900	1882	75,000	1861	83,000[2]
1979	7,050	1978	17,500	1861	68,000[2]	1966	66,800
1995	6,370	1979	17,300	1996	58,100	1996	66,700
1978	6,250	1952	16,300	2001	55,800[4]	1999	58,600
1986	6,140	1943	16,000	1966	55,000	2001	58,500[5]
1951	6,090	1975	13,200	1978	54,200	1969	54,700
1993	6,080	1965	11,400	1950	54,000	1948	51,800
1965	5,690	1994	11,200	1969	53,500	1978	50,600
1962	5,650	1995	11,000	1893	53,300	1965	46,200
1996	5,400	1966	10,700	1965	52,000	1916	46,200
1994	5,000	1993	10,100	1999	50,000	1974	43,500
1943	5,000	1996	9,940	1975	42,800	1975	42,800
1966	4,760	1962	9,580	1989	39,600	1989	42,700
1984	4,710	1984	9,550	1883	38,600	1995	42,400
1947	4,610	1947	9,300	1947	35,000	1970	39,600

1. 1997 flow at Wahpeton includes 2,200 cfs that broke out of the Bois de Sioux River upstream of the USGS gage.
2. Flow is estimated as an average between Corps of Engineers and U S Geological Survey estimated values.
3. U S Geological Survey measured 137,000 cfs but recommends 114,000 cfs should be used for discharge - frequency analyses.
4. Provisional data from the U S Geological Survey – subject to revision.
5. Provisional data from Manitoba Water Resources – subject to revision.

Table 4

Frequency Data for the Red River of the North at Wahpeton/Breckenridge

Location	Flood Event (Years)	All-Season Peak Q – F (CFS)	(1) Combined-Population Elevation (Feet)
Red River of the North	500	18,300	964.8
At Wahpeton	100	12,150	962.6
U.S.G.S. Gage	50	10,850	961.5
(With Breakout Flows)	10	7,180	958.5
Bois de Sioux River	500	13,100	
Upstream of the Otter	100	9,250	
Tail River	50	8,450	
	10	5,700	
Bois de Sioux River	500	19,800	
Near Doran	100	10,500	
(Upstream of	50	9,100	
Breakout Flows)	10	5,700	
Otter Tail River	500	7,800	
At Mouth	100	5,000	
	50	4,100	
	10	2,000	

Notes:

(1) Peak elevations based on combined–population frequency analysis of 2 subpopulations of ice-affected elevations and open water elevations

Table 5
Without Dams Natural Flows
Red River at Fargo, ND
USGS Gage NO. 05054000

EVENTS ANALYZED				ORDERED EVENTS			
MON	DAY	YEAR	FLOW CFS	RANK	WATER YEAR	FLOW CFS	MEDIAN PLOT POS
0	0	1882	20000.	1	1969	31700.	.60
0	0	1902	1180.	2	1997	31000.	1.46
0	0	1903	2450.	3	1897	25000.	2.32
0	0	1904	5220.	4	1978	21700.	3.26
0	0	1905	4250.	5	1979	20200.	4.28
0	0	1906	3050.	6	1989	20150.	5.30
0	0	1907	7000.	7	1882	20000.	6.33
0	0	1908	2600.	8	1952	19800.	7.35
0	0	1909	1780.	9	1943	17900.	8.37
0	0	1910	5000.	10	1995	14200.	9.39
0	0	1911	608.	11	1966	13700.	10.41
0	0	1912	1100.	12	1965	13350.	11.44
0	0	1913	1560.	13	1994	13100.	12.46
0	0	1914	3140.	14	1975	12900.	13.48
0	0	1915	3130.	15	1986	12700.	14.50
0	0	1916	7740.	16	1993	11900.	15.52
0	0	1917	5240.	17	1962	11400.	16.54
0	0	1918	874.	18	1984	11200.	17.57
0	0	1919	680.	19	1996	10700.	18.59
0	0	1920	6200.	20	1947	9710.	19.61
0	0	1921	1970.	21	1951	9180.	20.63
0	0	1922	5200.	22	1972	8410.	21.65
0	0	1923	3960.	23	1950	8120.	22.68
0	0	1924	530.	24	1916	7740.	23.70
0	0	1925	940.	25	1945	7340.	24.72
0	0	1926	1600.	26	1907	7000.	25.74
0	0	1927	2650.	27	1982	6740.	26.76
0	0	1928	3840.	28	1963	6340.	27.79
0	0	1929	4440.	29	1946	6250.	28.81
0	0	1930	1340.	30	1967	6240.	29.83
0	0	1931	365.	31	1920	6200.	30.85
0	0	1932	875.	32	1953	5820.	31.87
0	0	1933	605.	33	1980	5810.	32.89
0	0	1934	323.	34	1985	5480.	33.92
0	0	1935	942.	35	1917	5240.	34.94
0	0	1936	1050.	36	1904	5220.	35.96
0	0	1937	1390.	37	1922	5200.	36.98
0	0	1938	1350.	38	1910	5000.	38.00
0	0	1939	3870.	39	1944	4570.	39.03
0	0	1940	1030.	40	1929	4440.	40.05
0	0	1941	1390.	41	1905	4250.	41.07
0	0	1942	3610.	42	1948	3970.	42.09
0	0	1943	17900.	43	1923	3960.	43.11
0	0	1944	4570.	44	1974	3900.	44.14
0	0	1945	7340.	45	1939	3870.	45.16
0	0	1946	6250.	46	1928	3840.	46.18
0	0	1947	9710.	47	1960	3650.	47.20
0	0	1948	3970.	48	1942	3610.	48.22

0	0	1949	2730.	49	1956	3440.	49.24
0	0	1950	8120.	50	1991	3210.	50.27
0	0	1951	9180.	51	1914	3140.	51.29
0	0	1952	19800.	52	1915	3130.	52.31
0	0	1953	5820.	53	1976	3090.	53.33
0	0	1954	2080.	54	1987	3060.	54.35
0	0	1955	2750.	55	1906	3050.	55.38
0	0	1956	3440.	56	1957	3030.	56.40
0	0	1957	3030.	57	1955	2750.	57.42
0	0	1958	1990.	58	1949	2730.	58.44
0	0	1959	1790.	59	1971	2680.	59.46
0	0	1960	3650.	60	1964	2650.	60.49
0	0	1961	876.	61	1927	2650.	61.51
0	0	1962	11400.	62	1908	2600.	62.53
0	0	1963	6340.	63	1992	2580.	63.55
0	0	1964	2650.	64	1903	2450.	64.57
0	0	1965	13350.	65	1970	2280.	65.60
0	0	1966	13700.	66	1954	2080.	66.62
0	0	1967	6240.	67	1958	1990.	67.64
0	0	1968	1100.	68	1921	1970.	68.66
0	0	1969	31700.	69	1973	1920.	69.68
0	0	1970	2280.	70	1959	1790.	70.70
0	0	1971	2680.	71	1909	1780.	71.73
0	0	1972	8410.	72	1981	1760.	72.75
0	0	1973	1920.	73	1983	1680.	73.77
0	0	1974	3900.	74	1926	1600.	74.79
0	0	1975	12900.	75	1913	1560.	75.81
0	0	1976	3090.	76	1941	1390.	76.84
0	0	1977	1150.	77	1937	1390.	77.86
0	0	1978	21700.	78	1938	1350.	78.88
0	0	1979	20200.	79	1930	1340.	79.90
0	0	1980	5810.	80	1902	1180.	80.92
0	0	1981	1760.	81	1977	1150.	81.95
0	0	1982	6740.	82	1912	1100.	82.97
0	0	1983	1680.	83	1968	1100.	83.99
0	0	1984	11200.	84	1936	1050.	85.01
0	0	1985	5480.	85	1940	1030.	86.03
0	0	1986	12700.	86	1988	990.	87.05
0	0	1987	3060.	87	1935	942.	88.08
0	0	1988	990.	88	1925	940.	89.10
0	0	1989	20150.	89	1990	940.	90.12
0	0	1990	940.	90	1961	876.	91.14
0	0	1991	3210.	91	1932	875.	92.16
0	0	1992	2580.	92	1918	874.	93.19
0	0	1993	11900.	93	1919	680.	94.21
0	0	1994	13100.	94	1911	608.	95.23
0	0	1995	14200.	95	1933	605.	96.25
0	0	1996	10700.	96	1924	530.	97.27
0	0	1997	31000.	97	1931	365.	98.30
0	0	1897	25000.	98	1934	323.	99.32

NOTE- PLOTTING POSITIONS BASED ON-HISTORIC PERIOD (H) = 116
NUMBER OF HISTORIC EVENTS PLUS HIGH OUTLIERS(Z) = 3
WEIGHTING FACTOR FOR SYSTEMATIC EVENTS (W) = 1.1895

Table 6
With Dams - Regulated Flows
Red River at Fargo, ND
USGS Gage NO. 05054000

EVENTS ANALYZED				ORDERED EVENTS			
			FLOW		WATER	FLOW	MEDIAN
MON	DAY	YEAR	CFS	RANK	YEAR	CFS	PLOT POS
0	0	1882	17094.	1	1997	28000.	.60
0	0	1902	1180.	2	1969	25300.	1.46
0	0	1903	2425.	3	1897	21273.	2.32
0	0	1904	4740.	4	1989	18900.	3.26
0	0	1905	3930.	5	1978	17500.	4.28
0	0	1906	2927.	6	1979	17300.	5.30
0	0	1907	6228.	7	1882	17094.	6.33
0	0	1908	2550.	8	1952	16300.	7.35
0	0	1909	1780.	9	1943	16000.	8.37
0	0	1910	4556.	10	1975	13200.	9.39
0	0	1911	608.	11	1965	11400.	10.41
0	0	1912	1100.	12	1994	11200.	11.44
0	0	1913	1560.	13	1995	11000.	12.46
0	0	1914	3002.	14	1966	10700.	13.48
0	0	1915	2993.	15	1993	10100.	14.50
0	0	1916	6847.	16	1996	9940.	15.52
0	0	1917	4757.	17	1962	9580.	16.54
0	0	1918	874.	18	1984	9550.	17.57
0	0	1919	680.	19	1947	9300.	18.59
0	0	1920	5559.	20	1986	8640.	19.61
0	0	1921	1970.	21	1951	8010.	20.63
0	0	1922	4724.	22	1950	7800.	21.65
0	0	1923	3687.	23	1945	7700.	22.68
0	0	1924	530.	24	1972	7250.	23.70
0	0	1925	940.	25	1916	6847.	24.72
0	0	1926	1600.	26	1953	6720.	25.74
0	0	1927	2592.	27	1907	6228.	26.76
0	0	1928	3587.	28	1946	5970.	27.79
0	0	1929	4088.	29	1982	5920.	28.81
0	0	1930	1340.	30	1967	5900.	29.83
0	0	1931	365.	31	1920	5559.	30.85
0	0	1932	875.	32	1980	5470.	31.87
0	0	1933	605.	33	1963	4930.	32.89
0	0	1934	323.	34	1917	4757.	33.92
0	0	1935	942.	35	1904	4740.	34.94
0	0	1936	1050.	36	1922	4724.	35.96
0	0	1937	1390.	37	1985	4690.	36.98
0	0	1938	1350.	38	1910	4556.	38.00
0	0	1939	3612.	39	1974	4150.	39.03
0	0	1940	1030.	40	1944	4150.	40.05
0	0	1941	1390.	41	1929	4088.	41.07
0	0	1942	3380.	42	1905	3930.	42.09
0	0	1943	16000.	43	1960	3900.	43.11
0	0	1944	4150.	44	1956	3870.	44.14
0	0	1945	7700.	45	1923	3687.	45.16
0	0	1946	5970.	46	1939	3612.	46.18
0	0	1947	9300.	47	1928	3587.	47.20

0	0	1948	3390.	48	1948	3390.	48.22
0	0	1949	2660.	49	1942	3380.	49.24
0	0	1950	7800.	50	1987	3300.	50.27
0	0	1951	8010.	51	1976	3200.	51.29
0	0	1952	16300.	52	1914	3002.	52.31
0	0	1953	6720.	53	1915	2993.	53.33
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0	0	1955	2760.	55	1955	2760.	55.38
0	0	1956	3870.	56	1949	2660.	56.40
0	0	1957	2540.	57	1991	2630.	57.42
0	0	1958	2280.	58	1927	2592.	58.44
0	0	1959	1250.	59	1992	2590.	59.46
0	0	1960	3900.	60	1908	2550.	60.49
0	0	1961	1020.	61	1957	2540.	61.51
0	0	1962	9580.	62	1970	2480.	62.53
0	0	1963	4930.	63	1903	2425.	63.55
0	0	1964	2400.	64	1964	2400.	64.57
0	0	1965	11400.	65	1958	2280.	65.60
0	0	1966	10700.	66	1921	1970.	66.62
0	0	1967	5900.	67	1973	1950.	67.64
0	0	1968	788.	68	1954	1920.	68.66
0	0	1969	25300.	69	1971	1910.	69.68
0	0	1970	2480.	70	1909	1780.	70.70
0	0	1971	1910.	71	1983	1750.	71.73
0	0	1972	7250.	72	1981	1710.	72.75
0	0	1973	1950.	73	1926	1600.	73.77
0	0	1974	4150.	74	1913	1560.	74.79
0	0	1975	13200.	75	1941	1390.	75.81
0	0	1976	3200.	76	1937	1390.	76.84
0	0	1977	878.	77	1938	1350.	77.86
0	0	1978	17500.	78	1930	1340.	78.88
0	0	1979	17300.	79	1959	1250.	79.90
0	0	1980	5470.	80	1990	1220.	80.92
0	0	1981	1710.	81	1902	1180.	81.95
0	0	1982	5920.	82	1912	1100.	82.97
0	0	1983	1750.	83	1936	1050.	83.99
0	0	1984	9550.	84	1940	1030.	85.01
0	0	1985	4690.	85	1961	1020.	86.03
0	0	1986	8640.	86	1988	981.	87.05
0	0	1987	3300.	87	1935	942.	88.08
0	0	1988	981.	88	1925	940.	89.10
0	0	1989	18900.	89	1977	878.	90.12
0	0	1990	1220.	90	1932	875.	91.14
0	0	1991	2630.	91	1918	874.	92.16
0	0	1992	2590.	92	1968	788.	93.19
0	0	1993	10100.	93	1919	680.	94.21
0	0	1994	11200.	94	1911	608.	95.23
0	0	1995	11000.	95	1933	605.	96.25
0	0	1996	9940.	96	1924	530.	97.27
0	0	1997	28000.	97	1931	365.	98.30
0	0	1897	21273.	98	1934	323.	99.32

NOTE- PLOTTING POSITIONS BASED ON-HISTORIC PERIOD (H) = 116
NUMBER OF HISTORIC EVENTS PLUS HIGH OUTLIERS(Z) = 3
WEIGHTING FACTOR FOR SYSTEMATIC EVENTS (W) = 1.1895

Table 7

Red River at Fargo, ND
Discharge-Frequency

	UNREGULATED WITHOUT DAMS CONDITION cfs	REGULATED WITH DAMS CONDITION cfs	1971 FIS cfs	EFFECTIVE FIS (ADOPTED) cfs
500-YR	63,400	57,400	50,000	50,000
100-YR	37,300	31,600	29,000	29,300
50-YR	28,600	24,300	22,300	22,300
10-YR	13,300	11,500	10,300	10,300

500-yr HEC-5 Simulated Unregulated Flow based on Balanced Hydrograph routings = 69,000 cfs
500-yr HEC-5 Simulated Regulated Flow based on Balanced Hydrograph routings = 63,000 cfs

Table 8

Summary Table of Discharge-Frequency Statistics
Red River of the North Main Stem Stations

Location	Mean Log	Standard Deviation	Adopted Skew	Discharge-Frequency (cfs) % Chance of Exceedance			
				10.0	2.0	1.0	0.2
Wahpeton	--	--	--	7,180	10,850	12,150	18,300
Fargo							
Effective FIS (Adopted)		--	--	10,300	22,300	29,300	50,000
This Study	--	--	--	11,500	24,300	31,600	57,400
Halstad	3.9470	0.3935	-0.2344	27,600	50,700	62,200	93,000
Grand Forks	4.1889	0.3903	-0.2247	47,700	87,600	108,000	161,000
Drayton	4.2688	0.3413	-0.0537	50,600	91,200	112,000	169,000
Emerson	4.3105	0.3302	-0.0376	54,000	95,900	117,000	176,000

FIGURES

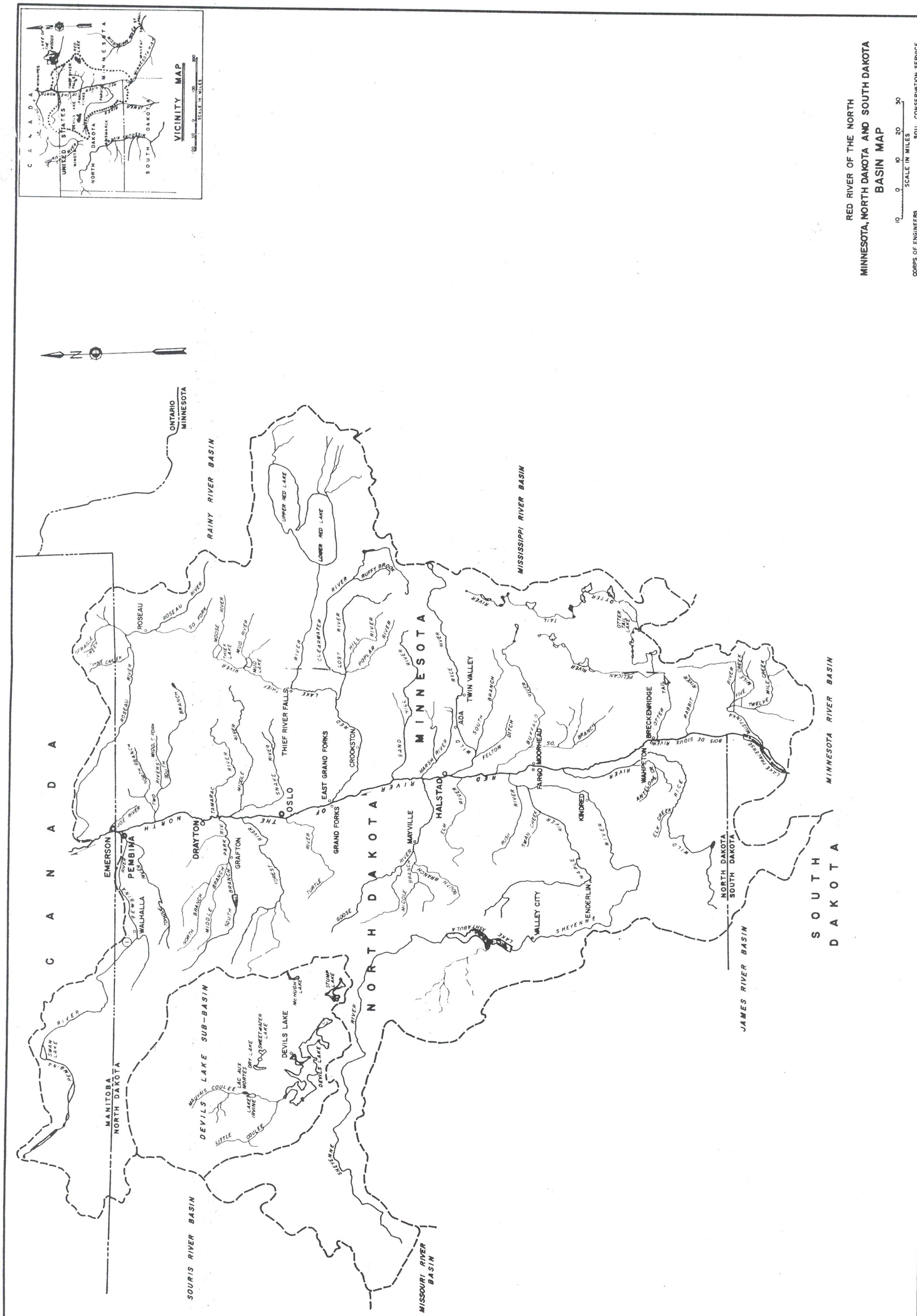
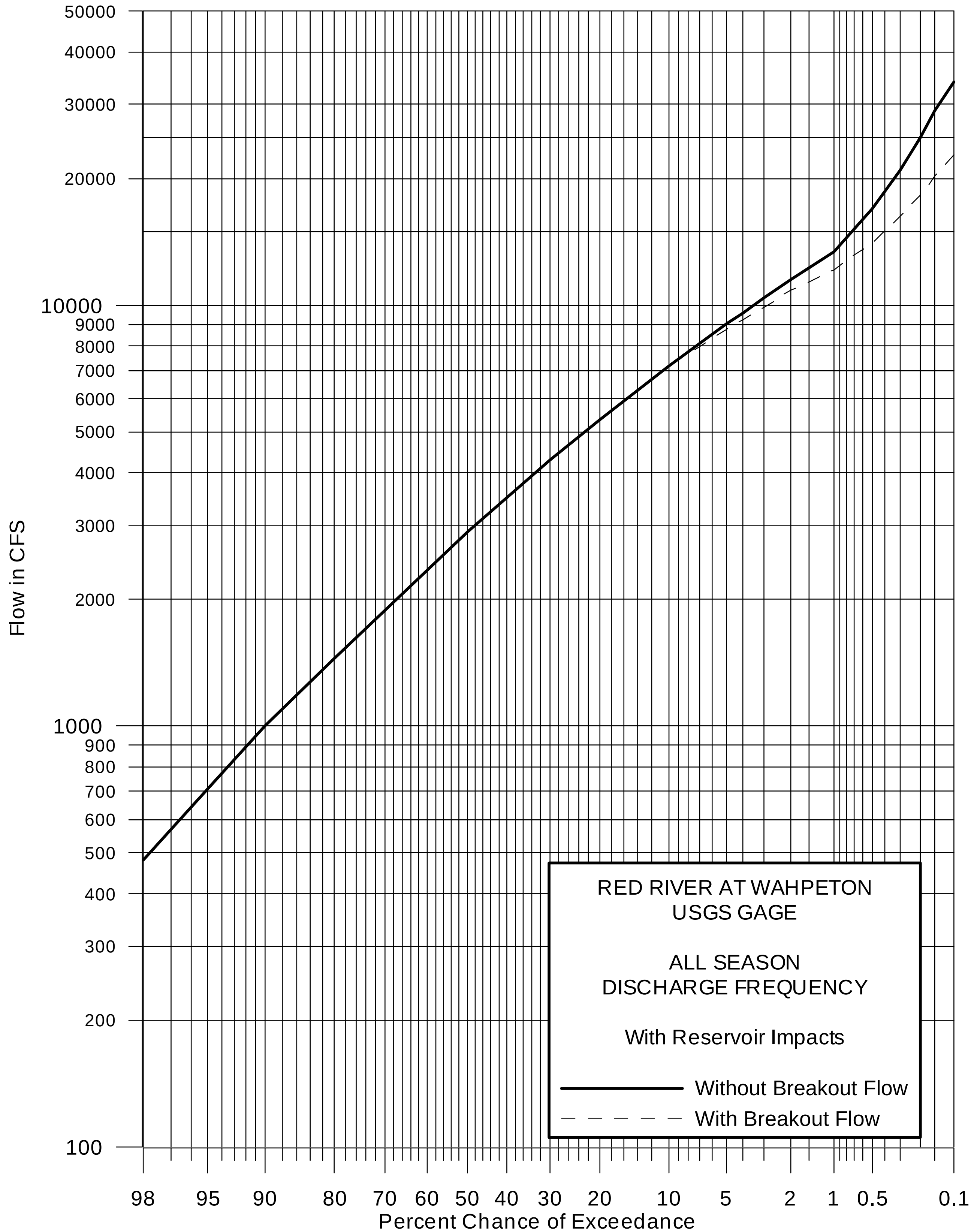

RED RIVER OF THE NORTH
MINNESOTA, NORTH DAKOTA AND SOUTH DAKOTA
BASIN MAP
SCALE IN MILES
CORPS OF ENGINEERS
U.S. ARMY
SOIL CONSERVATION SERVICE
U.S. DEPARTMENT OF AGRICULTURE
R-R-200/1
VICINITY MAP
CANADA
MINNESOTA
NORTH DAKOTA
SOUTH DAKOTA
MANITOBA
ONTARIO
RAINY RIVER BASIN
MISSISSIPPI RIVER BASIN
MINNESOTA RIVER BASIN
JAMES RIVER BASIN
MISSOURI RIVER BASIN
SOURIS RIVER BASIN
DEVILS LAKE SUB-BASIN
UPPER RED LAKE
LOWER RED LAKE
ROSEAU
THIEF RIVER FALLS
EAST GRAND FORKS
CROOKSTON
ADA
TWIN VALLEY
MOORHEAD
BRECKENRIDGE
WAHPETON
FARGO
HALSTAD
MAYVILLE
GRAND FORKS
OSLO
DRAYTON
GRAFTON
EMERSON
PEMBINA
WALHALLA
KINDRED
VALLEY CITY
DEVILS LAKE
STUMP LAKE
LAKE ASHTABULA
OTTER TAIL LAKE
LAKE TRAVERSE

FIGURE 1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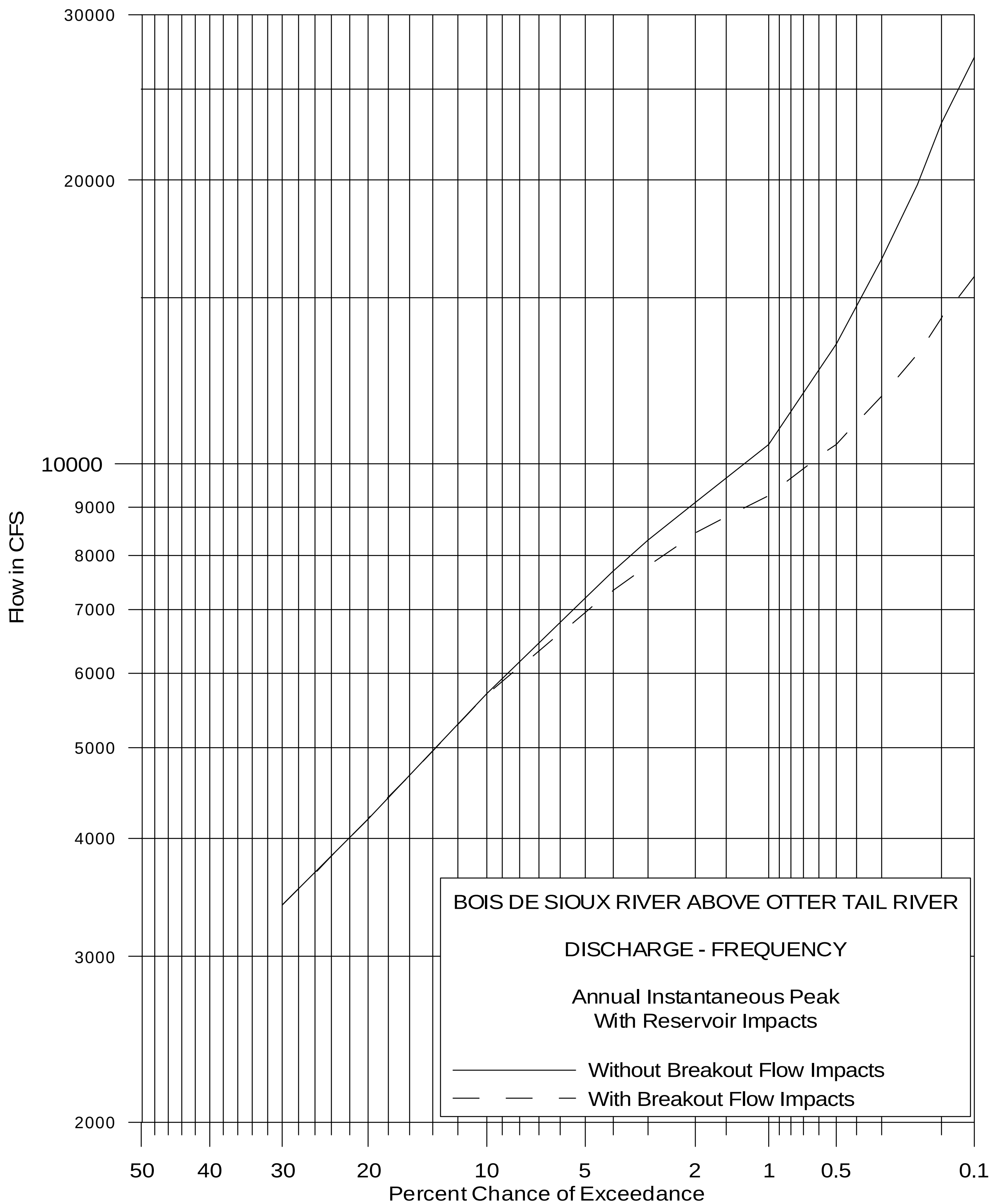
400
300
200
100
Flow in CFS
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.1
Percent Chance of Exceedance
RED RIVER AT WAHPETON
USGS GAGE
ALL SEASON
DISCHARGE FREQUENCY
With Reservoir Impacts
Without Breakout Flow
With Breakout Flow

FIGURE 2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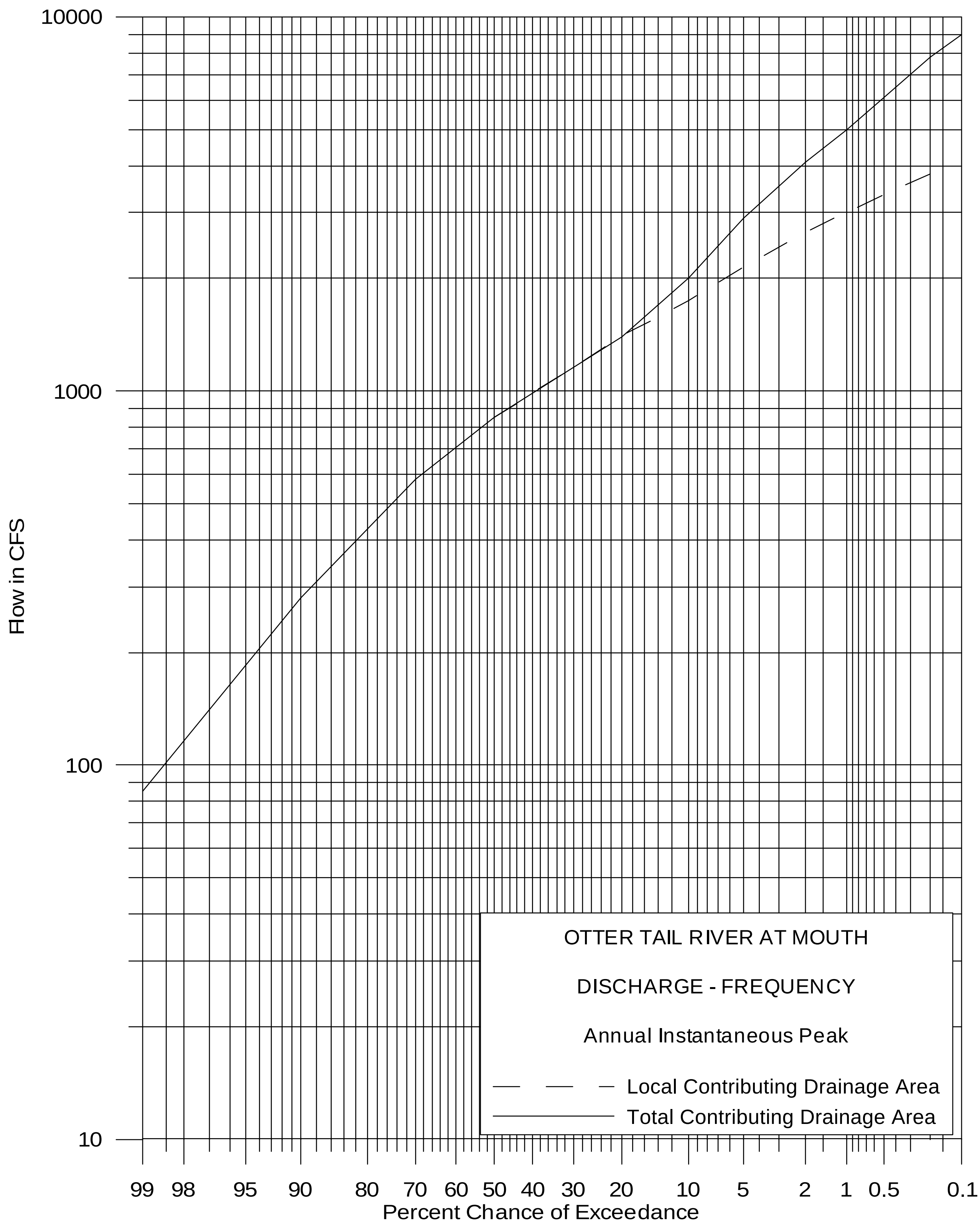
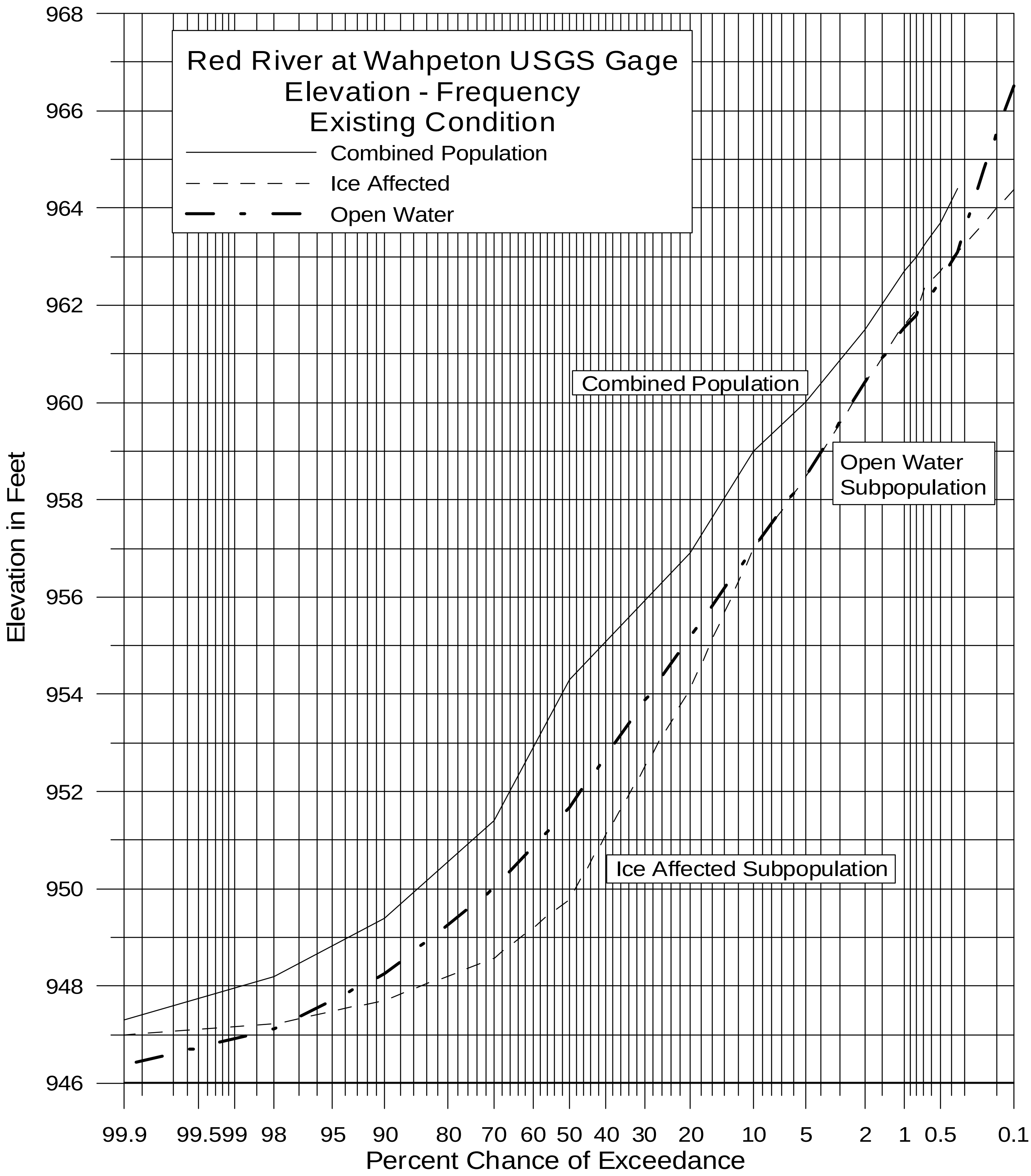
Flow in CFS
50
40
30
20
10
5
2
1
0.5
0.1
Percent Chance of Exceedance
BOIS DE SIOUX RIVER ABOVE OTTER TAIL RIVER
DISCHARGE - FREQUENCY
Annual Instantaneous Peak
With Reservoir Impacts
Without Breakout Flow Impacts
With Breakout Flow Impacts

FIGURE 3



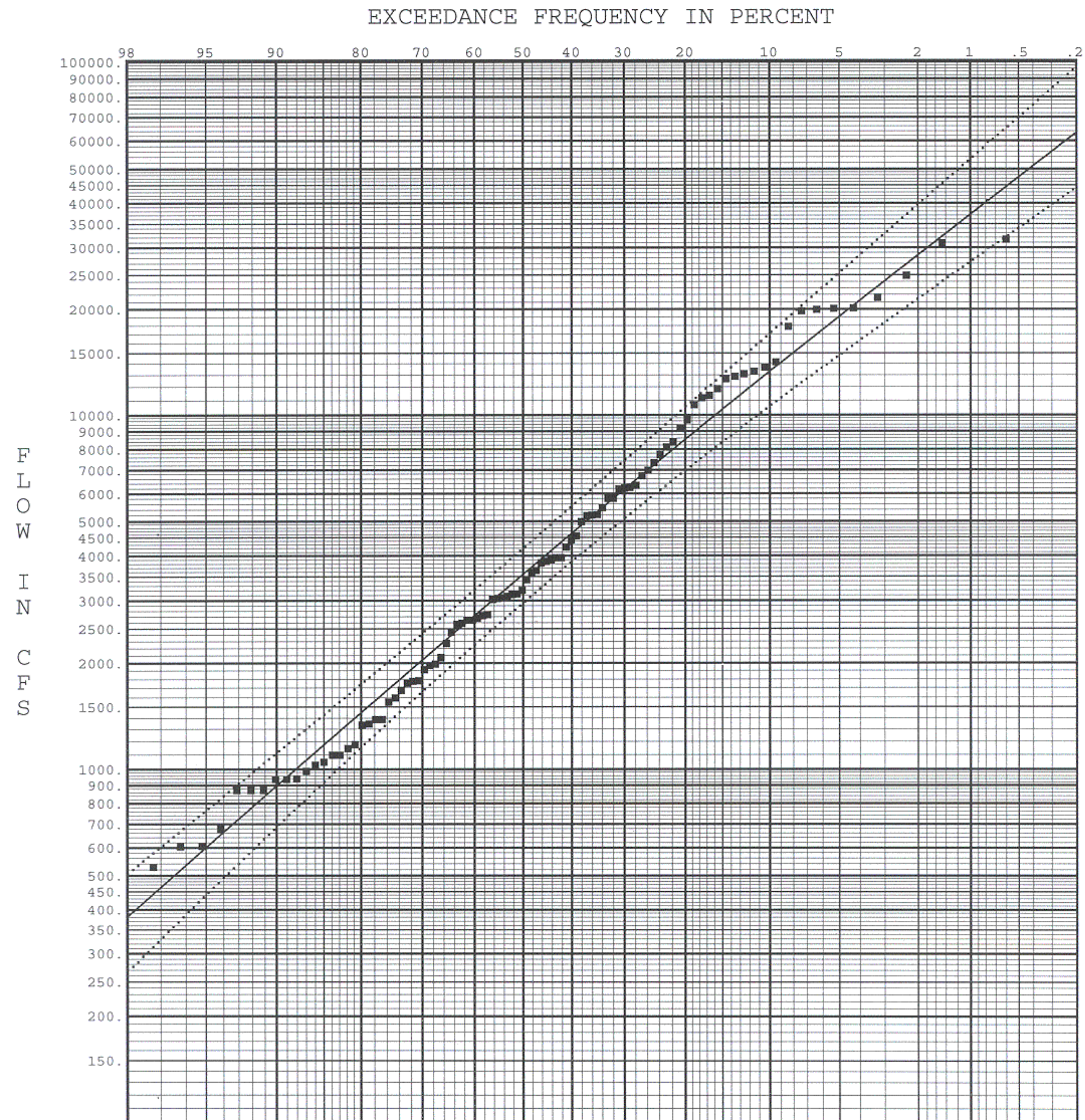
10000
1000
100
10
Flow in CFS
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.1
Percent Chance of Exceedance
OTTER TAIL RIVER AT MOUTH
DISCHARGE - FREQUENCY
Annual Instantaneous Peak
Local Contributing Drainage Area
Total Contributing Drainage Area

FIGURE 4



Red River at Wahpeton USGS Gage
Elevation - Frequency
Existing Condition
Combined Population
Ice Affected
Open Water
Combined Population
Open Water Subpopulation
Ice Affected Subpopulation
Elevation in Feet
968
966
964
962
960
958
956
954
952
950
948
946
99.9
99.5
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.1
Percent Chance of Exceedance

FIGURE 5



—— FLOW Frequency (without Exp. Prob.)
▪ Median Plotting Positions
······· 5% and 95% Confidence Limits

FREQUENCY STATISTICS		NUMBER OF EVENTS	
LOG TRANSFORM OF FLOW, CFS			
MEAN	3.5432	HISTORIC EVENTS	1
STANDARD DEV	.4566	HIGH OUTLIERS	2
SKEW	.0325	LOW OUTLIERS	0
REGIONAL SKEW	-.1000	ZERO OR MISSING	0
ADOPTED SKEW	-.1000	SYSTEMATIC EVENTS	97
		HISTORIC PERIOD(1882-1997)	116

RED RIVER AT FARGO
USGS GAGE 05054000
DISCHARGE - FREQUENCY
NATURAL FLOWS FOR 1942 - 1997
TOTAL BASIN AREA = 6,800 SQ MI
CONTRIBUTING DA = 4,625 SQ MI
WATER YEARS IN RECORD
1882,1897,1902-1997

FIGURE 6

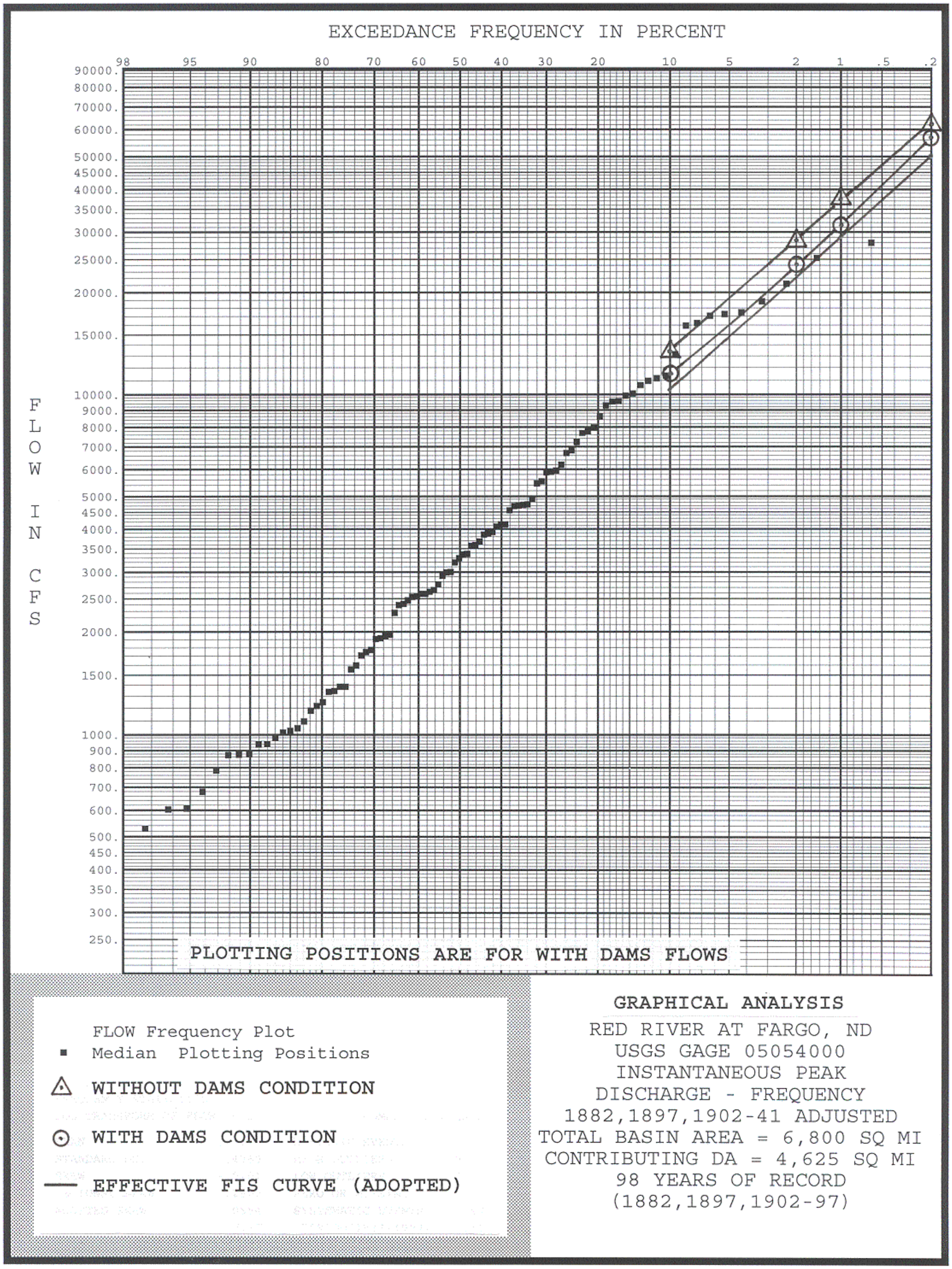

EXCEEDANCE FREQUENCY IN PERCENT
98
95
90
80
70
60
50
40
30
20
10
5
2
1
.5
.2
FLOW IN CFS
90000.
80000.
70000.
60000.
50000.
45000.
40000.
35000.
30000.
25000.
20000.
15000.
10000.
9000.
8000.
7000.
6000.
5000.
4500.
4000.
3500.
3000.
2500.
2000.
1500.
1000.
900.
800.
700.
600.
500.
450.
400.
350.
300.
250.
PLOTTING POSITIONS ARE FOR WITH DAMS FLOWS
FLOW Frequency Plot
Median Plotting Positions
WITHOUT DAMS CONDITION
WITH DAMS CONDITION
EFFECTIVE FIS CURVE (ADOPTED)
GRAPHICAL ANALYSIS
RED RIVER AT FARGO, ND
USGS GAGE 05054000
INSTANTANEOUS PEAK
DISCHARGE - FREQUENCY
1882,1897,1902-41 ADJUSTED
TOTAL BASIN AREA = 6,800 SQ MI
CONTRIBUTING DA = 4,625 SQ MI
98 YEARS OF RECORD
(1882,1897,1902-97)

FIGURE 7

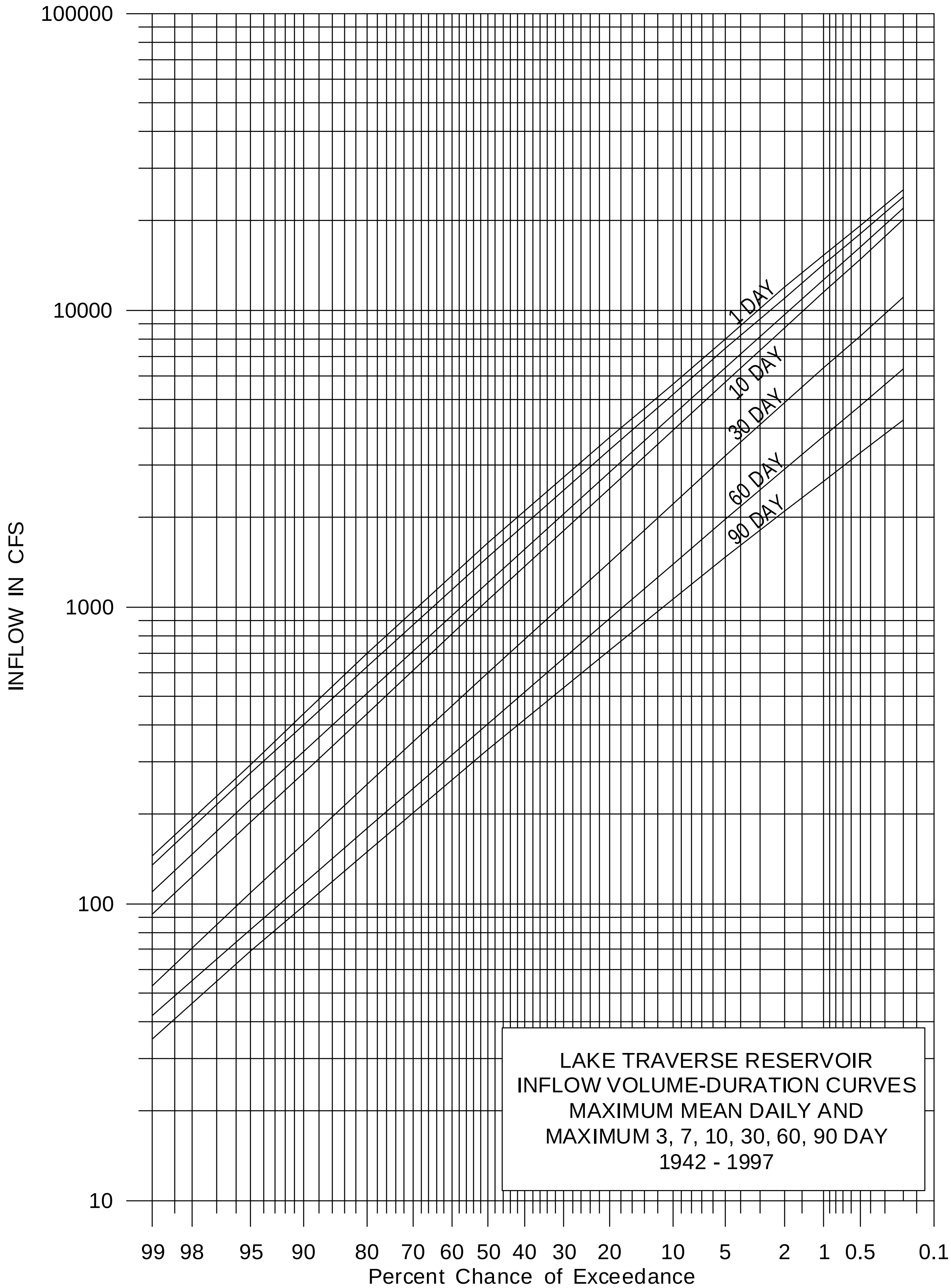

100000
10000
1000
100
10
INFLOW IN CFS
1 DAY
10 DAY
30 DAY
60 DAY
90 DAY
99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.1
Percent Chance of Exceedance
LAKE TRAVERSE RESERVOIR
INFLOW VOLUME-DURATION CURVES
MAXIMUM MEAN DAILY AND
MAXIMUM 3, 7, 10, 30, 60, 90 DAY
1942 - 1997

FIGURE 8

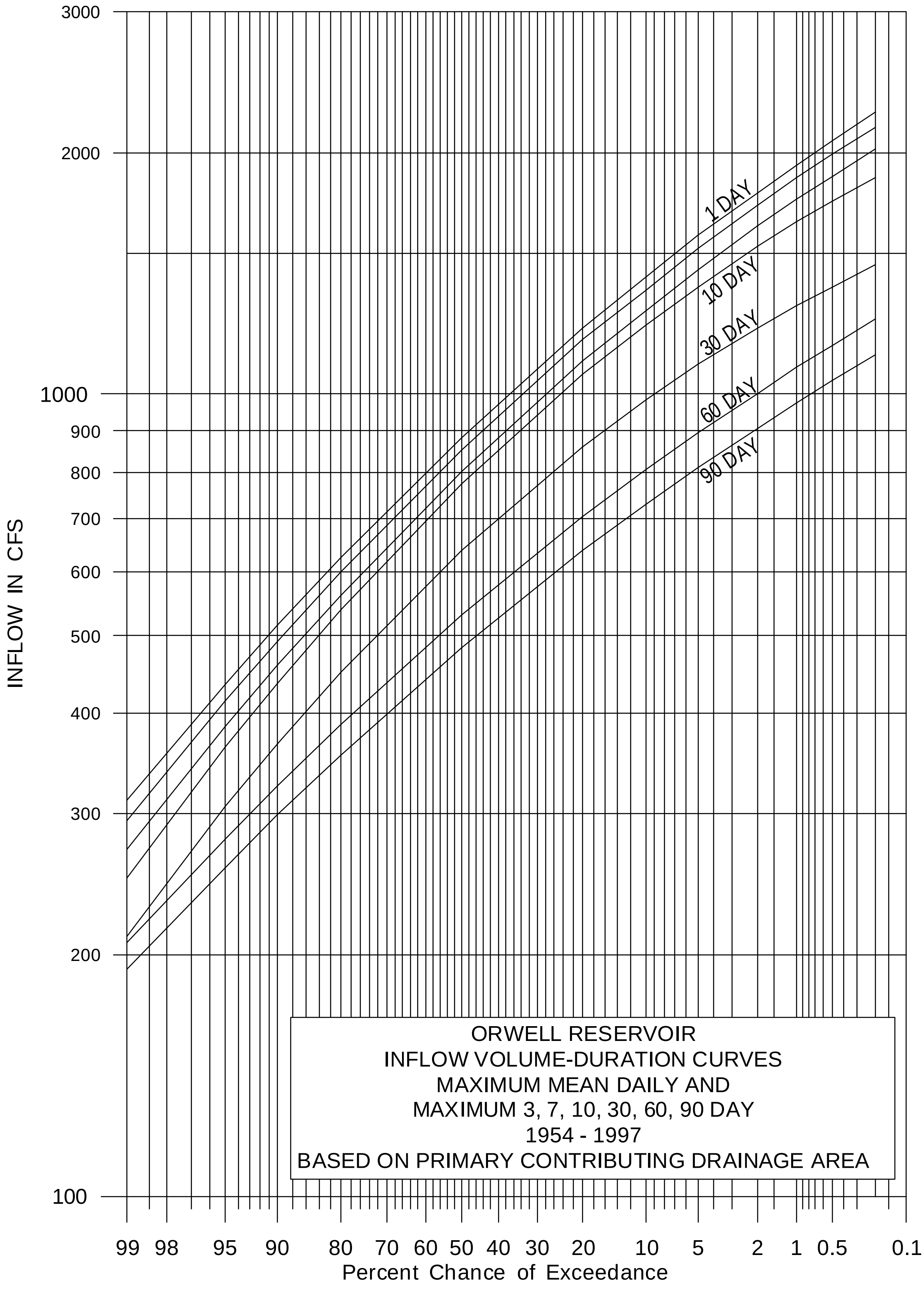

3000
2000
1000
900
800
700
600
500
400
300
200
100
INFLOW IN CFS
1 DAY
10 DAY
30 DAY
60 DAY
90 DAY
ORWELL RESERVOIR
INFLOW VOLUME-DURATION CURVES
MAXIMUM MEAN DAILY AND
MAXIMUM 3, 7, 10, 30, 60, 90 DAY
1954 - 1997
BASED ON PRIMARY CONTRIBUTING DRAINAGE AREA
99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.1
Percent Chance of Exceedance

FIGURE 9

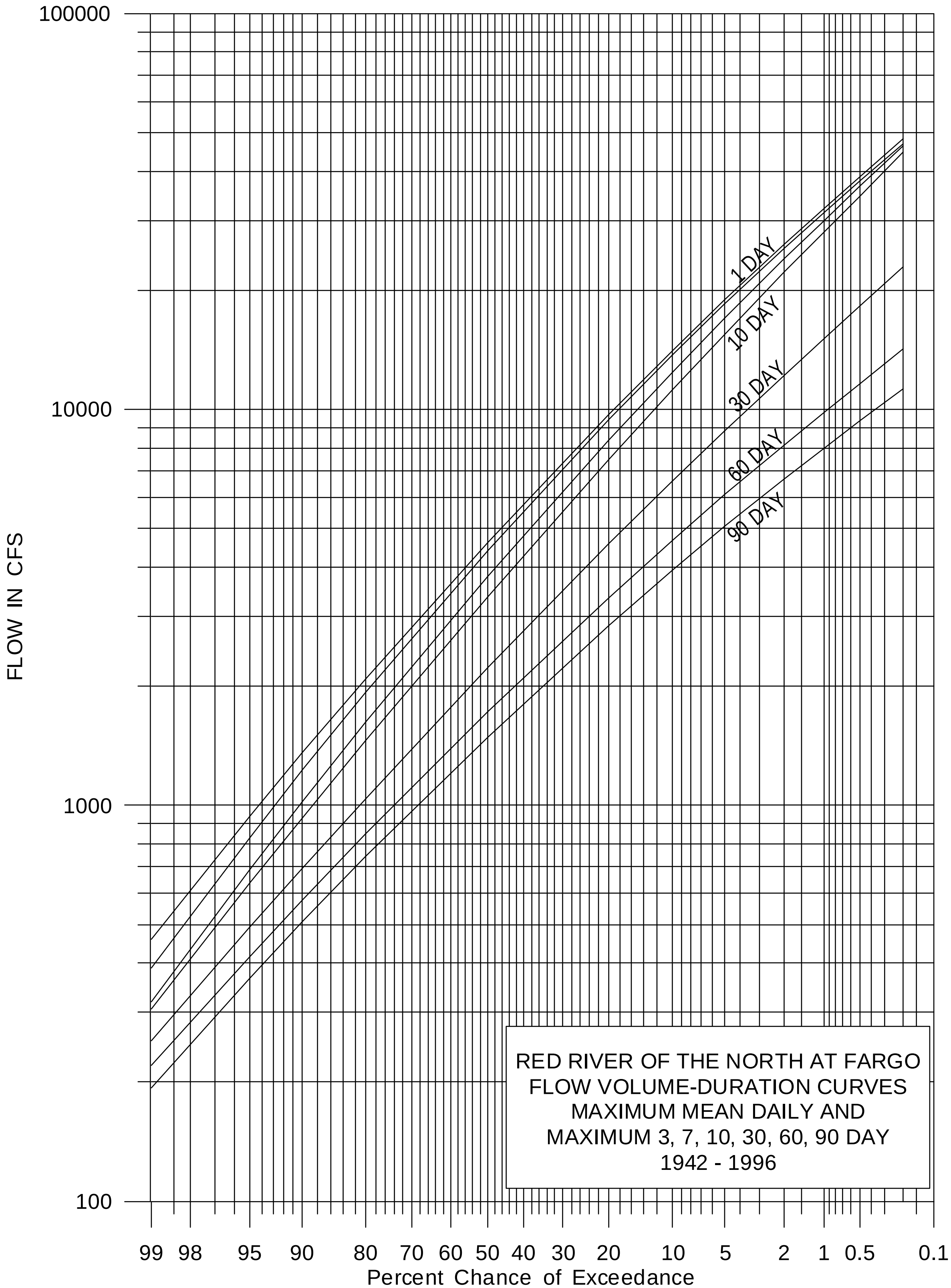
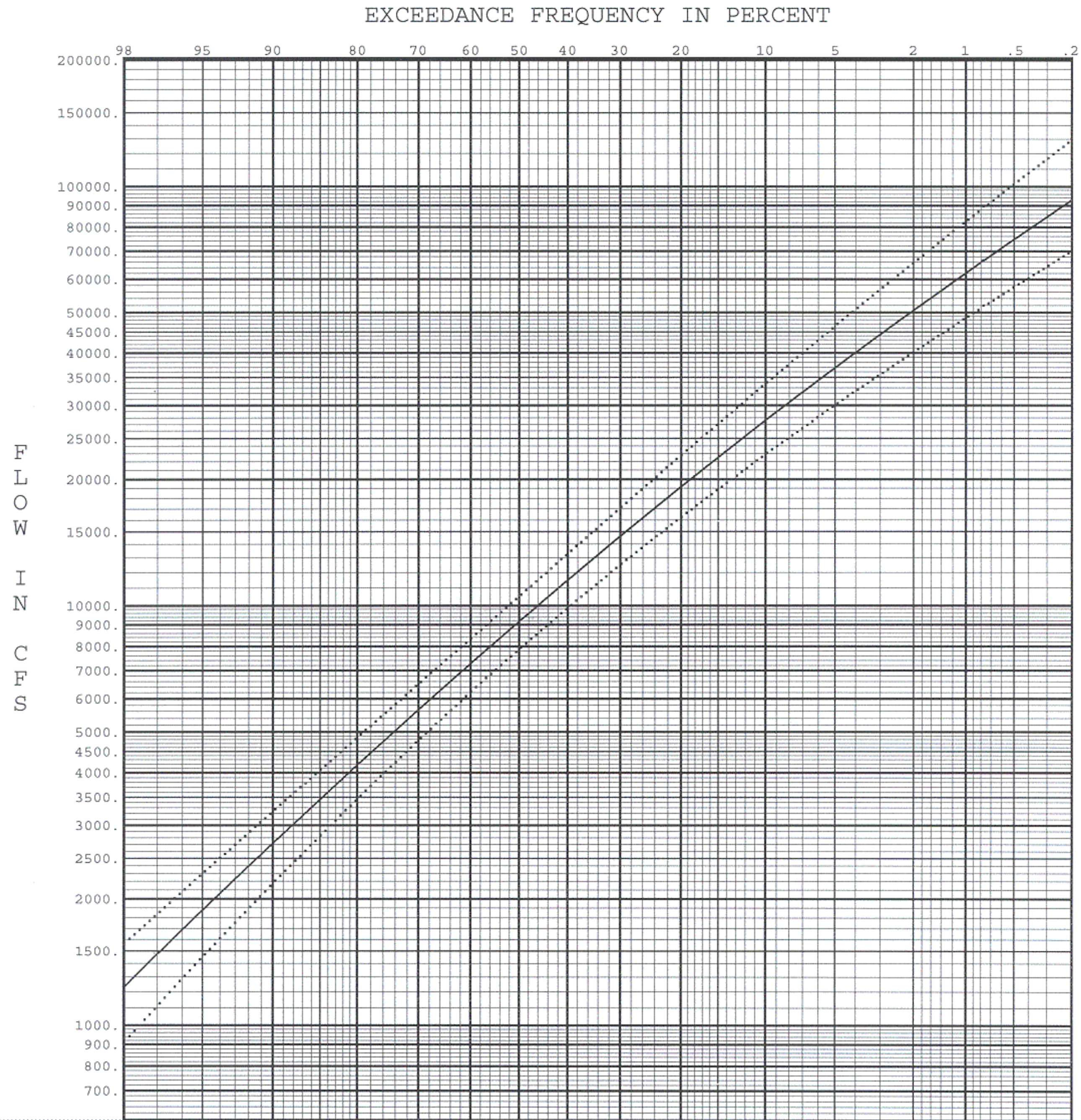

100000
10000
1000
100
FLOW IN CFS
1 DAY
10 DAY
30 DAY
60 DAY
90 DAY
RED RIVER OF THE NORTH AT FARGO
FLOW VOLUME-DURATION CURVES
MAXIMUM MEAN DAILY AND
MAXIMUM 3, 7, 10, 30, 60, 90 DAY
1942 - 1996
99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.1
Percent Chance of Exceedance

FIGURE 10



—— FLOW Frequency (without Exp. Prob.)

▪ Median Plotting Positions

······· 5% and 95% Confidence Limits

FREQUENCY STATISTICS LOG TRANSFORM OF FLOW, CFS		NUMBER OF EVENTS	
MEAN	3.9470	HISTORIC EVENTS	0
STANDARD DEV	.3935	HIGH OUTLIERS	0
SKEW	-.2363	LOW OUTLIERS	0
REGIONAL SKEW	-.2247	ZERO OR MISSING	0
ADOPTED SKEW	-.2344	SYSTEMATIC EVENTS	107

RED RIVER OF THE NORTH
AT HALSTAD, MN
USGS GAGE 05064500

BASED ON ADJUSTED STATISTICS
USING GRAND FORKS

CONTRIBUTING DA = 15,205 SQ MI
BASIN AREA = 21,800 SQ MI

FIGURE 11

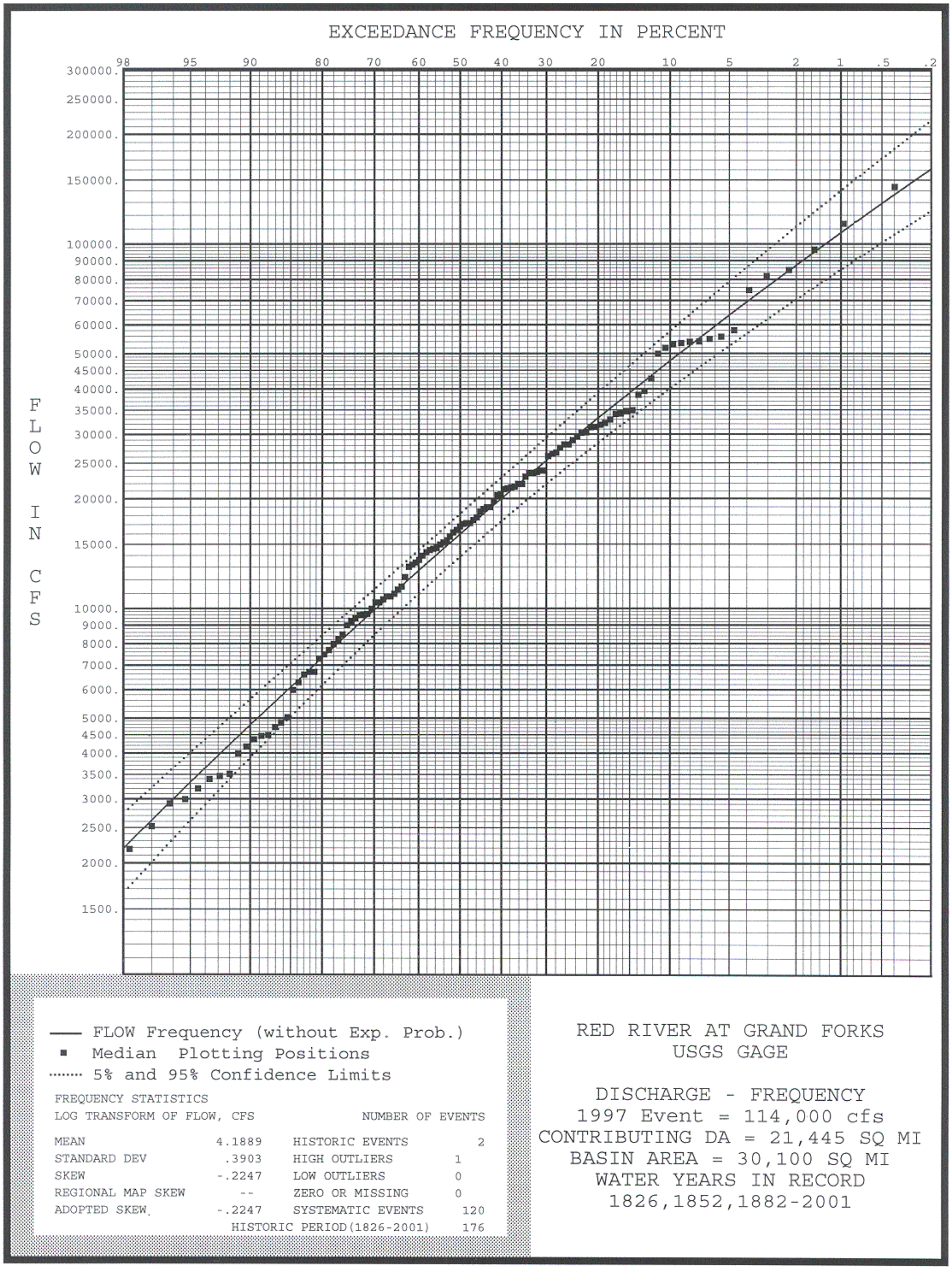
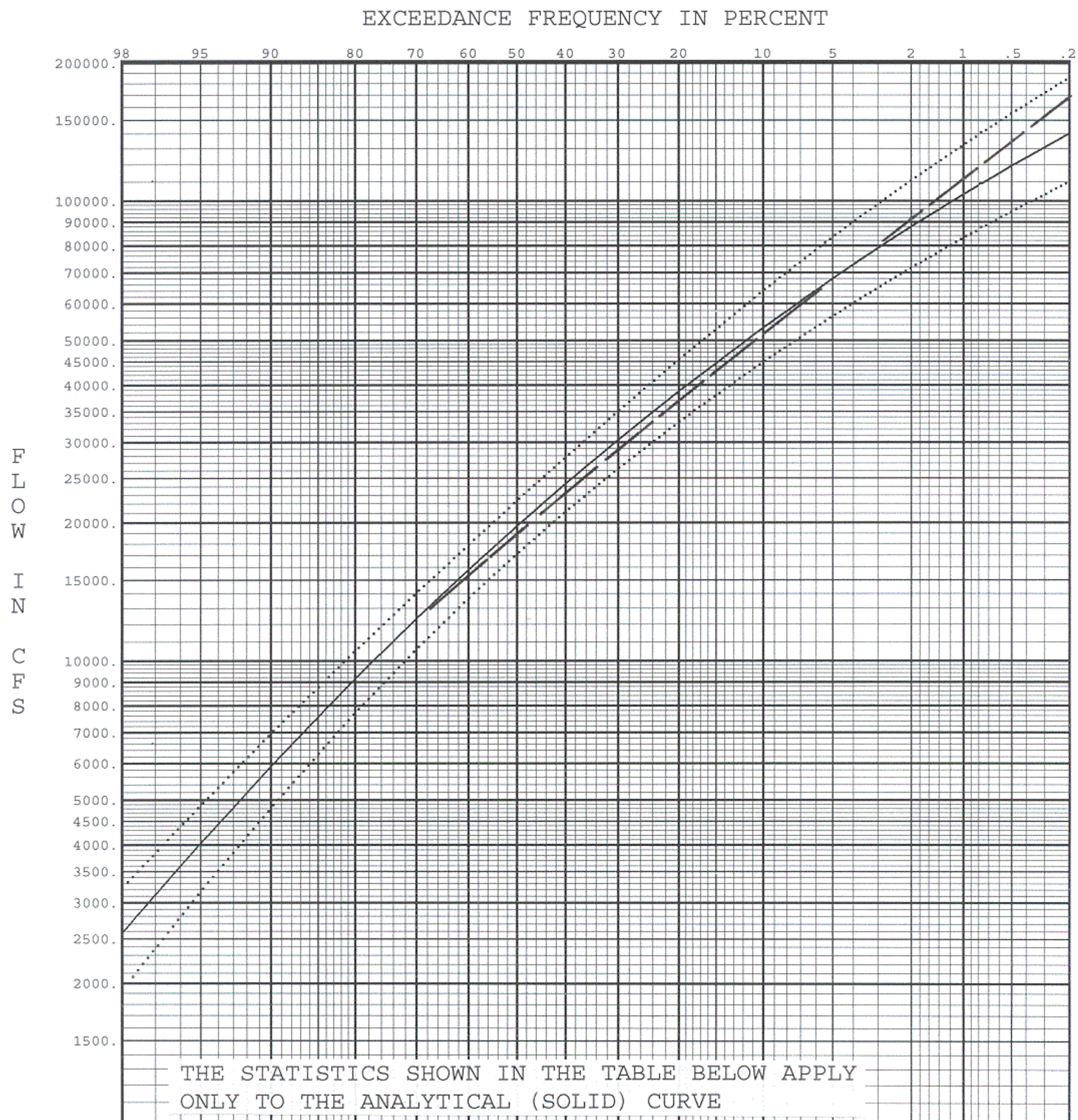

EXCEEDANCE FREQUENCY IN PERCENT
98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .2
300000.
250000.
200000.
150000.
100000.
90000.
80000.
70000.
60000.
50000.
45000.
40000.
35000.
30000.
25000.
20000.
15000.
10000.
9000.
8000.
7000.
6000.
5000.
4500.
4000.
3500.
3000.
2500.
2000.
1500.
FLOW IN CFS
FLOW Frequency (without Exp. Prob.)
Median Plotting Positions
5% and 95% Confidence Limits
FREQUENCY STATISTICS
LOG TRANSFORM OF FLOW, CFS
NUMBER OF EVENTS
MEAN 4.1889
STANDARD DEV .3903
SKEW -.2247
REGIONAL MAP SKEW --
ADOPTED SKEW -.2247
HISTORIC EVENTS 2
HIGH OUTLIERS 1
LOW OUTLIERS 0
ZERO OR MISSING 0
SYSTEMATIC EVENTS 120
HISTORIC PERIOD (1826-2001) 176
RED RIVER AT GRAND FORKS
USGS GAGE
DISCHARGE - FREQUENCY
1997 Event = 114,000 cfs
CONTRIBUTING DA = 21,445 SQ MI
BASIN AREA = 30,100 SQ MI
WATER YEARS IN RECORD
1826,1852,1882-2001

FIGURE 12



- **– – Regionally Adjusted Curve**
- —— FLOW Frequency (without Exp. Prob.)
- ▪ Median Plotting Positions
- ······· 5% and 95% Confidence Limits

FREQUENCY STATISTICS LOG TRANSFORM OF FLOW, CFS		NUMBER OF EVENTS	
MEAN	4.2663	HISTORIC EVENTS	0
STANDARD DEV	.3749	HIGH OUTLIERS	0
SKEW	-.4936	LOW OUTLIERS	0
REGIONAL SKEW	-.2247	ZERO OR MISSING	0
ADOPTED SKEW	-.4424	SYSTEMATIC EVENTS	114

PRELIMINARY CURVES
RED RIVER OF THE NORTH
AT DRAYTON, ND
USGS GAGE 05092000

BASED ON ADJUSTED STATISTICS
USING GRAND FORKS
1997 G. F. FLOW = 114,000 CFS
CONTRIBUTING DA = 31,000 SQ MI
BASIN AREA = 34,800 SQ MI

FIGURE 13

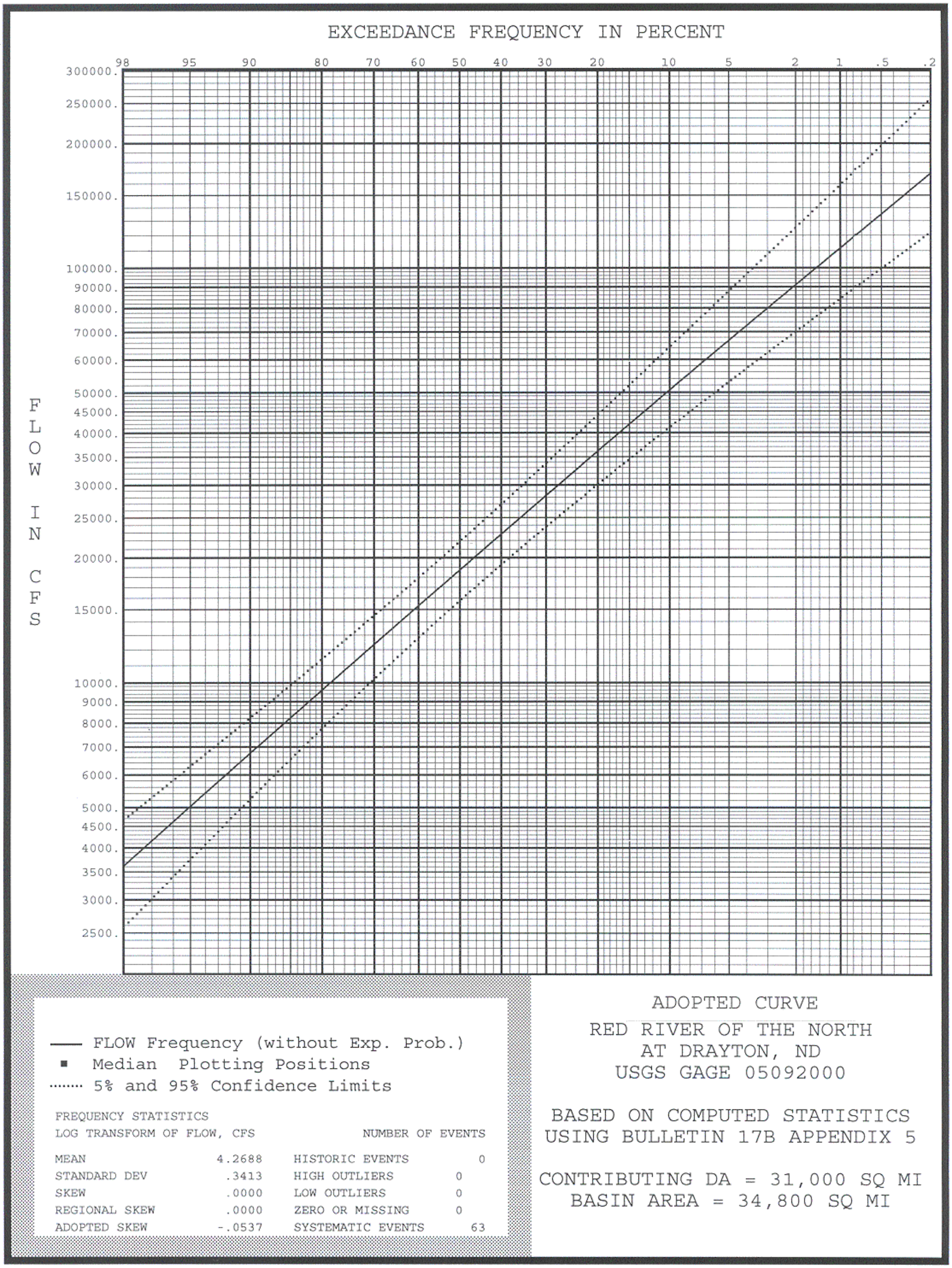

EXCEEDANCE FREQUENCY IN PERCENT
98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .2
FLOW IN CFS
300000. 250000. 200000. 150000. 100000. 90000. 80000. 70000. 60000. 50000. 45000. 40000. 35000. 30000. 25000. 20000. 15000. 10000. 9000. 8000. 7000. 6000. 5000. 4500. 4000. 3500. 3000. 2500.
FLOW Frequency (without Exp. Prob.)
Median Plotting Positions
5% and 95% Confidence Limits
FREQUENCY STATISTICS
LOG TRANSFORM OF FLOW, CFS
NUMBER OF EVENTS
MEAN 4.2688
STANDARD DEV .3413
SKEW .0000
REGIONAL SKEW .0000
ADOPTED SKEW -.0537
HISTORIC EVENTS 0
HIGH OUTLIERS 0
LOW OUTLIERS 0
ZERO OR MISSING 0
SYSTEMATIC EVENTS 63
ADOPTED CURVE
RED RIVER OF THE NORTH
AT DRAYTON, ND
USGS GAGE 05092000
BASED ON COMPUTED STATISTICS
USING BULLETIN 17B APPENDIX 5
CONTRIBUTING DA = 31,000 SQ MI
BASIN AREA = 34,800 SQ MI

FIGURE 14

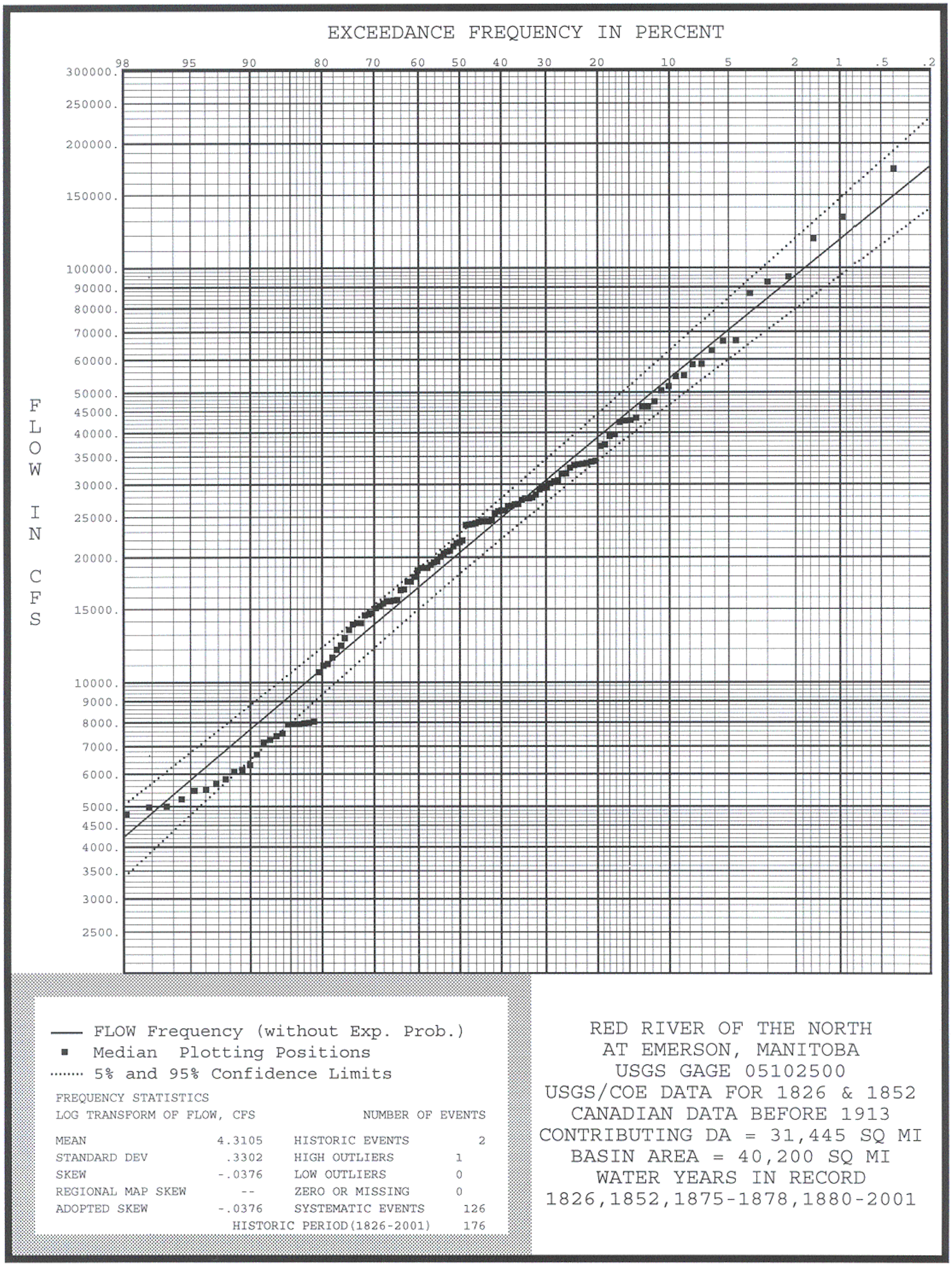

EXCEEDANCE FREQUENCY IN PERCENT
98 95 90 80 70 60 50 40 30 20 10 5 2 1 .5 .2
FLOW IN CFS
300000.
250000.
200000.
150000.
100000.
90000.
80000.
70000.
60000.
50000.
45000.
40000.
35000.
30000.
25000.
20000.
15000.
10000.
9000.
8000.
7000.
6000.
5000.
4500.
4000.
3500.
3000.
2500.
FLOW Frequency (without Exp. Prob.)
Median Plotting Positions
5% and 95% Confidence Limits
FREQUENCY STATISTICS
LOG TRANSFORM OF FLOW, CFS
NUMBER OF EVENTS
MEAN 4.3105
STANDARD DEV .3302
SKEW -.0376
REGIONAL MAP SKEW --
ADOPTED SKEW -.0376
HISTORIC EVENTS 2
HIGH OUTLIERS 1
LOW OUTLIERS 0
ZERO OR MISSING 0
SYSTEMATIC EVENTS 126
HISTORIC PERIOD(1826-2001) 176
RED RIVER OF THE NORTH
AT EMERSON, MANITOBA
USGS GAGE 05102500
USGS/COE DATA FOR 1826 & 1852
CANADIAN DATA BEFORE 1913
CONTRIBUTING DA = 31,445 SQ MI
BASIN AREA = 40,200 SQ MI
WATER YEARS IN RECORD
1826,1852,1875-1878,1880-2001

FIGURE 15

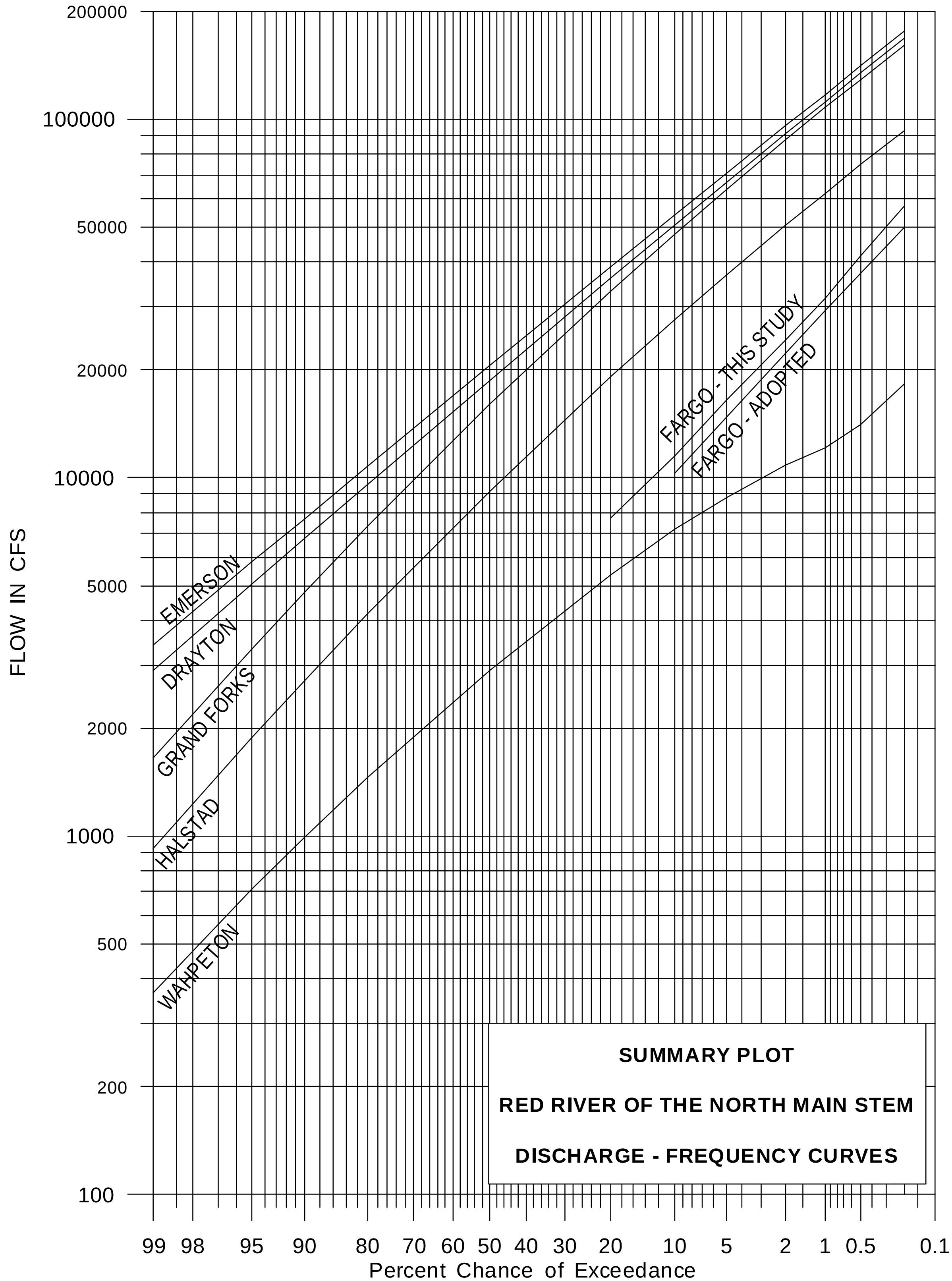

SUMMARY PLOT
RED RIVER OF THE NORTH MAIN STEM
DISCHARGE - FREQUENCY CURVES
FLOW IN CFS
Percent Chance of Exceedance
EMERSON
DRAYTON
GRAND FORKS
HALSTAD
WAHPETON
FARGO - THIS STUDY
FARGO - ADOPTED
200000
100000
50000
20000
10000
5000
2000
1000
500
200
100
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.1

FIGURE 16

APPENDICES

APPENDIX A

EXISTING F.I.S. HYDROLOGY
RED RIVER MAIN STEM

<u>**EXISTING F.I.S. HYDROLOGY**</u>
<u>**RED RIVER MAIN STEM**</u>

COMMUNITY	METHOD	FREQUENCY CURVE (CFS)			
		10 YR	**50 YR**	**100 YR**	**500 YR**
Breckenridge, MN (4,010 sq mi), 8/15/89	Bulletin 17B, 1971 Study (Bull. 15)[1]	5,700	9,250	11,000	17,150
Briarwood, ND (6,800 sq mi), 9/27/85 (From Stanley TWNP F.I.S.)	Administrative Agreement (1979)[2]	10,150	22,150	29,000	50,000
Cass County, ND (6,210 sq mi) 8/3/81 (RRN at USGS gage, Fargo)	1971 Study (Bull. 15)[1] and regional corr.	10,300	22,300	29,000	50,000
Clay County, MN 4/16/84 at Wild Rice River, ND (4,570 sq mi) at Sheyenne River (6,800 sq mi) at Buffalo River (13,940 sq mi) at CSAH 36 (15,130 sq mi)	Administrative Agreement (1979)[2]	 7,600 10,150 16,000 17,500	 14,000 22,150 31,000 33,000	 17,500 29,000 38,300 41,200	 27,000 50,000 60,000 61,800
Drayton, ND (34,800 sq mi) 2/1980 at State Highway 66 bridge	Not Known[3]	48,000	82,500	99,000	144,000

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[1] This study is titled ARed River of the North Regional Flood Analysis,≅ and is dated August 1971. It was prepared by the ND State Water Commission and the MN DNR in cooperation with the SCS, USACE and the USGS. It provides regional (100-year) discharges and stages for the Red River main stem, used Bulletin 15 methodology, and appears to be an administrative agreement between all agencies listed above. It was the basis for most of the F.I.S. hydrologic data in this table.

[2] Regional correlation from USGS gage data at Wahpeton, Fargo, Halstad and/or Emerson. The COE used the FFA (log-Pearson Type III) and REGFREQ computer programs and compared the results to Bulletin 17 methodology. The USGS used a log-Pearson Type III analysis. An administrative agreement was finalized by each agency issuing a letter in 1979, setting the flows as shown.

[3] Frequency curve from ARed River of the North, Main Stem, Hydrologic Data,≅ St. Paul District, October 1977. Methodology was not described, but the 100-year value matches the 1971 Regional (100-year) Flood Analysis Study value which was computed with Bulletin 15 methodology. Both of these are the same numbers as the 1979 Administrative Agreement between the COE and the USGS.

East Grand Forks, MN (30,100 sq mi) 9/1977	1971 Study (Bull. 15)[1]	49,000[4]	71,000[4]	89,000	138,000[4]
Fargo, ND (6,800 sq mi) 2/2/95	Administrative Agreement (1979)[2]	10,300	22,300	29,300	50,000
Grand Forks, ND (30,100 sq mi) 9/27/85	1971 Study (Bull 15)[1] Admn. Agrmnt. (>73)	49,000[4]	71,000[4]	89,000	139,000[4]
Halstad, MN (21,800 sq mi) 12/1978	Bulletin 17	25,000	42,000	50,000	71,000
Harwood, City of (6,210 sq mi) 8/19/91 from Red River at Fargo	Administrative Agreement (1979)[2]	10,300	22,300	29,000	50,000
Harwood, Township 12/18/85 D.S. of Sheyenne River (13,940 sq mi) U.S. of Sheyenne River (6,800 sq mi)	Administrative Agreement (1979)[2]	 16,000 10,150	 31,000 22,150	 38,300 29,000	 60,000 50,000
Hendrum, MN (20,200 sq mi) 6/1979 Red River at Cty Hwy 25 (See also Norman County FIS)	1971 Study (Bull 15)[1] log-Pearson type III with historic events, D.A. ratio transfer	22,400	38,900	46,900	68,500
Kittson County, MN 8/4/80 At St. Vincent, MN (40,200 sq mi) At southern cty. bndy. (34,800 sq mi)	log-Pearson type III, Bull 17, USGS/COE with historic events	 54,000 51,000	 92,000 84,000	 112,000 99,000	 162,000 140,000
Marshall County, MN (31,200 sq mi) 10/16/87	Not Known[3]	43,000	75,500	91,000	132,000
Moorhead, MN 5/4/87 (6,800 sq mi) from Fargo gage data	Administrative Agreement (1979)[2]	10,300	22,300	29,000	50,000
Norman County, MN 7/18/94 At MN Hwy 200 (Shelly: 21,800 sq mi) At Cty Hwy 25 (Hendrum: 20,200 sq mi) At Cty Hwy 39 (Perley: 19,000 sq mi)	1971 Study (Bull 15)[1], Administrative Agreement (1979)[2], D.A. ratio transfer	 25,000 22,400 22,400	 42,000 38,900 38,900	 50,000 46,900 46,900	 71,000 68,500 68,500
North River, ND 9/27/85 (6,800 sq mi) from Fargo gage data	Administrative Agreement (1979)[2]	10,150	22,150	29,000	50,000

[4] No tabular data published. The 10-, 50-, and 500-year flows were estimated from a plot in the F.I.S.

Oslo, MN 3/16/1982 (31,200 sq mi)	Not Known[3]	43,000	75,500	91,000	132,000
Perley, MN 12/1978 at County Highway 39 (19,000 sq mi) Note: Text references office memos by USGS (6/16/71) and COE (7/12/77)	1971 Study (Bull 15)[1], log-Pearson type III with historic events, D.A. ratio transfer	22,400	38,900	46,900	68,500
Polk County, MN 2/15/83 At Grand Forks (30,100 sq mi) At Oslo (31,200 sq mi)	Not Known[3]	 41,000 43,000	 74,000 75,500	 89,000 91,000	 130,000 132,000
Reed Township, ND 11/1/83 (6,800 sq mi)	Administrative Agreement (1979)[2]	10,150	22,150	29,000	50,000
St. Vincent, MN 3/2/82 (40,200 sq mi) Adjacent to Pembina, ND	Not Known[3]	54,000	92,000	112,000	162,000
Stanley Township, ND (revised 2/2/95) Upstream of Wild Rice R. (4,570 sq mi) Downstream of Wild Rice R. (6,800 mi^2)	Administrative Agreement (1979)[2], Bulletin 17A (COE)	 7,600 10,150	 14,000 22,150	 17,500 29,000	 27,000 50,000
Wahpeton, ND 6/4/87 Red River of the North (4,010 sq mi) Bois de Sioux River (1,967 sq mi) (Based on flows from the Bois de Sioux and Otter Tail Rivers, 1969 flood)	1971 Study (Bull 15)[1], Bulletin 17B (1982 by COE): HEC-2 for the Bois de Sioux (USGS, 1970)	 5,700 3,670	 9,250 5,300	 11,000 6,200	 17,150 9,760
Wilkin County, MN 3/1978 Otter Tail River at HWY 75 (2,070 mi^2) Bois de Sioux River at mouth(1,940 mi^2)	Data from 1970 Breckenridge FIS (HEC-2 analysis of 1969 flood on Bois de Sioux) and USGS files	 2,830 3,670	 4,090 5,300	 4,800 6,200	 7,540 9,760

APPENDIX B

FLOW DATA AT RED RIVER MAIN STEM GAGES

Red River of the North at Fargo, ND, Station 05054000

Year	Date	Discharge	Dcode	Stage	Scode	High	AltStage	AltDate	Acode	#Par
1882	04/11/82	20000.0	1	37.800	0					0
1897	04/07/97	25000.0	1	40.100	0					0
1902	05/23/02	1180.0	64	10.500	0					0
1903	04/06/03	2450.0	64	13.900	0					0
1904	04/20/04	5220.0	64	21.300	0					0
1905	05/17/05	4250.0	64	18.400	0					0
1906	04/09/06	3050.0	64	15.500	0					0
1907	03/31/07	7000.0	64	29.800	0					0
1908	06/13/08	2600.0	64	14.700	0					0
1909	05/30/09	1780.0	64	12.500	32		13.040	03/30/09	0	0
1910	03/19/10	5000.0	96	23.100	0					0
1911	04/11/11	608.0	64	8.700	0					0
1912	05/14/12	1100.0	64	10.600	0					0
1913	07/08/13	1560.0	64	11.900	0					0
1914	06/12/14	3140.0	0	16.100	0					0
1915	07/03/15	3130.0	0	9.730	0					0
1916	07/11/16	7740.0	0	---	32		23.630	04/06/16	64	0
1917	04/03/17	5240.0	0	17.800	64					0
1918	03/31/18	874.0	0	6.870	0					0
1919	04/06/19	680.0	0	6.500	0					0
1920	03/28/20	6200.0	0	17.200	0					0
1921	04/06/21	1970.0	0	8.400	0					0
1922	04/11/22	5200.0	0	14.700	0					0
1923	06/29/23	3960.0	0	11.600	0					0
1924	04/30/24	530.0	0	6.200	0					0
1925	06/21/25	940.0	0	7.000	0					0
1926	03/24/26	1600.0	0	8.000	0					0
1927	03/19/27	2650.0	0	9.100	0					0
1928	03/28/28	3840.0	0	13.300	64					0
1929	03/20/29	4440.0	0	12.800	0					0
1930	03/17/30	1340.0	0	10.000	0					0
1931	04/03/31	365.0	0	8.550	0					0
1932	04/11/32	875.0	0	9.450	0					0
1933	04/05/33	605.0	0	9.040	0					0
1934	04/10/34	323.0	0	8.550	0					0
1935	03/20/35	942.0	0	9.720	0					0
1936	04/14/36	1050.0	0	9.900	0					0
1937	04/12/37	1390.0	0	10.170	0					0
1938	05/02/38	1350.0	0	10.020	0					0
1939	03/31/39	3870.0	0	13.000	0					0
1940	04/08/40	1030.0	0	9.630	0					0
1941	04/03/41	1390.0	0	10.100	0					0
1942	06/11/42	3380.0	2	12.270	0					0
1943	04/07/43	16000.0	2	28.400	0					0
1944	06/10/44	4150.0	2	14.260	0					0
1945	03/22/45	7700.0	2	20.700	0					0
1946	03/27/46	5970.0	2	17.130	0					0
1947	04/15/47	9300.0	2	22.930	0					0
1948	04/10/48	3390.0	2	12.450	0					0
1949	07/12/49	2660.0	2	11.270	0					0
1950	04/07/50	7800.0	2	20.880	0					0
1951	04/11/51	8010.0	2	20.730	0					0
1952	04/16/52	16300.0	2	28.790	0					0
1953	06/01/53	6720.0	2	18.050	0					0
1954	07/04/54	1920.0	2	10.530	0					0
1955	04/04/55	2760.0	2	11.120	0					0
1956	04/16/56	3870.0	2	12.540	0					0
1957	04/24/57	2540.0	2	11.100	0					0
1958	07/06/58	2280.0	2	10.900	0					0
1959	07/08/59	1250.0	2	10.420	0					0
1960	04/08/60	3900.0	2	12.480	64					0
1961	06/09/61	1020.0	2	9.240	0					0
1962	06/14/62	9580.0	2	22.830	0					0
1963	06/14/63	4930.0	2	19.970	0					0

Red River of the North at Fargo, ND, Station 05054000 - Continued

Year	Date	Discharge	Dcode	Stage	Scode	High	AltStage	AltDate	Acode	#Par
1964	04/18/64	2400.0	2	16.220	0					0
1965	04/15/65	11400.0	2	30.500	0					0
1966	03/22/66	10700.0	2	30.160	0					0
1967	06/19/67	5900.0	2	22.340	0					0
1968	04/30/68	788.0	2	14.710	32		14.770	05/20/68	64	0
1969	04/15/69	25300.0	2	37.340	0	1882				0
1970	06/18/70	2480.0	2	16.270	0					0
1971	07/07/71	1910.0	2	15.870	0					0
1972	03/24/72	7250.0	2	25.360	0					0
1973	03/15/73	1950.0	2	16.410	64					0
1974	04/14/74	4150.0	2	20.250	0					0
1975	07/04/75	13200.0	2	33.260	0					0
1976	03/30/76	3200.0	2	18.700	0					0
1977	07/04/77	878.0	2	14.990	0					0
1978	04/02/78	17500.0	2	34.410	0					0
1979	04/19/79	17300.0	2	34.930	0					0
1980	04/05/80	5470.0	2	20.740	0					0
1981	05/24/81	1710.0	2	15.840	0					0
1982	04/04/82	5920.0	2	25.070	64					0
1983	07/04/83	1750.0	2	15.990	0					0
1984	04/01/84	9550.0	2	28.270	0					0
1985	06/05/85	4690.0	2	20.080	0					0
1986	04/02/86	8640.0	2	27.190	0					0
1987	03/27/87	3300.0	2	17.750	0					0
1988	03/11/88	981.0	2	15.100	0					0
1989	04/09/89	18900.0	2	35.390	0					0
1990	06/02/90	1220.0	2	15.400	0					0
1991	07/06/91	2630.0	2	16.990	0					0
1992	06/19/92	2590.0	66	16.930	0					0
1993	04/05/93	10100.0	2	28.270	0					0
1994	04/03/94	11200.0	2	26.690	0					0
1995	03/22/95	11000.0	2	28.370	0					0
1996	04/15/96	9940.0	2	28.750	0					0
1997	04/17/97	28000.0	2	---	0		39.720	04/18/97	0	0
1998	05/19/98	8610.0	2	24.870	0					0
1999	03/22/99	4900.0	34	20.810	64					0
2000	06/20/00	5630.0	2	22.200	32		22.820	06/21/00		0
2001	04/14/01	20300.0	2	36.630						0

NOTE: Data for water year 2001 from the U.S.G.S. is provisional and subject to change

Red River of the North at Halstad, MN, Station 05064500

Year	Date	Discharge	Dcode	Stage	Scode	High	AltStage	AltDate	Acode	#Par
1936	04/15/36	7670.0	0	16.330	0					0
1937	04/15/37	2660.0	0	9.390	64					0
1942	05/05/42	5060.0	2	12.860	0					0
1943	04/11/43	21800.0	2	31.310	0					0
1944	07/13/44	7200.0	2	15.790	0					0
1945	03/23/45	13300.0	34	23.600	0					0
1946	03/29/46	10000.0	2	19.500	0					0
1947	04/16/47	24500.0	2	33.500	32		34.000	04/17/47	0	0
1948	04/10/48	16000.0	2	---	32		26.780	04/13/48	0	0
1949	04/07/49	7710.0	2	16.530	0					0
1950	05/11/50	18700.0	2	---	32		32.000	04/11/50	0	0
1951	04/10/51	12900.0	2	22.430	0					0
1952	04/18/52	20700.0	2	29.780	0					0
1953	06/22/53	13600.0	2	22.780	0					0
1954	04/13/54	4660.0	2	11.440	0					0
1955	04/06/55	7200.0	2	19.280	64					0
1956	04/15/56	12900.0	2	23.670	64					0
1957	06/24/57	4980.0	2	12.200	0					0
1958	07/08/58	4420.0	2	11.310	0					0
1959	06/13/59	3780.0	2	10.130	0					0
1960	04/10/60	8600.0	2	21.660	64					0
1961	05/22/61	1900.0	2	6.960	0					0
1962	06/16/62	15900.0	2	24.700	0					0
1963	06/16/63	5850.0	2	13.140	0					0
1964	04/23/64	7820.0	2	15.270	0					0
1965	04/17/65	25600.0	2	35.270	0					0
1966	03/27/66	26800.0	2	35.350	64					0
1967	04/23/67	13800.0	2	22.710	0					0
1968	06/19/68	2350.0	2	7.800	32		9.820	03/28/68	64	0
1969	04/18/69	35700.0	2	38.290	0					0
1970	04/10/70	11600.0	2	22.360	64					0
1971	04/01/71	5480.0	2	15.620	64					0
1972	03/24/72	16200.0	2	28.960	0					0
1973	03/18/73	6200.0	2	17.710	64					0
1974	04/16/74	17800.0	2	26.720	64					0
1975	07/10/75	39900.0	2	38.550	0					0
1976	03/31/76	9950.0	2	23.300	64					0
1977	05/07/77	2050.0	2	7.500	0					0
1978	04/09/78	28800.0	2	37.610	0					0
1979	04/22/79	42000.0	2	39.000	0					0
1980	04/05/80	12900.0	2	21.980	0					0
1981	05/25/81	3920.0	2	10.570	0					0
1982	04/09/82	13200.0	2	27.130	64					0
1983	07/06/83	7800.0	2	14.980	32		17.100	03/07/83	64	0
1984	04/01/84	21900.0	2	29.990	64					0
1985	05/13/85	10400.0	2	19.070	0					0
1986	03/31/86	17400.0	2	25.890	0					0
1987	03/30/87	9860.0	2	21.430	64					0
1988	03/28/88	5010.0	2	12.420	32		12.570	03/12/88	64	0
1989	04/09/89	26000.0	2	35.650	64					0
1990	04/10/90	2880.0	2	8.550	32		12.590	04/04/90	64	0
1991	07/08/91	3700.0	2	9.990	0					0
1992	03/09/92	5200.0	34	15.640	64					0
1993	08/02/93	22500.0	2	30.560	0					0
1994	04/03/94	16600.0	2	---	0		25.620	03/29/94	0	0
1995	03/31/95	23300.0	2	30.510	0					0
1996	04/18/96	25200.0	2	35.110	0					0
1997	04/19/97	71500.0	2	40.740	0					0
1998	05/20/98	19200.0	2		32		28.300	03/02/98		0
1999	03/29/99	18100.0	2	28.210	32		30.460	03/26/99	64	0
2000	06/26/00	29100.0	2	31.270	0					0
2001	04/15/01	37800.0		38.440	0					0

NOTE: Data for water year 2001 from the U.S.G.S. is provisional and subject to change

Red River of the North at Grand Forks, ND, Station 05082500

Year	Date	Discharge	Dcode	Stage	Scode	High	AltStage	AltDate	Acode	#Par
1882	04/18/82	75000.0	0	48.000	0					0
1883	04/26/83	38600.0	0	42.200	0					0
1884	04/16/84	20600.0	0	31.100	0					0
1885	04/17/85	13040.0	0	23.100	0					0
1886	05/03/86	10800.0	0	20.600	0					0
1887	04/15/87	7300.0	0	16.300	0					0
1888	04/19/88	19000.0	0	29.500	0					0
1889	04/01/89	3000.0	0	12.000	64					0
1890	04/15/90	3470.0	0	10.600	0					0
1891	04/13/91	6000.0	0	17.700	64					0
1892	04/17/92	23000.0	0	33.400	0					0
1893	04/24/93	53300.0	0	45.500	0					0
1894	04/24/94	16450.0	0	26.900	0					0
1895	04/06/95	2000.0	0	9.900	64					0
1896	05/30/96	21600.0	0	32.000	0					0
1897	04/10/97	85000.0	0	50.200	0					0
1898	04/14/98	4500.0	0	15.000	64					0
1899	04/17/99	9000.0	0	20.900	64					0
1900	04/10/00	4000.0	0	13.200	64					0
1901	04/07/01	14000.0	0	26.300	64					0
1902	03/30/02	15000.0	0	26.000	64					0
1903	04/11/03	18800.0	0	28.000	0					0
1904	04/27/04	33000.0	0	40.650	0					0
1905	05/16/05	16800.0	0	26.110	0					0
1906	04/18/06	27600.0	0	36.000	0					0
1907	04/07/07	30400.0	0	39.950	0					0
1908	04/11/08	20500.0	0	32.800	0					0
1909	07/30/09	9260.0	0	18.800	0					0
1910	03/22/10	18500.0	0	30.700	0					0
1911	06/12/11	3520.0	0	10.700	0					0
1912	04/08/12	4730.0	0	12.730	0					0
1913	04/08/13	17200.0	0	26.700	0					0
1914	06/16/14	8240.0	0	17.500	0					0
1915	07/03/15	21500.0	0	30.800	0					0
1916	04/23/16	29000.0	32	37.700	32		41.000	04/17/16	64	0
1917	04/06/17	19800.0	0	32.500	64					0
1918	03/28/18	4480.0	0	11.300	0					0
1919	07/08/19	13600.0	0	23.200	0					0
1920	03/31/20	30300.0	0	---	32		41.000	03/29/20	64	0
1921	04/10/21	11500.0	0	20.900	0					0
1922	04/11/22	19000.0	32	28.720	0					0
1923	04/22/23	16200.0	0	26.150	32		26.600	04/21/23	64	0
1924	05/02/24	2530.0	0	8.200	0					0
1925	06/12/25	9690.0	0	19.000	0					0
1926	03/28/26	7720.0	0	18.100	64					0
1927	04/13/27	10600.0	0	20.000	32		21.700	03/21/27	64	0
1928	04/02/28	12200.0	0	21.800	0					0
1929	03/24/29	17100.0	0	---	32		28.300	03/23/29	64	0
1930	04/07/30	9610.0	0	18.900	0					0
1931	04/10/31	1630.0	0	6.480	0					0
1932	04/10/32	10400.0	0	22.070	64					0
1933	04/03/33	4380.0	0	15.180	64					0
1934	04/12/34	3210.0	0	10.020	0					0
1935	03/29/35	2920.0	0	13.070	64					0
1936	04/18/36	14500.0	0	25.000	0					0
1937	05/04/37	4180.0	0	11.570	0					0
1938	05/12/38	6600.0	0	15.490	0					0
1939	04/06/39	6720.0	0	20.130	64					0
1940	04/18/40	10000.0	0	21.880	64					0
1941	04/12/41	13400.0	2	27.860	0					1
1942	04/05/42	11000.0	2	24.100	0					3
1943	04/12/43	28200.0	2	38.160	0					1
1944	08/13/44	10400.0	2	19.790	0					0
1945	03/29/45	21300.0	2	---	0		32.000	03/30/45	0	0

Red River of the North at Grand Forks, ND, Station 05082500 – Continued

Year	Date	Discharge	Dcode	Stage	Scode	High	AltStage	AltDate	Acode	#Par
1946	03/27/46	22000.0	2	33.100	32		33.230	03/28/46	0	0
1947	04/21/47	35000.0	2	40.600	32		40.710	04/22/47	0	2
1948	04/16/48	34200.0	2	41.680	0					0
1949	04/10/49	15200.0	2	29.110	0					2
1950	05/12/50	54000.0	2	45.610	0					2
1951	04/12/51	23600.0	2	33.520	0					0
1952	04/20/52	23900.0	2	---	0		33.600	04/21/52	0	2
1953	06/25/53	14600.0	2	24.630	0					2
1954	04/15/54	9620.0	2	18.630	0					1
1955	04/10/55	15400.0	2	26.170	0					0
1956	04/23/56	21400.0	2	32.430	0					2
1957	07/02/57	14700.0	2	24.670	0					3
1958	07/09/58	7500.0	2	16.030	0					0
1959	04/06/59	6300.0	2	---	32		16.100	04/07/59	64	0
1960	04/12/60	17200.0	2	28.880	0					1
1961	03/28/61	3400.0	2	9.750	0					0
1962	06/16/62	26600.0	2	34.450	0					0
1963	04/11/63	10800.0	2	21.230	0					0
1964	04/19/64	13200.0	2	22.710	0					0
1965	04/17/65	52000.0	2	44.920	0					0
1966	04/04/66	55000.0	2	45.550	0					0
1967	04/04/67	28200.0	2	37.500	0					0
1968	06/11/68	9420.0	2	20.030	0					0
1969	04/16/69	53500.0	2	45.690	0					0
1970	04/28/70	23700.0	2	34.300	32		34.420	04/13/70	64	0
1971	04/11/71	15800.0	2	27.860	0					0
1972	04/17/72	31400.0	2	38.500	32		38.730	04/18/72	64	0
1973	03/20/73	11300.0	2	27.320	0					0
1974	04/19/74	34300.0	2	40.250	0					0
1975	07/14/75	42800.0	2	43.080	32		43.300	04/23/75	0	0
1976	04/03/76	23600.0	2	34.580	0					0
1977	04/10/77	2190.0	2	8.520	32		8.710	04/05/77	64	0
1978	04/11/78	54200.0	2	45.730	0					0
1979	04/23/79	82000.0	2	48.630	32		48.810	04/26/79	0	0
1980	04/06/80	22000.0	2	31.010	0					0
1981	07/01/81	6710.0	2	14.680	0					0
1982	04/12/82	23900.0	2	37.180	0					0
1983	04/06/83	14300.0	2	29.170	0					0
1984	04/02/84	32300.0	2	37.060	0					0
1985	05/19/85	17800.0	2	25.900	0					0
1986	04/02/86	31900.0	2	37.000	0					0
1987	03/29/87	17500.0	2	33.190	0					0
1988	04/05/88	8500.0	2	21.160	0					0
1989	04/13/89	39600.0	2	43.210	32		44.370	04/12/89	0	0
1990	04/05/90	5040.0	2	17.560	0					0
1991	07/08/91	4870.0	2	17.630	0					0
1992	03/12/92	8000.0	34	23.300	64					0
1993	08/03/93	26200.0	2	36.390	0					0
1994	07/12/94	26800.0	2	34.300	0					0
1995	03/31/95	34800.0	2	39.810	0					0
1996	04/21/96	58400.0	2	45.930	0					0
1997	04/18/97	137000.0	2	---	32		54.350	04/22/97	0	0
1998	05/21/98	29700.0	2		32		39.840	03/04/98		0
1999	03/31/99	50000.0	2	44.110	32		44.260	04/01/99		0
2000	06/26/00	31500.0	2		32		37.140	06/28/00		0
2001	04/12/01	55800.0		44.870						0

NOTES:

1. The North Dakota District of the U.S.G.S. recommends using a flow value of 114,000 cfs for the 1997 flood for the computation of discharge-frequency curves, as noted on page 381 of Open-File Report 00-344.

2. Data for water year 2001 from the U.S.G.S. is provisional and subject to change

Red River of the North at Drayton, ND, Station 05092000

Year	Date	Discharge	Dcode	Stage	Scode	High	AltStage	AltDate	Acode	#Par
1897	04/ /97	---	0	41.000	0					0
1936	04/19/36	16600.0	0	---	32		24.260	04/20/36	0	0
1937	05/05/37	4530.0	0	---	32		10.260	05/06/37	0	0
1941	04/15/41	22800.0	0	32.000	0					0
1942	04/07/42	21900.0	2	---	32		31.560	04/09/42	0	0
1943	04/17/43	28700.0	2	33.660	0					0
1944	04/18/44	12300.0	2	21.050	0					0
1945	04/02/45	24600.0	2	31.700	0					0
1946	03/30/46	23000.0	2	---	32		29.710	04/01/46	0	0
1947	04/28/47	29300.0	2	---	32		33.120	04/29/47	0	0
1948	04/21/48	57000.0	2	39.810	32		40.050	04/22/48	0	0
1949	04/12/49	27900.0	2	---	32		31.650	04/15/49	0	0
1950	05/12/50	86500.0	2	41.580	0					0
1951	04/15/51	24600.0	2	30.100	32		30.250	04/17/51	0	0
1952	04/25/52	23900.0	2	---	32		28.830	04/26/52	0	0
1953	06/26/53	14700.0	2	20.000	32		20.170	06/27/53	0	0
1954	04/15/54	11100.0	2	16.380	0					0
1955	04/11/55	18000.0	2	27.280	32		27.420	04/09/55	64	0
1956	04/27/56	28000.0	2	35.160	0					0
1957	07/04/57	14100.0	2	22.330	0					0
1958	07/12/58	7850.0	2	14.530	0					0
1959	04/08/59	11200.0	2	23.780	0					0
1960	04/14/60	24700.0	2	33.710	0					0
1961	03/31/61	3600.0	2	12.980	64					0
1962	04/24/62	32300.0	2	36.260	0					0
1963	04/12/63	12900.0	2	20.420	0					0
1964	04/20/64	15600.0	2	23.600	0					0
1965	04/22/65	47200.0	2	40.430	0					0
1966	04/08/66	67500.0	2	42.150	0					0
1967	04/08/67	32200.0	2	36.700	0					0
1968	07/23/68	12500.0	2	20.410	0					0
1969	04/19/69	59000.0	2	41.080	32		41.350	04/23/69	0	0
1970	04/29/70	31700.0	2	38.200	0					0
1971	04/11/71	23400.0	2	29.500	32		31.750	04/14/71	0	0
1972	04/20/72	31100.0	2	34.750	32		35.730	04/23/72	64	0
1973	03/25/73	13400.0	2	24.490	0					0
1974	04/25/74	43900.0	2	---	32		39.850	04/27/74	0	0
1975	05/04/75	44000.0	2	39.800	0					0
1976	04/07/76	27600.0	2	35.000	0					0
1977	04/09/77	3400.0	2	12.120	64					0
1978	04/16/78	56200.0	2	41.190	0					0
1979	04/28/79	92900.0	2	43.660	0	1882				0
1980	04/10/80	22400.0	2	29.000	0					0
1981	07/03/81	7520.0	2	13.960	0					0
1982	04/17/82	35500.0	2	36.780	0					0
1983	04/09/83	21300.0	2	30.880	0					0
1984	04/06/84	32400.0	2	---	0		35.330	04/07/84	0	0
1985	05/21/85	17700.0	2	28.120	0					0
1986	04/07/86	29700.0	2	36.590	0					0
1987	04/07/87	27600.0	2	36.610	0					0
1988	04/07/88	13900.0	2	22.120	0					0
1989	04/19/89	41800.0	2	39.350	32		39.700	04/21/89	0	0
1990	04/07/90	5080.0	2	15.540	0					0
1991	07/11/91	4940.0	2	13.260	0					0
1992	03/16/92	8800.0	34	23.280	64					0
1993	08/14/93	27600.0	2	36.480	0					0
1994	04/06/94	27900.0	2	33.570	0					0
1995	04/01/95	37800.0	2	---	0		39.730	04/03/95	0	0
1996	04/25/96	61300.0	2	42.410	0					0
1997	04/24/97	124000.0	2	45.550	0					0
1998	05/24/98	28400.0	2		32		36.000	03/10/98		0
1999	04/09/99	59500.0	2	41.660	0					0
2000	06/30/00	29300.0	2		32		33.680	07/03/00		0
2001	04/20/01	56400.0		41.38						0

NOTE: Data for water year 2001 from the U.S.G.S. is provisional and subject to change

Red River of the North at Emerson, Manitoba, Station 05102500

Year	Date	Discharge	Dcode	Stage	Scode	High	AltStage	AltDate	Acode	#Par
1861	/ /61	---	0	95.000	4					0
1913	04/11/13	25600.0	0	74.520	0					0
1914	06/19/14	7260.0	0	58.360	0					0
1915	07/09/15	20100.0	0	69.060	0					0
1916	04/24/16	46200.0	0	85.740	0					0
1917	04/12/17	25900.0	0	---	32		75.330	04/11/17	64	0
1918	04/03/18	4990.0	0	---	32		58.170	03/31/18	64	0
1919	07/12/19	13400.0	0	---	32		67.380	04/09/19	64	0
1920	04/16/20	26700.0	0	---	32		78.620	04/08/20	64	0
1921	04/15/21	12800.0	0	---	32		67.800	04/13/21	64	0
1922	04/14/22	18900.0	0	69.400	0					0
1923	04/25/23	26000.0	0	74.980	0					0
1924	04/28/24	6320.0	0	57.250	0					0
1925	06/21/25	17500.0	0	---	32		68.000	04/01/25	64	0
1926	04/01/26	8000.0	0	61.020	0					0
1927	05/16/27	20500.0	0	71.580	0					0
1928	04/06/28	16800.0	0	67.910	0					0
1929	04/01/29	19200.0	0	---	32		73.010	03/29/29	64	0
1930	04/10/30	20800.0	0	72.510	0					0
1931	04/10/31	7940.0	0	---	32		60.800	04/07/31	64	0
1932	04/15/32	18900.0	0	---	32		72.990	04/14/32	64	0
1933	04/09/33	11000.0	0	---	32		67.520	04/10/33	64	0
1934	04/13/34	4800.0	0	---	32		55.170	04/12/34	64	0
1935	04/03/35	5470.0	0	59.650	64					0
1936	04/21/36	18000.0	0	68.160	0					0
1937	05/07/37	5840.0	0	65.550	0					0
1938	05/20/38	7530.0	0	---	32		58.770	03/27/38	64	0
1939	04/10/39	6700.0	0	60.770	64					0
1940	04/21/40	14600.0	0	66.840	64					0
1941	04/16/41	27800.0	2	76.940	0					0
1942	04/10/42	27900.0	2	78.770	0					0
1943	04/20/43	29500.0	2	77.540	0					0
1944	04/19/44	12300.0	2	66.820	0					0
1945	04/04/45	29400.0	2	---	32		78.520	04/01/45	64	0
1946	04/05/46	24100.0	2	---	32		74.270	04/03/46	64	0
1947	04/28/47	28400.0	2	76.070	0					0
1948	04/27/48	51800.0	2	87.620	0					0
1949	04/15/49	29200.0	2	77.130	0					0
1950	05/13/50	95500.0	2	90.890	0					0
1951	04/15/51	26000.0	2	74.550	0					0
1952	04/24/52	24200.0	2	---	32		73.000	04/14/52	64	0
1953	06/28/53	14500.0	2	63.700	0					0
1954	04/17/54	11500.0	2	---	32		63.040	04/16/54	64	0
1955	04/10/55	24000.0	2	72.250	0					0
1956	04/27/56	33800.0	2	81.020	0					0
1957	07/04/57	15300.0	2	65.370	0					0
1958	07/12/58	7940.0	2	57.170	0					0
1959	04/10/59	15700.0	66	---	0					0
1960	04/13/60	30500.0	2	77.650	0					0
1961	03/31/61	4320.0	2	57.260	64					0
1962	04/25/62	33400.0	2	81.930	0					0
1963	04/13/63	13800.0	2	64.140	0					0
1964	06/25/64	17500.0	2	66.820	32		67.640	04/18/64	64	0
1965	04/26/65	46200.0	2	85.190	0					0
1966	04/11/66	66800.0	2	89.150	0					0
1967	04/09/67	33600.0	2	80.790	0					0
1968	07/24/68	13900.0	2	---	32		64.120	07/25/68	64	0
1969	04/26/69	54700.0	0	87.590	0					0
1970	04/29/70	39600.0	0	84.670	32		84.720	05/01/70	64	0
1971	04/16/71	26600.0	66	---	32		78.280	04/15/71	64	0
1972	04/24/72	30700.0	66	78.160	0					0
1973	03/27/73	14700.0	2	---	32		67.320	03/26/73	0	0
1974	04/28/74	43500.0	2	86.510	0					0
1975	05/08/75	42800.0	2	84.320	0					0

Red River of the North at Emerson, Manitoba, Station 05102500 - Continued

Year	Date	Discharge	Dcode	Stage	Scode	High	AltStage	AltDate	Acode	#Par
1976	04/06/76	32900.0	2	79.060	0					0
1977	04/10/77	4590.0	2	53.770	0					0
1978	04/18/78	50600.0	2	86.890	0					0
1979	05/01/79	92700.0	2	91.190	0					0
1980	04/09/80	22000.0	2	74.560	0					0
1981	07/04/81	6150.0	2	55.190	0					0
1982	04/18/82	34000.0	66	---	0					0
1983	04/09/83	24600.0	66	---	0					0
1984	04/08/84	30200.0	66	---	0					0
1985	03/29/85	16700.0	66	---	0					0
1986	04/07/86	34200.0	66	---	0					0
1987	04/09/87	37400.0	64	---	0					0
1988	04/08/88	15700.0	66	---	0					0
1989	04/23/89	42700.0	2	72.860	0					0
1990	04/10/90	5510.0	2	60.900	0					0
1991	07/12/91	5690.0	2	56.150	0					0
1992	04/04/92	15800.0	2	74.190	0					0
1993	08/16/93	31900.0	2	79.020	0					0
1994	04/09/94	26900.0	2	---	0		77.100	04/06/94	0	0
1995	04/02/95	42400.0	2	84.800	0					0
1996	04/26/96	66700.0	2	89.100	0					0
1997	04/26/97	133000.0	2	92.410	0					0
1998	03/12/98	27500.0	2	77.800	64					0
1999	04/13/99	58600.0	2	87.730	0					0
2000	07/02/00	31800.0	2		32		75.300	07/05/00		0
2001	04/25/01	58500.0								0

NOTE: Data for water year 2001 from Manitoba Water Resources is provisional and subject to change

Additional Data for Emerson from Manitoba Water Resources:

1875	20697
1876	15117
1877	21298
1878	6075
1879	NONE
1880	24017
1881	26914
1882	63293
1883	39205
1884	27797
1885	18614
1886	15788
1887	12009
1888	24512
1889	7417
1890	7912
1891	10596
1892	37121
1893	54922
1894	24406
1895	7170
1896	33518
1897	87028
1898	13916
1899	7982
1900	5227
1901	18896
1902	24512
1903	19602
1904	47611
1905	15505
1906	24512
1907	19497
1908	21792
1909	11090
1910	21686
1911	5015
1912	8053

APPENDIX C

LINEAR REGRESSION ANALYSIS FROM GRAND FORKS TO WINNIPEG

LINEAR REGRESSION ANALYSIS, EMERSON TO WINNIPEG (ABOVE THE ASSINIBOINE RIVER)

WATER YEAR	WINNIPEG GAGE	HEADINGLEY	WINNIPEG ABOVE ASSINIBOINE	EMERSON
1913	45103	9042	36062	25600
1914	15611	4486	11126	7260
1915	11514	1243	10271	20100
1916	85721	10349	75372	46200
1917	39699	5757	33942	25900
1918	14305	4132	10172	4990
1919	23488	6923	16565	13400
1920	38499	8795	29704	26700
1921	22216	5263	16954	12800
1922	28998	10031	18967	18900
1923	63894	14199	49695	26000
1924	23099	9996	13104	6320
1925	41995	13457	28538	17500
1926	13386	3504	9882	8000
1927	51390	11691	39699	20500
1928	32212	10243	21969	16800
1929	32212	3567	28644	19200
1930	36803	8865	27938	20800
1931	24300	1759	22541	7940
1932	37510	6534	30975	18900
1933	38711	5651	33059	11000
1934	15611	6675	8936	4800
1935	15011	8194	6817	5470
1936	37439	11620	25819	18000
1937	7735	2133	5602	5840
1938	15399	5015	10384	7530
1939	12609	3069	9540	6700
1940	17589	2087	15502	14600
1941	41819	9077	32741	27800
1942	45598	9113	36485	27900
1943	42207	9784	32424	29500
1944	17413	3285	14128	12300
1945	52521	5157	47364	29400
1946	38110	6464	31647	24100
1947	36697	9925	26772	28400
1948	75019	9925	65094	51800
1949	48106	10702	37404	29200
1950	108008	8265	99743	95500
1951	37616	10137	27479	26000
1952	35602	7735	27867	24200
1953	12609	8018	4592	14500
1954	18508	9784	8724	11500
1955	53721	12327	41395	24000
1956	69721	12892	56830	33800
1957	23099	5863	17236	15300
1958	18508	8018	10490	7940
1959	35002	4698	30304	15700
1960	69403	13527	55876	30500
1961	16989	2045	14944	4320
1962	59620	10596	49024	33400
1963	23311	7099	16212	13800
1964	35390	7947	27443	17500
1965	63894	11444	52450	46200
1966	88229	10349	77880	66800
1967	60997	7947	53050	33600
1968	18013	5263	12750	13900
1969	78021	11938	66083	54700
1970	80494	13245	67249	39600
1971	53898	7594	46304	26600
1972	56123	10596	45527	30700
1973	18719	2080	16639	14700
1974	95999	17059	78940	43500
1975	59019	10278	48741	42800
1976	63823	19673	44150	32900

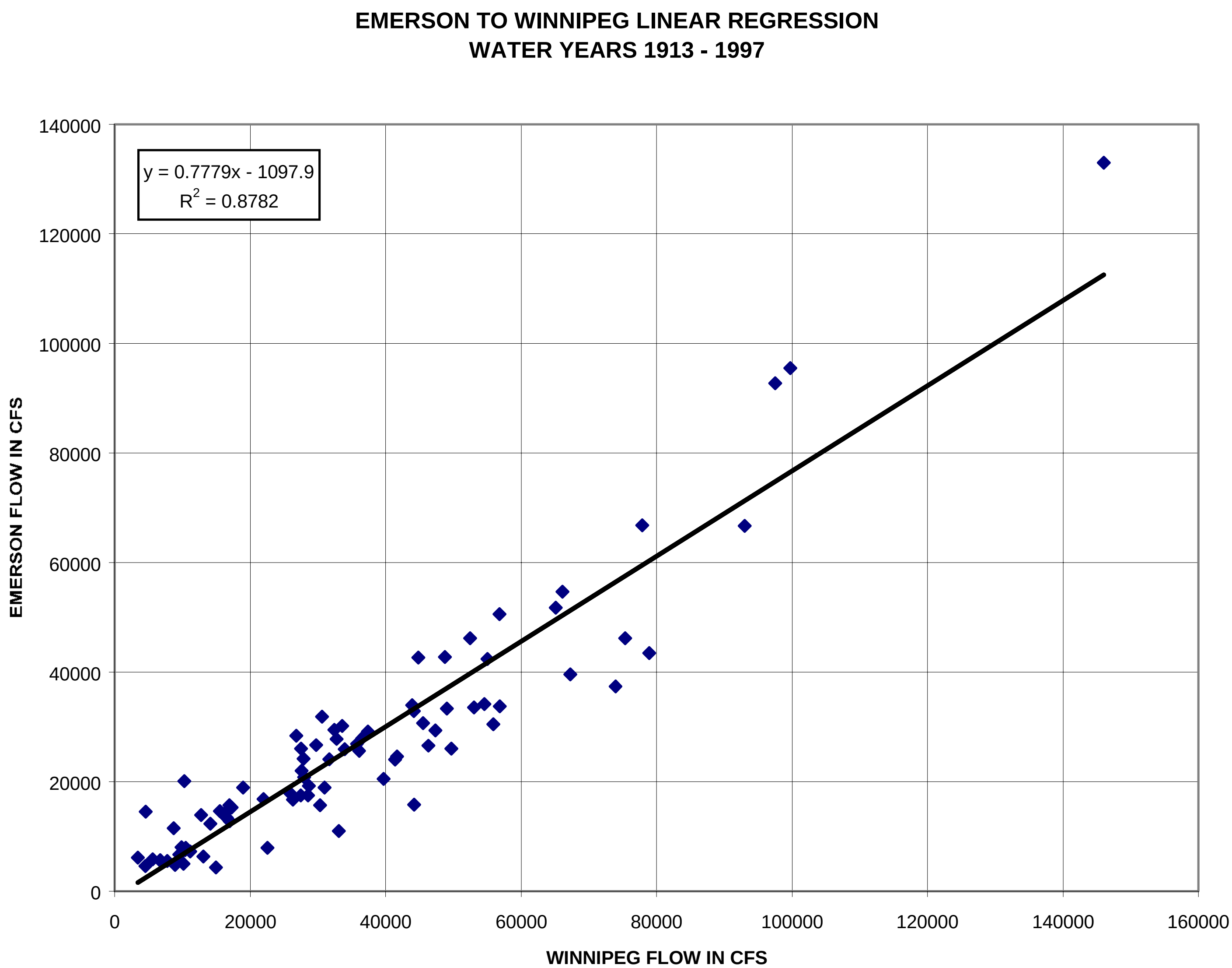
WATER YEAR	WINNIPEG GAGE	HEADINGLEY	WINNIPEG ABOVE ASSINIBOINE	EMERSON
1977	6605	2059	4546	4590
1978	61810	5015	56794	50600
1979	107019	9536	97483	92700
1980	31117	3525	27592	22000
1981	5616	2172	3444	6150
1982	51496	7558	43938	34000
1983	49200	7523	41677	24600
1984	37015	3472	33543	30200
1985	35002	8724	26278	16700
1986	63999	9430	54569	34200
1987	82613	8689	73924	37400
1988	19885	2963	16922	15700
1989	49095	4274	44821	42700
1990	13987	6216	7770	5510
1991	9890	3154	6735	5690
1992	49412	5192	44220	15800
1993	33413	2826	30587	31900
1994	39593	3850	35744	26900
1995	66295	11267	55028	42400
1996	104511	11514	92997	66700
1997	162012	16000	146012	133000

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.937136089
R Square	0.878224049
Adjusted R Sq	0.876756869
Standard Erro	7457.70545
Observations	85

	Coefficients	*Standard Error*
Intercept	-1097.913326	1387.700244
X Variable 1	0.777893952	0.031795046

Emerson to Winnipeg



LINEAR REGRESSION ANALYSIS, GRAND FORKS TO EMERSON

Water Year	Emerson Flow	Grand Forks Flow
1913	25600	17200
1914	7260	8240
1915	20100	21500
1916	46200	29000
1917	25900	19800
1918	4990	4480
1919	13400	13600
1920	26700	30300
1921	12800	11500
1922	18900	19000
1923	26000	16200
1924	6320	2530
1925	17500	9690
1926	8000	7720
1927	20500	10600
1928	16800	12200
1929	19200	17100
1930	20800	9610
1931	7940	1630
1932	18900	10400
1933	11000	4380
1934	4800	3210
1935	5470	2920
1936	18000	14500
1937	5840	4180
1938	7530	6600
1939	6700	6720
1940	14600	10000
1941	27800	13400
1942	27900	11000
1943	29500	28200
1944	12300	10400
1945	29400	21300
1946	24100	22000
1947	28400	35000
1948	51800	34200
1949	29200	15200
1950	95500	54000
1951	26000	23600
1952	24200	23900
1953	14500	14600
1954	11500	9620
1955	24000	15400
1956	33800	21400
1957	15300	14700
1958	7940	7500
1959	15700	6300
1960	30500	17200
1961	4320	3400
1962	33400	26600
1963	13800	10800
1964	17500	13200
1965	46200	52000
1966	66800	55000
1967	33600	28200
1968	13900	9420
1969	54700	53500
1970	39600	23700
1971	26600	15800
1972	30700	31400
1973	14700	11300
1974	43500	34300
1975	42800	42800
1976	32900	23600

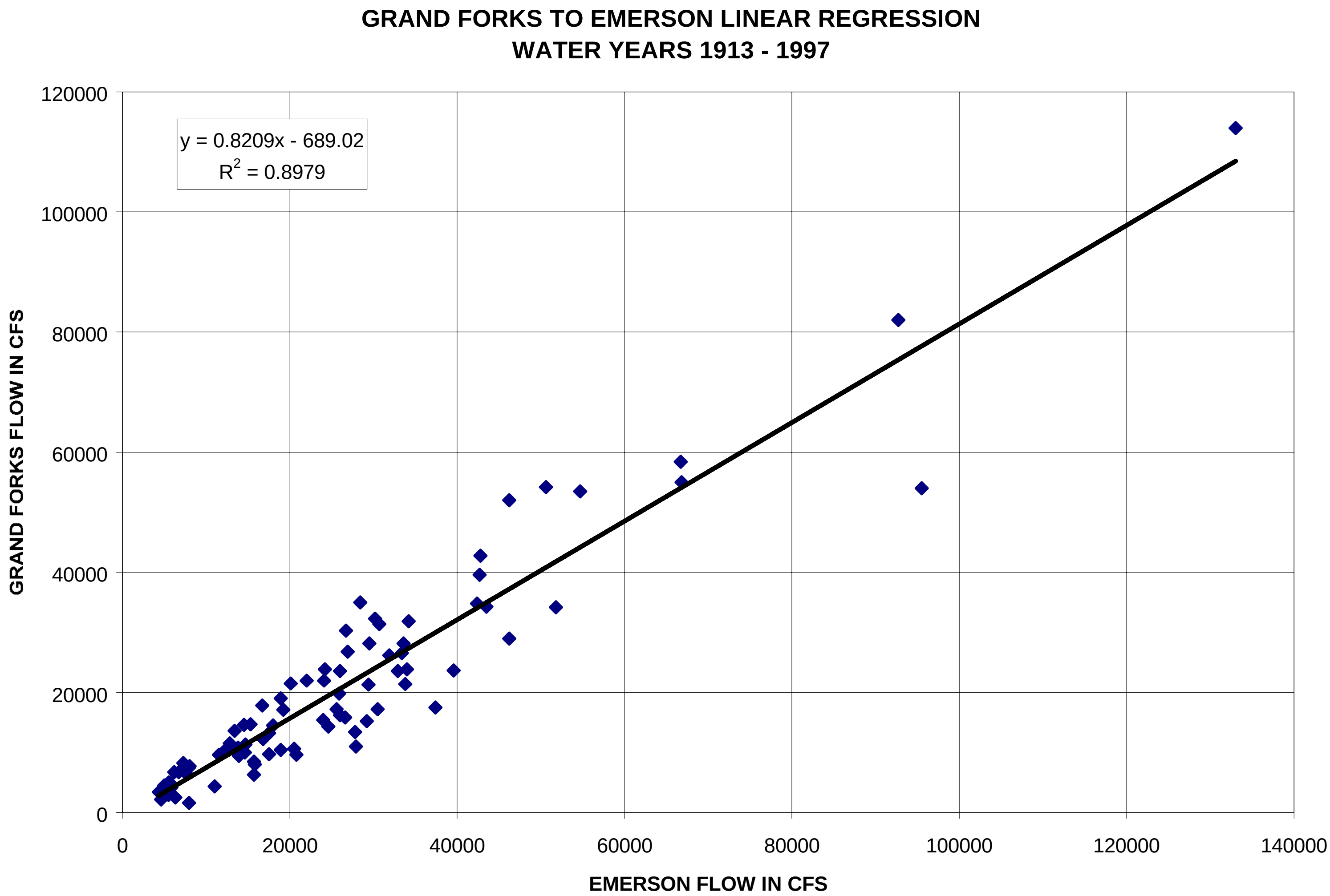
Water Year	Emerson Flow	Grand Forks Flow
1977	4590	2190
1978	50600	54200
1979	92700	82000
1980	22000	22000
1981	6150	6710
1982	34000	23900
1983	24600	14300
1984	30200	32300
1985	16700	17800
1986	34200	31900
1987	37400	17500
1988	15700	8500
1989	42700	39600
1990	5510	5040
1991	5690	4870
1992	15800	8000
1993	31900	26200
1994	26900	26800
1995	42400	34800
1996	66700	58400
1997	133000	114000

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.947580746
R Square	0.897909271
Adjusted R Sq	0.896679262
Standard Erro	5915.596346
Observations	85

	Coefficients	*Standard Error*
Intercept	-689.0202272	1029.285902
X Variable 1	0.820913024	0.030383306

Grand Forks to Emerson



APPENDIX D

1979 CORPS OF ENGINEERS MEMO TO THE U.S. GEOLOGICAL SURVEY REGARDING ESTIMATION OF HISTORIC FLOODS FOR GRAND FORKS

NCSED-HF

27 September 1979

District Chief
U.S. Geological Survey
702 U.S. Post Office and Custom House
St. Paul, Minnesota 55101

Dear Sir:

We have revised our flood frequency curve on the Red River at Grand Forks taking into account the additional record through 1979 and your revised flood peak estimates for 1882 and 1897.

Past studies of flood frequencies at Grand Forks, performed by this office, have included estimates of the 1826, 1852, and 1861 floods. We are including a short write-up (inclosure 1) which details our rational for using these historical floods and how the estimated discharges were determined. We have included these estimated discharges, shown in the table below, in our frequency analysis:

Historical Flood	Peak Discharge
1826	135,000 cfs
1852	95,000 cfs
1861	65,000 cfs

Results of the flood frequency computer runs yield the following estimated flood frequency flows at Grand Forks:

Flood Frequency	Flood Peak Discharge
10-year	45,000
50-year	84,900
100-year	106,000
500-year	163,000

NCSED-HF
District Chief

Johnson/jg/7586
27 September 1979

A copy of the computer run is included as inclosure 2.

An analysis of the lower end of the frequency curve shows that 7 of the lowest 20 floods occurred in the 1930's. The 1930's drought has been estimated to have a rare frequency of occurrence, perhaps as low as 0.5 to 0.2% (200-500 year). If consideration isn't given to these facts in the frequency analysis, a high negative skew will result. The actual record skew is about -0.3. Using the historical floods changes the skew to about -0.2. We prefer to use the -0.2 value as a better representative skew for the Red River Basin.

The Province of Manitoba, Department of Mines, Resources and Environmental Management, Water Resources Division, has recently developed a flood frequency curve at Emerson on the Red River. Their analysis includes the historical floods of 1826, 1852, and 1861. The values used by the Canadians for these historical floods is in agreement with the values we estimated. Consequently, we are in agreement with the Canadians on flood frequency values at the border.

Adopting a value of 106,000 cfs for the 100-year discharge, from a flood plain regulatory point of view, may be difficult. The previously developed regulatory flood discharge of 89,000 cfs is within the error limit curves and is, therefore, acceptable to us for that purpose. The stage difference between these two discharge values is about 1.8 feet. We will, however, be using the higher frequency values for any project design undertaken by the Corps.

We would appreciate any comments which you may have relative to our analysis. Please contact Bud Johnson at 725-7586 if you have questions.

Sincerely,

2 Incl
As stated

PETER A. FISCHER
Chief, Hydraulic Engineering
& Foundation Materials Branch

JOHNSON__________
FISCHER__________

HISTORICAL FLOODS
RED RIVER OF THE NORTH AT GRAND FORKS

Significant floods in the 19th century have been written and reported on at the time of occurrence. The floods of 1826, 1852, and 1861 are written about in letters and journals which contain specific information as to water levels, duration of floods, etc.

In 1879, the Canadian Pacific Railway(1) conducted a survey to plot the levels of high water of 1826, 1852, and 1861 along the Red River for the purpose of finding the best location for a railway bridge—one that would not be washed away by flood. Bench marks were established along the river bank and connected by levelling with those along the existing line of railway. Eyewitnesses to the 1852 flood were individually taken to the river and asked to point out high water marks. The individual marks were then tested with the railway level and were found to agree very closely in most cases.

Discharges at Winnipeg for the 1826, 1852, and 1861 floods have been estimated at 225,000 cfs, 165,000 cfs, and 125,000 cfs respectively(2)(3). These discharges are all below the mouth of the Assiniboine River.

During a conference in the St. Paul District Office (Corps of Engineers) on 2-4 May 1951, Mr. Clark, of the Canadian Department of Natural Resources and Development, stated that he believed the Assiniboine River would never discharge more than 30,000 cfs at its mouth. This is because of large diversions overbank (to the north) during high states. The Canadian frequency curve for the Assiniboine at Winnipeg shows a 1000-year flood peak of 35,000 cfs. This is shown in Appedix C and H of reference (3). Reference (1) also states that a natural diversion of the Assiniboine River occurs at Big Bog entering Lake Winnipeg through Netley Creek at times of high flow.

Translation of historical floods from Winnipeg to Grand Forks was accomplished as follows:

a) A table was constructed, listing peak flows at Emerson and at Headingly (the latter by subtracting Assiniboine flow at Headingly from Red River below confluence flow) for annual spring peaks. The peaks were plotted against each other, with Emerson discharge on the x-axis, Winnipeg above Assiniboine on the y-axis. A discharge relation line was drawn, using a combination of the least squares method, power of the drainage area and graphical extension.

b) A similar table was constructed listing annual peaks at Emerson and at Grand Forks, and the discharges were plotted against each other with Emerson at the x-axis and Grand Forks at the y-axis. Another peak discharge relation was drawn, again using the above method.

c) The 1826, 1852, and 1861 discharges at Winnipeg below the Assiniboine were each reduced by 30,000 cfs to account for maximum peak at the Assiniboine, and the remaining flow (above the confluence) was used to enter the Winnipeg-Emerson relation. With the resulting Emerson discharge, the Grand Forks peak was found on the Emerson-Grand Forks relation.

Resulting peak flows at Grand Forks were: 1826, 135,000 cfs; 1852, 95,000 cfs; 1861, 65,000 cfs.

Additional historical information indicates that extremely large floods occurred at Crookston in 1826 and 1852.[4]

In summary, there can be no doubt that large floods occurred in 1826, 1852, and 1861. We cannot be sure of the exact magnitude of these floods but believe our estimates shown above are reasonable.

REFERENCES

(1) Canadian Sessional Papers (No. 123) A. 1880, Appendix 16, Documents in Reference to the Bridging of Red River, Letter from the Engineer-in-Chief to the Minister of Railways and Canals, 24 September 1879.

(2) Notes on Red River Floods with Particular Reference to the Flood of 1950. October 1950, R. H. Clark. Province of Manitoba Department of Mines and Natural Resources.

(3) Report on Investigations into Measures for the Reduction of the Flood Hazard in the Greater Winnipeg Area. 1953, River Basin Investigation, Water Resources Division, Canadian Department of Resources and Development. pp 23 and 25.

(4) USGS Water Supply Paper 771, Floods in the United States, Magnitude and Frequency, 1936.

APPENDIX E

LINEAR REGRESSION ANALYSIS FOR FARGO DISCHARGE NATURAL (NO DAMS) AND WITH DAMS CONDITIONS

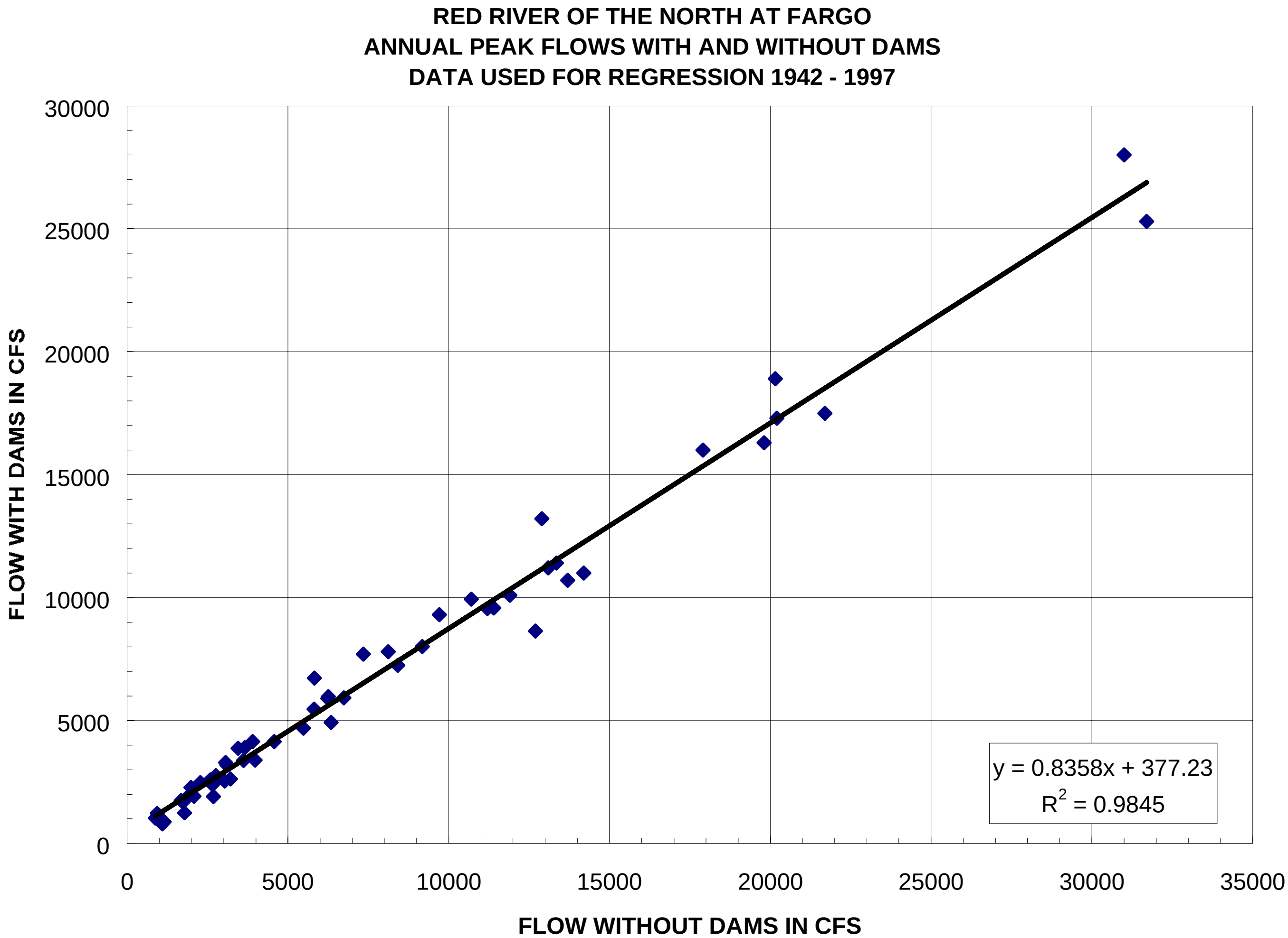
RED RIVER OF THE NORTH AT FARGO, NORTH DAKOTA - ANNUAL PEAK FLOWS
LINEAR REGRESSION ANALYSIS COMPARING "WITH DAMS" AND "WITHOUT DAMS" FLOWS
"WITH DAMS" DATA REPRESENTS EXISTING CONDITIONS AT USGS GAGE
"WITHOUT DAMS" DATA IS FROM HEC-5 RESERVOIR ROUTING ANALYSIS

WATER YEAR	WITHOUT DAMS (CFS)	WITH DAMS (CFS)
1942	3610	3380
1943	17900	16000
1944	4570	4150
1945	7340	7700
1946	6250	5970
1947	9710	9300
1948	3970	3390
1949	2730	2660
1950	8120	7800
1951	9180	8010
1952	19800	16300
1953	5820	6720
1954	2080	1920
1955	2750	2760
1956	3440	3870
1957	3030	2540
1958	1990	2280
1959	1790	1250
1960	3650	3900
1961	876	1020
1962	11400	9580
1963	6340	4930
1964	2650	2400
1965	13350	11400
1966	13700	10700
1967	6240	5900
1968	1100	788
1969	31700	25300
1970	2280	2480
1971	2680	1910
1972	8410	7250
1973	1920	1950
1974	3900	4150
1975	12900	13200
1976	3090	3200
1977	1150	878
1978	21700	17500
1979	20200	17300
1980	5810	5470
1981	1760	1710
1982	6740	5920
1983	1680	1750
1984	11200	9550
1985	5480	4690
1986	12700	8640
1987	3060	3300
1988	990	981
1989	20150	18900
1990	940	1220
1991	3210	2630
1992	2580	2590
1993	11900	10100
1994	13100	11200
1995	14200	11000
1996	10700	9940
1997	31000	28000

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.992220187
R Square	0.9845009
Adjusted R Square	0.98421388
Standard Error	768.8875921
Observations	56

	Coefficients	*Standard Error*
Intercept	377.2306961	152.1856912
X Variable 1	0.835842696	0.014271606


RED RIVER OF THE NORTH AT FARGO
ANNUAL PEAK FLOWS WITH AND WITHOUT DAMS
DATA USED FOR REGRESSION 1942 - 1997
FLOW WITH DAMS IN CFS
FLOW WITHOUT DAMS IN CFS
0
5000
10000
15000
20000
25000
30000
35000
y = 0.8358x + 377.23
R2 = 0.9845

APPENDIX F

TWO-STATION COMPARISONS FOR HALSTAD AND DRAYTON

EQUATIONS FOR TWO-STATION COMPARISON FOR ADJUSTMENT OF SHORT RECORD STATION STATISTICS TO A LONG RECORD STATION

1. Compute mean log flow, standard deviation and station skew (**X_S, S_S, G_S**) for **short record station** using Bulletin 17B discharge-frequency methodology using **N_S** years of record

2. Compute mean log flow, standard deviation and station skew (**X_{LT}, S_{LT}, G_{LT}**) for **long record station** using Bulletin 17B discharge-frequency methodology using total **N_{LT}** years of record

3. Compute mean log flow, standard deviation and station skew (**X_{LC}, S_{LC}, G_{LC}**) for **long record station** using Bulletin 17B discharge-frequency methodology using the **same (concurrent) years of record as the short record station, N_{LC}**

4. Compute correlation coefficient R^2 for annual flow data from 1 and 3 above

5. Adjust R^2 to remove sample bias

$$\overline{R}^2 = 1-\left(1-R^2\right)\left(\frac{N_1-1}{N_1-2}\right)$$

$$\overline{R} = \sqrt{\overline{R}^2}$$

where N_1 = number of years when flows were concurrently observed at both sites

6. $$B = \overline{R}\left(\frac{S_S}{S_{LC}}\right)$$

7. Adjust the mean log flow

$$\overline{Y} = X_S + B\left(X_{LT} - X_{LC}\right)$$

8. Adjust the standard deviation using Beard's Approximation

$$S_Y = S_S + \left(\overline{R}\right)\left(B\right)\left(S_{LT} - S_{LC}\right)$$

9. Compute equivalent years of record as a measure of improvement of the adjusted mean log

$$N_E = \frac{N_1}{1-\left(\frac{N_{LC}-N_S}{N_1+N_{LC}-N_S}\right)\left(\overline{R}^2 - \frac{\left(1-\overline{R}^2\right)}{\left(N_1-3\right)}\right)}$$

Two-Station Comparison: Adjustment of the Statistics for the Red River at Halstad

WATER YEAR	GRAND FORKS FLOW	HALSTAD FLOW
1936	14500	7670
1937	4180	2660
1942	11000	5060
1943	28200	21800
1944	10400	7200
1945	21300	13300
1946	22000	10000
1947	35000	24500
1948	34200	16000
1949	15200	7710
1950	54000	18700
1951	23600	12900
1952	23900	20700
1953	14600	13600
1954	9620	4660
1955	15400	7200
1956	21400	12900
1957	14700	4980
1958	7500	4420
1959	6300	3780
1960	17200	8600
1961	3400	1900
1962	26600	15900
1963	10800	5850
1964	13200	7820
1965	52000	25600
1966	55000	26800
1967	28200	13800
1968	9420	2350
1969	53500	35700
1970	23700	11600
1971	15800	5480
1972	31400	16200
1973	11300	6200
1974	34300	17800
1975	42800	39900
1976	23600	9950
1977	2190	2050
1978	54200	28800
1979	82000	42000
1980	22000	12900
1981	6710	3920
1982	23900	13200
1983	14300	7800
1984	32300	21900
1985	17800	10400
1986	31900	17400
1987	17500	9860
1988	8500	5010
1989	39600	26000
1990	5040	2880
1991	4870	3700
1992	8000	5200
1993	26200	22500
1994	26800	16600
1995	34800	23300
1996	58400	25200
1997	114000	71500
1998	29700	19200
1999	50000	18100
2000	31500	29100
2001	55800	37800

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9347
R Square	0.8736
Adjusted R Square	0.8715
Standard Error	4426.3183
Observations	62

	Coefficients	*Standard Error*
Intercept	268.6292	927.1988
X Variable 1	0.5686	0.0279

R-BAR 0.9335 R-BAR^2 0.8715

HALSTAD (SHORT RECORD STATION)

N	62
X	4.0511
S	0.3580
G	-0.2363

GRAND FORKS (LONG RECORD STATION)

	CONCURRENT RECORD	TOTAL RECORD
N	62	120
X	4.2980	4.1889
S	0.3504	0.3903
G	-0.4506	-0.2247

B 0.9538

ADJUSTMENT OF THE MEAN (X)

Y-BAR 3.9470

ADJUSTMENT OF THE STANDARD DEVIATION (BEARD EQN.)

Sy 0.3935

EQUIVALENT LENGTH OF RECORD

Ne 107

Two-Station Comparison: Adjustment of the Statistics for the Red River at Drayton

WATER YEAR	GRAND FORKS FLOW	DRAYTON FLOW
1936	14500	16600
1937	4180	4530
1941	13400	22800
1942	11000	21900
1943	28200	28700
1944	10400	12300
1945	21300	24600
1946	22000	23000
1947	35000	29300
1948	34200	57000
1949	15200	27900
1950	54000	86500
1951	23600	24600
1952	23900	23900
1953	14600	14700
1954	9620	11100
1955	15400	18000
1956	21400	28000
1957	14700	14100
1958	7500	7850
1959	6300	11200
1960	17200	24700
1961	3400	3600
1962	26600	32300
1963	10800	12900
1964	13200	15600
1965	52000	47200
1966	55000	67500
1967	28200	32200
1968	9420	12500
1969	53500	59000
1970	23700	31700
1971	15800	23400
1972	31400	31100
1973	11300	13400
1974	34300	43900
1975	42800	44000
1976	23600	27600
1977	2190	3400
1978	54200	56200
1979	82000	92900
1980	22000	22400
1981	6710	7520
1982	23900	35500
1983	14300	21300
1984	32300	32400
1985	17800	17700
1986	31900	29700
1987	17500	27600
1988	8500	13900
1989	39600	41800
1990	5040	5080
1991	4870	4940
1992	8000	8800
1993	26200	27600
1994	26800	27900
1995	34800	37800
1996	58400	61300
1997	114000	124000
1998	29700	28400
1999	50000	59500
2000	31500	29300
2001	55800	56400

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.9659
R Square	0.9331
Adjusted R Square	0.9320
Standard Error	5898.4336
Observations	63.0000

	Coefficients	*Standard Error*
Intercept	1897.3124	1223.2862
X Variable 1	1.0814	0.0371

R-BAR 0.9654 R-BAR^2 0.9320

DRAYTON (SHORT RECORD STATION)

N	63
X	4.3657
S	0.3369
G	-0.4936

GRAND FORKS (LONG RECORD STATION)

	CONCURRENT RECORD	TOTAL RECORD
N	63	120
X	4.2953	4.1889
S	0.3482	0.3903
G	-0.4293	-0.2247

B 0.9341

ADJUSTMENT OF THE MEAN (X)

Y-BAR 4.2663

ADJUSTMENT OF THE STANDARD DEVIATION (BEARD EQN.)

Sy 0.3749

EQUIVALENT LENGTH OF RECORD

Ne 114

APPENDIX G

DRAYTON ADJUSTED STATISTICS
FROM BULLETIN 17B APPENDIX 5 METHODOLOGY

Computation of Synthetic Statistics for the Red River of the North
USGS Gage No. 05092000 at Drayton, ND

Note: All equations shown below are from Bulletin 17B (Reference 3), Appendix 5, page 5-4.

Step 1 – Determine the 2-, 10- and 100-year discharges from the adjusted discharge-frequency curve on Figure 13:

Q2 = 18,700 cfs
Q10 = 51,000 cfs
Q100 = 112,000 cfs

Step 2 – Compute the synthetic skew coefficient by Equation 5-3:

$$G_S = -2.50 + 3.12 \frac{Log\left(Q_{100} / Q_{10} \right)}{Log\left(Q_{10} / Q_2 \right)} \qquad = \quad \underline{\mathbf{-0.0537}}$$

Step 3 – Compute the synthetic standard deviation by Equation 5-4:

$$S_S = \frac{Log\left(Q_{100} / Q_2 \right)}{K_{100} - K_2} \qquad = \quad \underline{\mathbf{0.3413}}$$

where K_X is the Pearson type III deviate, found in Appendix 3 of Bulletin 17B.

- Interpolate K values when necessary based on skew and exceedance probability
- See an excerpt from Appendix 3 on the next page
- $K_2 = 0.00892$ and $K_{100} = 2.28674$

Step 4 – Compute the synthetic mean by Equation 5-5:

$$\overline{X}_S = Log(Q_2) - K_2(S_S) \qquad = \quad \underline{\mathbf{4.2688}}$$

Step 5 – Check the synthetic statistics by putting them in the HEC-FFA computer program to see if the adjusted curve is duplicated.

In this case, the new computed discharge-frequency curve is nearly identical to the adjusted curve (dashed line) on Figure 13. Thus, the synthetic statistics and the new discharge-frequency curve with confidence limits can be adopted, and are shown on Figure 14. Flow values can be found in Table 8.

Excerpt from Bulletin 17B Appendix 3

P	G =-0.0	G =-0.1	G =-0.2	G =-0.3	G =-0.4	G =-0.5	G =-0.6
0.9999	-3.71902	-3.93453	-4.15301	-4.37394	-4.59687	-4.82141	-5.04718
0.9995	-3.29053	-3.45513	-3.62113	-3.78820	-3.95605	-4.12443	-4.29311
0.9990	-3.09023	-3.23322	-3.37703	-3.52139	-3.66608	-3.81090	-3.95567
0.9980	-2.87816	-2.99978	-3.12169	-3.24371	-3.36566	-3.48737	-3.60872
0.9950	-2.57583	-2.66965	-2.76321	-2.85636	-2.94900	-3.04102	-3.13232
0.9900	-2.32635	-2.39951	-2.47226	-2.54421	-2.61539	-2.68572	-2.75514
0.9800	-2.05375	-2.10697	-2.15935	-2.21081	-2.26133	-2.31084	-2.35931
0.9750	-1.95996	-2.00689	-2.05290	-2.09795	-2.14202	-2.18505	-2.22702
0.9600	-1.75069	-1.78462	-1.81756	-1.84949	-1.88039	-1.91022	-1.93896
0.9500	-1.64485	-1.67279	-1.69971	-1.72562	-1.75048	-1.77428	-1.79701
0.9000	-1.28155	-1.29178	-1.30105	-1.30936	-1.31671	-1.32309	-1.32850
0.8000	-0.84162	-0.83639	-0.83044	-0.82377	-0.81638	-0.80829	-0.79950
0.7000	-0.52440	-0.51207	-0.49927	-0.48600	-0.47228	-0.45812	-0.44352
0.6000	-0.25335	-0.23763	-0.22168	-0.20552	-0.18916	-0.17261	-0.15589
0.5704	-0.17733	-0.16111	-0.14472	-0.12820	-0.11154	-0.09478	-0.07791
0.5000	0.0	0.01662	0.03325	0.04993	0.06651	0.08302	0.09945
0.4296	0.17733	0.19339	0.20925	0.22492	0.24037	0.25558	0.27047
0.4000	0.25335	0.26882	0.28403	0.29897	0.31362	0.32796	0.34198
0.3000	0.52440	0.53624	0.54757	0.55839	0.56867	0.57840	0.58757
0.2000	0.84162	0.84611	0.84986	0.85285	0.85508	0.85653	0.85718
0.1000	1.28155	1.27037	1.25824	1.24516	1.23114	1.21618	1.20028
0.0500	1.64485	1.61594	1.58607	1.55527	1.52357	1.49101	1.45762
0.0400	1.75069	1.71580	1.67999	1.64329	1.60574	1.56740	1.52830
0.0250	1.95996	1.91219	1.86360	1.81427	1.76427	1.71366	1.66253
0.0200	2.05375	1.99973	1.94499	1.88959	1.83361	1.77716	1.72033
0.0100	2.32635	2.25258	2.17840	2.10394	2.02933	1.95472	1.88029
0.0050	2.57583	2.48187	2.38795	2.29423	2.20092	2.10825	2.01644
0.0020	2.87816	2.75706	2.63672	2.51741	2.39942	2.28311	2.16884
0.0010	3.09023	2.94834	2.80786	2.66915	2.53261	2.39867	2.26780
0.0005	3.29053	3.12767	2.96698	2.80889	2.65390	2.50257	2.35549
0.0001	3.71902	3.50703	3.29921	3.09631	2.89907	2.70836	2.52507

APPENDIX H

FLOWS AT UNGAGED RED RIVER OF THE NORTH MAIN STEM LOCATIONS

RED RIVER OF THE NORTH MAIN STEM FIS STUDY
DISCHARGES BETWEEN GAGES BY DRAINAGE AREA RATIO
10 % CHANCE EXCEEDANCE FLOOD (10-YEAR)
DRAINAGE AREAS ARE CONTRIBUTING ONLY AS COMPUTED BY THE USACE, ST. PAUL DISTRICT
TERRY R. ZIEN 12 JULY 2001

LOCATION	CONTRIBUTING DRAINAGE AREA (SQ MI)	10-YEAR PEAK FLOW (CFS)	COMPUTED 10-YEAR FLOW (CFS)	D.A. RATIO EXPONENT
WHITE ROCK	1,160		3,546	0.957
DORAN	1,880		5,628	0.957
WAHPETON	2,425	7,180		
HICKSON	2,715		7,648	0.559
ABOVE WILD RICE, ND	2,845		7,850	0.559
BELOW WILD RICE, ND	4,485		10,125	0.559
FARGO	4,625	10,300		
ABOVE SHEYENNE	5,055		11,087	0.828
BELOW SHEYENNE	11,335		21,640	0.828
ABOVE BUFFALO	11,545		21,972	0.828
BELOW BUFFALO	12,735		23,831	0.828
ABOVE ELM	13,085		24,373	0.828
BELOW ELM	13,485		24,988	0.828
ABOVE WILD RICE, MN	13,515		25,034	0.828
BELOW WILD RICE, MN	15,165		27,540	0.828
HALSTAD	15,205	27,600		
ABOVE GOOSE	15,495		28,442	1.591
BELOW GOOSE	16,655		31,904	1.591
ABOVE MARSH	16,655		31,904	1.591
BELOW MARSH	16,805		32,363	1.591
ABOVE SANDHILL	17,015		33,008	1.591
BELOW SANDHILL	17,445		34,346	1.591
ABOVE RED LAKE	17,645		34,974	1.591

LOCATION	CONTRIBUTING DRAINAGE AREA (SQ MI)	10-YEAR PEAK FLOW (CFS)	COMPUTED 10-YEAR FLOW (CFS)	D.A. RATIO EXPONENT
GRAND FORKS	21,445	47,700		
ABOVE GRAND MARAIS, MN	21,475		47,720	0.301
BELOW GRAND MARAIS, MN	21,649		47,836	0.301
ABOVE TURTLE	21,749		47,903	0.301
BELOW TURTLE	22,369		48,310	0.301
OSLO	22,520		48,408	0.301
ABOVE FOREST	22,595		48,457	0.301
BELOW FOREST	23,495		49,030	0.301
ABOVE SNAKE	23,525		49,049	0.301
BELOW SNAKE	24,475		49,638	0.301
ABOVE PARK	24,505		49,656	0.301
BELOW PARK	25,515		50,264	0.301
ABOVE TAMARAC	25,535		50,276	0.301
BELOW TAMARAC	25,865		50,471	0.301
DRAYTON	26,085	50,600		
ABOVE TWO RIVERS	26,195		50,674	0.348
BELOW TWO RIVERS	27,425		51,490	0.348
ABOVE PEMBINA	27,455		51,509	0.348
BELOW PEMBINA	31,405		53,976	0.348
EMERSON	31,445	54,000		

RED RIVER OF THE NORTH MAIN STEM FIS STUDY
DISCHARGES BETWEEN GAGES BY DRAINAGE AREA RATIO
2 % CHANCE EXCEEDANCE FLOOD (50-YEAR)
DRAINAGE AREAS ARE CONTRIBUTING ONLY AS COMPUTED BY THE USACE, ST. PAUL DISTRICT
TERRY R. ZIEN 12 JULY 2001

LOCATION	CONTRIBUTING DRAINAGE AREA (SQ MI)	50-YEAR PEAK FLOW (CFS)	COMPUTED 50-YEAR FLOW (CFS)	D.A. RATIO EXPONENT
WHITE ROCK	1,160		3,891	1.391
DORAN	1,880		7,615	1.391
WAHPETON	2,425	10,850		
HICKSON	2,715		12,307	1.116
ABOVE WILD RICE, ND	2,845		12,967	1.116
BELOW WILD RICE, ND	4,485		21,548	1.116
FARGO	4,625	22,300		
ABOVE SHEYENNE	5,055		23,711	0.690
BELOW SHEYENNE	11,335		41,397	0.690
ABOVE BUFFALO	11,545		41,925	0.690
BELOW BUFFALO	12,735		44,862	0.690
ABOVE ELM	13,085		45,709	0.690
BELOW ELM	13,485		46,669	0.690
ABOVE WILD RICE, MN	13,515		46,741	0.690
BELOW WILD RICE, MN	15,165		50,608	0.690
HALSTAD	15,205	50,700		
ABOVE GOOSE	15,495		52,246	1.590
BELOW GOOSE	16,655		58,603	1.590
ABOVE MARSH	16,655		58,603	1.590
BELOW MARSH	16,805		59,444	1.590
ABOVE SANDHILL	17,015		60,630	1.590
BELOW SANDHILL	17,445		63,085	1.590
ABOVE RED LAKE	17,645		64,239	1.590

LOCATION	CONTRIBUTING DRAINAGE AREA (SQ MI)	50-YEAR PEAK FLOW (CFS)	COMPUTED 50-YEAR FLOW (CFS)	D.A. RATIO EXPONENT
GRAND FORKS	21,445	87,600		
ABOVE GRAND MARAIS, MN	21,475		87,625	0.206
BELOW GRAND MARAIS, MN	21,649		87,771	0.206
ABOVE TURTLE	21,749		87,854	0.206
BELOW TURTLE	22,369		88,363	0.206
OSLO	22,520		88,485	0.206
ABOVE FOREST	22,595		88,546	0.206
BELOW FOREST	23,495		89,260	0.206
ABOVE SNAKE	23,525		89,283	0.206
BELOW SNAKE	24,475		90,013	0.206
ABOVE PARK	24,505		90,036	0.206
BELOW PARK	25,515		90,787	0.206
ABOVE TAMARAC	25,535		90,801	0.206
BELOW TAMARAC	25,865		91,041	0.206
DRAYTON	26,085	91,200		
ABOVE TWO RIVERS	26,195		91,303	0.269
BELOW TWO RIVERS	27,425		92,437	0.269
ABOVE PEMBINA	27,455		92,464	0.269
BELOW PEMBINA	31,405		95,867	0.269
EMERSON	31,445	95,900		

RED RIVER OF THE NORTH MAIN STEM FIS STUDY
DISCHARGES BETWEEN GAGES BY DRAINAGE AREA RATIO
1 % CHANCE EXCEEDANCE FLOOD (100-YEAR)
DRAINAGE AREAS ARE CONTRIBUTING ONLY AS COMPUTED BY THE USACE, ST. PAUL DISTRICT
TERRY R. ZIEN 12 JULY 2001

LOCATION	CONTRIBUTING DRAINAGE AREA (SQ MI)	100-YEAR PEAK FLOW (CFS)	COMPUTED 100-YEAR FLOW (CFS)	D.A. RATIO EXPONENT
WHITE ROCK	1,160		3,982	1.513
DORAN	1,880		8,267	1.513
WAHPETON	2,425	12,150		
HICKSON	2,715		14,173	1.363
ABOVE WILD RICE, ND	2,845		15,106	1.363
BELOW WILD RICE, ND	4,485		28,097	1.363
FARGO	4,625	29,300		
ABOVE SHEYENNE	5,055		30,995	0.632
BELOW SHEYENNE	11,335		51,654	0.632
ABOVE BUFFALO	11,545		52,257	0.632
BELOW BUFFALO	12,735		55,603	0.632
ABOVE ELM	13,085		56,564	0.632
BELOW ELM	13,485		57,652	0.632
ABOVE WILD RICE, MN	13,515		57,733	0.632
BELOW WILD RICE, MN	15,165		62,096	0.632
HALSTAD	15,205	62,200		
ABOVE GOOSE	15,495		64,115	1.605
BELOW GOOSE	16,655		71,989	1.605
ABOVE MARSH	16,655		71,989	1.605
BELOW MARSH	16,805		73,032	1.605
ABOVE SANDHILL	17,015		74,502	1.605
BELOW SANDHILL	17,445		77,546	1.605
ABOVE RED LAKE	17,645		78,978	1.605

LOCATION	CONTRIBUTING DRAINAGE AREA (SQ MI)	100-YEAR PEAK FLOW (CFS)	COMPUTED 100-YEAR FLOW (CFS)	D.A. RATIO EXPONENT
GRAND FORKS	21,445	108,000		
ABOVE GRAND MARAIS, MN	21,475		108,028	0.186
BELOW GRAND MARAIS, MN	21,649		108,190	0.186
ABOVE TURTLE	21,749		108,283	0.186
BELOW TURTLE	22,369		108,849	0.186
OSLO	22,520		108,985	0.186
ABOVE FOREST	22,595		109,053	0.186
BELOW FOREST	23,495		109,846	0.186
ABOVE SNAKE	23,525		109,872	0.186
BELOW SNAKE	24,475		110,683	0.186
ABOVE PARK	24,505		110,708	0.186
BELOW PARK	25,515		111,541	0.186
ABOVE TAMARAC	25,535		111,558	0.186
BELOW TAMARAC	25,865		111,824	0.186
DRAYTON	26,085	112,000		
ABOVE TWO RIVERS	26,195		112,110	0.234
BELOW TWO RIVERS	27,425		113,319	0.234
ABOVE PEMBINA	27,455		113,348	0.234
BELOW PEMBINA	31,405		116,965	0.234
EMERSON	31,445	117,000		

RED RIVER OF THE NORTH MAIN STEM FIS STUDY
DISCHARGES BETWEEN GAGES BY DRAINAGE AREA RATIO
0.2 % CHANCE EXCEEDANCE FLOOD (500-YEAR)
DRAINAGE AREAS ARE CONTRIBUTING ONLY AS COMPUTED BY THE USACE, ST. PAUL DISTRICT
TERRY R. ZIEN 12 JULY 2001

LOCATION	CONTRIBUTING DRAINAGE AREA (SQ MI)	500-YEAR PEAK FLOW (CFS)	COMPUTED 500-YEAR FLOW (CFS)	D.A. RATIO EXPONENT
WHITE ROCK	1,160		4,867	1.796
DORAN	1,880		11,585	1.796
WAHPETON	2,425	18,300		
HICKSON	2,715		21,818	1.557
ABOVE WILD RICE, ND	2,845		23,466	1.557
BELOW WILD RICE, ND	4,485		47,664	1.557
FARGO	4,625	50,000		
ABOVE SHEYENNE	5,055		52,372	0.521
BELOW SHEYENNE	11,335		79,793	0.521
ABOVE BUFFALO	11,545		80,561	0.521
BELOW BUFFALO	12,735		84,789	0.521
ABOVE ELM	13,085		85,996	0.521
BELOW ELM	13,485		87,357	0.521
ABOVE WILD RICE, MN	13,515		87,458	0.521
BELOW WILD RICE, MN	15,165		92,872	0.521
HALSTAD	15,205	93,000		
ABOVE GOOSE	15,495		95,847	1.596
BELOW GOOSE	16,655		107,552	1.596
ABOVE MARSH	16,655		107,552	1.596
BELOW MARSH	16,805		109,102	1.596
ABOVE SANDHILL	17,015		111,286	1.596
BELOW SANDHILL	17,445		115,808	1.596
ABOVE RED LAKE	17,645		117,934	1.596

LOCATION	CONTRIBUTING DRAINAGE AREA (SQ MI)	500-YEAR PEAK FLOW (CFS)	COMPUTED 500-YEAR FLOW (CFS)	D.A. RATIO EXPONENT
GRAND FORKS	21,445	161,000		
ABOVE GRAND MARAIS, MN	21,475		161,056	0.248
BELOW GRAND MARAIS, MN	21,649		161,378	0.248
ABOVE TURTLE	21,749		161,562	0.248
BELOW TURTLE	22,369		162,690	0.248
OSLO	22,520		162,962	0.248
ABOVE FOREST	22,595		163,096	0.248
BELOW FOREST	23,495		164,681	0.248
ABOVE SNAKE	23,525		164,733	0.248
BELOW SNAKE	24,475		166,355	0.248
ABOVE PARK	24,505		166,406	0.248
BELOW PARK	25,515		168,078	0.248
ABOVE TAMARAC	25,535		168,111	0.248
BELOW TAMARAC	25,865		168,646	0.248
DRAYTON	26,085	169,000		
ABOVE TWO RIVERS	26,195		169,155	0.217
BELOW TWO RIVERS	27,425		170,849	0.217
ABOVE PEMBINA	27,455		170,889	0.217
BELOW PEMBINA	31,405		175,951	0.217
EMERSON	31,445	176,000		

APPENDIX I

EXCERPTS FROM BARR ENGINEERING REVIEW DOCUMENTS (PUBLIC COMMENTS)

Hydrologic Review of FIS Study
Red River of the North at Grand Forks, ND

Executive Summary

The report, *Hydrologic Analyses for Flood Insurance Studies, The Red River of the North Main Stem, From Wahpeton/Breckenridge to Emerson, Manitoba, Revised Draft Interim Report*, (Draft Interim Report) dated May 2000, was published on behalf of the Federal Emergency Management Agency (FEMA) by the St. Paul District, U.S. Army Corps of Engineers. The Draft Interim Report presents proposed revised values for regulatory flood discharges that would be used in updating the Flood Insurance Studies. The Draft Interim Report was intended for review by potentially affected state and local agencies. Barr Engineering Company (Barr) reviewed the report on behalf of the City of Grand Forks, ND. The findings of Barr's review are presented in this report to the City of Grand Forks.

The Draft Interim Report explains the methods by which flood flows were analyzed to arrive at the proposed revised values for the regulatory discharges. The proposed revised values are 110,000 cfs for the 100-year flood, and 169,000 cfs for the 500-year flood. Both of these values are higher than the currently adopted and FEMA-approved regulatory values.
Because the entire City of Grand Forks is very flat, even minor changes in the regulatory flood level can have major consequences for the City and its residents and businesses. Of principal concern is the regulatory value for the 100-year flood, because that value affects many activities in the floodplain. Because of the significance of the value for the 100-year flood, it is imperative that any changes to the existing regulatory values be justified and based on the best available technical assumptions and methodology.

Barr reviewed the technical aspects of the flood flow analysis presented in the Draft Interim Report for the Red River at Grand Forks. Barr's review found several areas in which alternate approaches would be acceptable, or even preferable. While it was beyond the scope of Barr's effort to produce a revised estimate of the flood flows, it is clear that applying the alternate approaches would result in a flood flow estimate for the 100-year flood lower than that proposed in the Draft Interim Report.

Barr's review found that the value used for the peak discharge for the 1997 flood and the manner in which historic floods are used in the analysis can affect the values of the 100-year flood. Based on a review of the methods and assumptions used in the Draft Interim Report and on consideration of the effects of changing the assumptions used in the analysis relating to the 1997 flood and the historic floods, it appears that a more reasonable, technically justifiable estimate of the 100-year flood flow would be in the range of from 95,600 cfs to 105,000 cfs. The 95,600 cfs estimate would rely on the 116 years of discharge records and not include any of the historic floods, whereas including the 1826 and the 1852 historic floods in the analysis could produce a value of 105,000 cfs.

Overview of Analysis

The report, *Hydrologic Analyses for Flood Insurance Studies, The Red River of the North Main Stem, From Wahpeton/Breckenridge to Emerson, Manitoba, Revised Draft Interim Report* ,(Draft Interim Report) published on behalf of the Federal Emergency Management Agency (FEMA) by the St. Paul District, U.S. Army Corps of Engineers, dated May 2000, presents revised regulatory flood discharges that FEMA is proposing to use for updating the Flood Insurance Studies. This Draft Interim Report is the subject of the following review analysis.

Barr Engineering conducted the review analysis for the City of Grand Forks. The purpose of the review analysis was to evaluate the reasonableness of the technical assumptions used in the Draft Interim Report and to determine if the technically most appropriate assumptions were used as the basis for determining the 100-year flood discharge value at Grand Forks for Flood Insurance purposes. The 100-year discharge is very important to Grand Forks because the very flat terrain of the city means that even small changes in the 100-year discharge can affect a large area of the city.

The review focused on several areas:

1) Use of historic floods values
2) Skew factors
3) Convergence of the discharge frequency curves at Grand Forks, Drayton and Emerson
4) Peak discharge value used for the 1997 flood at Grand Forks

These areas were analyzed separately and in various combinations.

Use of Historic Floods

Three historic floods from the 1800s (1826, 1852, and 1861) were estimated at Grand Forks based upon data for these floods at Winnipeg. Barr has reached the following conclusions regarding the use of these estimated historic floods in the discharge frequency analysis at Grand Forks:

Conclusion 1:

The use of the 1826 and possibly the 1852 estimated flood discharges at Grand Forks as historic events is appropriate to help define the upper end of the discharge frequency curve, especially if a peak discharge of 114,000 cfs is used for the 1997 flood. The use of the 1861 estimated flood discharge is not appropriate, as it is the seventh largest flood, with four recorded floods and two historic floods being larger. Since the 1861 flow is an estimate based on records at Winnipeg, its lack of reliability does not add accuracy to the upper end of the frequency curve.

Conclusion 2:

The methods used to estimate the historic flood flows at Grand Forks contain many assumptions in transferring the Winnipeg data to Grand Forks. These estimated historic flood flows at Grand Forks, although considered as "reasonable," are actually very approximate and subject to considerable variation, especially when compared with actual discharge measurements recorded at Grand Forks since 1882.

Conclusion 3:

Since the values of the estimated flows for the historic floods at Grand Forks were updated in the Draft Interim Report analysis, it would seem most appropriate to use the updated estimates of the historic flows rather than the original estimates made in 1979.

Discussion:

The following discussion will provide information to assist in understanding the basis for these conclusions on the use of historic floods.

Grand Forks has a long period of stream gaging records, 116 years, from 1882 to 1997. In addition to the events covered during this period, three historic floods (1826, 1852, and 1861) were also used in the Draft Interim Report analysis. The flow estimates at Grand Forks for these three flood events were developed by taking data from Winnipeg and using computed or graphical relationships to estimate peak flood flow values at Grand Forks. Two of these historic floods, the 1826 and the 1852, are in the top three flood events at Grand Forks. The 1861 flood is the seventh largest event, with two estimated and four recorded events being larger. Historical data is used when it represents a complete group of all events that exceed a certain threshold. The inclusion of the 1826 event as historic data meets this criteria. The 1861 event does not meet this criteria because there are six floods that are higher. The 1861 flood was treated in the Draft Interim Report analysis as a "systematic" event, which in essence results in extending the Grand Forks record. This is inappropriate.

Estimates of the three historical events at Grand Forks were made by the Corps in 1979 and were then updated in the Draft Interim Report. The Draft Interim Report categorizes these estimates as "reasonable." Both estimates, however, use many assumptions to transfer the Winnipeg data to provide "reasonable" estimates at Grand Forks. These estimated historic flood values at Grand Forks, although "reasonable," are very approximate and subject to considerable variation, especially when compared with actual discharge measurements recorded at Grand Forks since 1882. This is especially important when considering the confusion surrounding the peak discharge measurements for the most recent record flood of 1997 and how it should be considered in flood frequency analyses. Although the 1997 flood discharges were measured with modern technology and with the best available resources, there is still confusion regarding the peak discharge for the 1997 flood. The estimates for the historic floods should be used with caution in the Grand Forks situation.

Skew Factor

The regional skew factor for Grand Forks shown on the current published map in Bulletin 17B is -0.22. The results of the recommended approach in the Draft Interim Report use the computed skew factor of -0.1684; this will tend to result in higher values for the low frequency events such as the 100-year and 500-year flood discharge values. The following conclusion has been reached regarding the skew factor:

<u>Conclusion 4:</u>

The regional skew factor of -0.22 is appropriate for use at Grand Forks. Among the analysis options considered as potentially appropriate, the station skew factor ranged from -0.1879 to -0.2552, which are very close to -0.22. Since the station record is 116 years long, the use of the station skew in this range is reasonable in lieu of the regional skew.

<u>Discussion:</u>

A range of skew factors was used in the analysis which varies somewhat from the regional skew factor published in Bulletin 17B. The regional skew factor for Grand Forks is -0.22. The skew factor of the Corps recommended approach is -0.1684. The larger negative value of the regional skew will result in lower values for the low frequency events. Table 1 displays a comparison of the results of varying assumptions on a number of parameters, including various skew values. A sensitivity comparison of different adopted skews (keeping the other variables constant) is illustrated in comparing the differences between Options 2B and 2D shown in Table 1. An adopted skew of -0.20 was used in Option 2B and an adopted skew of -0.30 in Option 2D. The larger negative skew value of -0.30 in Option 2D resulted in a substantially lower 100-year discharge value. Option 2B resulted in a 100-year discharge value of 100,000 cfs and Option 2D with 93,800 cfs, a difference of 6,200 cfs. The computed skew factors for Options 2E, 3E, 3F, 4E and 4F ranged from –0.2552 to –0.1879. These skew factors are all very close to the regional skew of –0.22.

Convergence of Discharge Frequency Curves at Emerson, Drayton and Grand Forks

The discharge frequency curves for the Emerson, Drayton, and Grand Forks gaging stations as presented in the Draft Interim Report converge at the low frequency events and result in very similar values for the 100-year and the 500-year floods at all three locations. The following conclusion has been reached on this convergence:

<u>Conclusion 5:</u>

The convergence of the discharge frequency curves for Grand Forks, Drayton, and Emerson at the upper end is not consistent with the recorded data for the largest floods nor with the methodology used to estimate the historic floods at Emerson and Grand Forks.

Discussion:

The Draft Interim Report presents recommended 100-year discharge values at Grand Forks of 110,000 cfs, at Drayton of 113,000 cfs, and at Emerson of 116,000 cfs. The drainage area at Emerson is about 50% larger than the drainage area at Grand Forks. Although the very broad floodplain between Grand Forks to Drayton and Emerson may tend to reduce the peak flood discharges at Drayton and Emerson, for many of the large recorded floods, the flows at both Drayton and Emerson are substantially higher than at Grand Forks.

A comparison of the peak flow values between Emerson and Grand Forks is presented in Table 2. The peak discharges and ranking of the floods at each location and the difference in the peak flood discharges is shown. Based on the information shown in Table 2, of the 14 largest floods at Emerson, including both the actual recorded and the historic estimated floods, the difference should be larger. For example, for floods at Emerson greater than 50,000 cfs (approximately the 10-year frequency flood and larger), there are fourteen events, eleven recorded and three historic. When considering all fourteen events as shown in Table 2a, eleven of the fourteen events show an average increase of 11,600 cfs between Emerson and Grand Forks, with the average of all fourteen events showing an increase of about 7,800 cfs. When considering only the recorded events as shown in Table 2b, eight of the eleven recorded floods show an average increase of 11,900 cfs between Emerson and Grand Forks, with the average of all eleven events showing an increase of about 6,900 cfs. Table 2c was prepared to illustrate the variation if the lower estimated peak discharge of 114,000 cfs at Grand Forks for the 1997 flood was used. This would result in an average increase for the eleven events of about 9,000 cfs between Grand Forks and Emerson. Also, the three estimated historic events show an average of about 12,000 cfs larger flows at Emerson. This would indicate that the difference between Grand Forks and Emerson should be greater than the 6,000 cfs value presented in the Draft Interim Report.

A comparison of the peak flow values between Drayton and Grand Forks is presented in Table 3. There are eight recorded floods at Drayton that exceed 50,000 cfs as presented in Table 3. The record at Drayton starts in 1936, so information on the large floods prior to 1936 is not available for Drayton. The comparison between Drayton and Grand Forks is presented for the period from 1936 to 1997, when information is available at both locations. Table 3a presents the information using the peak recorded flows by the USGS at both Drayton and Grand Forks, including the 137,000 cfs value for the 1997 flood at Grand Forks. The average difference for all eight floods shows an increase in flow of 9,550 cfs at Drayton, with the 1997 flood as the only flood showing a decrease in flow. Table 3b presents the same information except the value of the 1997 flood at Grand Forks has been adjusted to 114,000 cfs. This adjustment results in a 10,000 cfs increase between Grand Forks and Drayton for the 1997 flood which is more consistent with the other flood events. The average difference for the eight floods with the adjusted 1997 value shows an increase of 12,400 cfs at Drayton. This data indicates that the difference between Grand Forks and Drayton for the 100-year flood event should be greater than the 3,000 cfs value presented in the Draft Interim Report.

Also, the analysis for Drayton presented in the Draft Interim Report indicates that the skew factor for the Drayton gage was adjusted so that the Drayton curve would not cross the Grand Forks curve. Thus, the Drayton flows were raised so that the 100-year value at Drayton would not be lower than the Grand Forks value. The statistical analysis of the Drayton gage calculated a 100-year flood value of 105,000 cfs; this was adjusted upward in the Draft Interim Report analysis to the 113,000 cfs value.

A 100-year value at Grand Forks in the range of 95,000 to 105,000 cfs would be more in line with the differences between Grand Forks and Emerson, and between Grand Forks and Drayton as shown in the recorded and historic floods comparisons presented in Tables 2 and 3.

Peak Discharge for the 1997 Flood at Grand Forks

There is confusion on the peak discharge to be used for the 1997 flood at Grand Forks. The USGS official published peak discharge measurement is 137,000 cfs. However, analysis of the relationship between stage and discharge and other factors indicate that a lower value should be used in frequency discharges analyses.

Conclusion 6:

The peak flood discharge for the 1997 flood at Grand Forks to be used in this discharge frequency analysis should be 114,000 cfs which occurred with the peak stage on 21 April 1997, as used by the Corps in their flood control project design report and as reported by the USGS in Open File Report 00-344 published in 2000.

Discussion:

The peak discharge for the 1997 flood at Grand Forks is reported by the USGS as 137,000 cfs on 18 April at a stage of 52.21. The peak stage for the 1997 flood was recorded four days later at 54.35 at a discharge of 114,000 cfs. Thus, the peak flow was reported to have occurred at an elevation about 2 feet lower than the peak stage. This is very unusual, especially at Grand Forks. The USGS has subsequently added a footnote to clarify this peak flow situation in their Open File Report 00-344, High-Streamflow Statistics of Selected Streams in the Red River of the North Basin, North Dakota, Minnesota, South Dakota, and Manitoba. The footnote states that a peak discharge value of 114,000 cfs should be used for the 1997 flood in frequency analyses. The 114,000 cfs value for the peak flow is consistent with the values used by the Corps and other hydrologists working on the Red River of the North. An analysis of the 1997 flood on the Red River of the North prepared by the Red River Watershed Management Board in January 1999 used a computed value of 111,000 cfs for the peak discharge in their hydrologic model. The Corps of Engineers hydraulic analysis for the flood control project design used the 114,000 cfs flow which occurred at the date of the peak stage in the calibration of their hydraulic model. Also, a review of the 1997 discharge hydrograph at Grand Forks in comparison with upstream and downstream locations and comparing it to other flood events shows the 137,000 cfs value as

an apparent unexplainable variance, perhaps representing an unsteady state flow condition that may have been occurring at the time of the discharge measurement.
The rating curve, which establishes the relationship between flow and elevation at the gaging station, does not match the elevation and discharge for the 137,000 cfs flow measured at Grand Forks in 1997. The discharges used for the discharge frequency analysis need to have consistency by using the same rating curve.

The value used for the 1997 peak discharge can affect the 100-year flood value. However, the flood frequency analyses summarized in Table 1 showed that at Grand Forks the value of the 1997 flood discharge did not cause a significant difference in the 100-year flood value. The differences are illustrated in Table 1 when comparing the results of the "B" options with the "C" options. The "B" options used the 137,000 cfs value for the 1997 flood, and the "C" options used a value of 111,000 cfs. The resulting difference in the 100-year discharge value was at most 1,000 cfs. Although this is not a large difference, for consistency purposes in using the rating curve for Grand Forks, the 114,000 cfs value appears to be the most appropriate value to be used in the frequency discharge analysis.

Sensitivity Analysis of Various Combinations of Assumptions

Comparison of results considering variations in each factor individually can illustrate the sensitivity of that individual factor. However different combinations of the variations in the factors may show different results. After comparing the results of different combinations of the variations, the following conclusions have been reached:

Conclusion 7:

There are several sets of assumptions that could be considered technically sound and provide a reliable estimate of the 100-year and 500-year frequency flood discharges at Grand Forks. The resulting 100-year flood discharge values could range from 95,600 cfs to 105,000 cfs.

Conclusion 8:

The technical analysis options which have consistency in assumptions use the station record from 1882 to 1997 with a 1997 flood discharge of 114,000 cfs; use the updated estimated flows for 1826 and 1852 used as historic values; and use the computed skew as the adopted skew. This results in a 100-year flood discharge value of 103,000 cfs if only the 1826 historic flood is used or 105,000 cfs if both the 1826 and the 1852 historic floods are used.

Discussion:

The sensitivity of different combinations of the various assumptions discussed under the areas of concern was analyzed and the results are displayed in Table 1. There are 14 different variations displayed in Table 1 in addition to the option presented in the Draft Interim Report. The Draft Interim Report option (Option 1A) results in the highest 100-year flood discharge. The other 14 options (Options 2B-E, 3B-C, 3E-F, 4B-C, 4E-F, and 5B-C) resulted in 100-year flood discharge values ranging from 93,800 cfs to 105,000 cfs.

If only the actual station record is used without consideration of the historic events, the 100-year discharge value ranged from 93,800 cfs to 100,000 cfs. When the historic events are considered, the 100-year discharge value ranged from 102,000 to 105,000 cfs.

If a value of 137,000 cfs is used for the 1997 flood, then the use of the historic events is not as important in the defining of the upper end of the curve, since the 1997 event is then the largest flood, especially considering the 116-year-long station record. If the historic events are excluded from the analysis, then the assumptions used in Option 2B would seem most appropriate, resulting in a 100-year discharge value of 100,000 cfs. Use of the computed skew or the regional skew in Option 2B would result in a 100-year discharge value slightly less than 100,000 cfs.

If a value of 114,000 cfs is used for the 1997 flood, which would correspond to the USGS published information for use in frequency analyses and to the Corps hydraulic analysis used in the flood control project design, then it would be much more appropriate to use either the highest (1826) or the two highest (1826 and 1852) historic floods. With these scenarios, using the computed skew appears appropriate, as it is very close to the regional skew. Options 3E and 3F illustrate using the highest flood as a historic flood, and results in a 100-year discharge value of 104,000 and 103,000 respectively. Options 4E and 4F illustrate using the two highest floods as historic floods, and result in a 100-year discharge value of 105,000 cfs.

Hydrologic Review of FIS Study
Red River of the North
at
Fargo, ND & Moorhead, MN

by Barr Engineering Company
14 February 2001

Executive Summary:

The report, *Hydrologic Analyses for Flood Insurance Studies, The Red River of the North Main Stem, From Wahpeton/Breckenridge to Emerson, Manitoba, Revised Draft Interim Report* (Draft Interim Report), dated May 2000, was published on behalf of the Federal Emergency Management Agency (FEMA) by the St. Paul District, U.S. Army Corps of Engineers. The Draft Interim Report presents proposed revised values for regulatory flood discharges that would be used in updating the Flood Insurance Studies. The Draft Interim Report was intended for review by potentially affected state and local agencies. Barr Engineering Company (Barr) reviewed the report on behalf of the cities of Fargo ND and Moorhead MN. The findings of Barr's review are presented in this report to the two cities.

The Draft Interim Report explains the methods by which flood flows were analyzed to arrive at the proposed revised values for the regulatory discharges. These proposed revised values are 31,600 cfs for the 100-year flood, and 57,400 cfs for the 500-year flood. Both of these values are higher than the currently adopted and FEMA-approved regulatory values.
Because of the fact that the floodplain in the Fargo-Moorhead area is flat and broad, even very minor changes in the regulatory flood level can have major consequences for the area's cities and residents. Of principal concern is the regulatory value for the 100-year flood, because that value affects many activities in the floodplain, including the perceived level of protection provided by existing flood damage reduction measures, restrictions on new developments, and the number of residents required to maintain flood insurance. It is therefore imperative that any changes to the existing regulatory values be completely justified, and based on the best possible technical assumptions and methodology.

Barr reviewed in detail the technical aspects of the flood flow analysis presented in the Draft Interim Report. Barr's review of the technical details of the flood flow analysis described in the Draft Interim Report found several areas in which alternate approaches would be acceptable, or even preferable. While it was beyond the scope of Barr's effort to produce a revised estimate of the flood flows, it is clear that applying the alternate approaches would likely result in a flood flow estimate lower than that proposed in the Draft Interim Report. Based on the review of the methodology of the Draft Interim Report, and on consideration of the likely effects of altering the approach to the analysis, it appears that a more technically-justifiable estimate of the 100-year flood flow would be in the range of 29,000 to 30,000 cfs.

However, when comparing FEMA guidelines for hydrologic reanalysis studies to the results from both the Draft Interim Report and the alternate analyses, there is insufficient justification for moving away from the previously accepted and FEMA-approved flood flow estimates. FEMA guidelines indicate that if the previous estimate falls within certain confidence limits of the revised analysis, the previous estimate should be left in place. The previous FEMA 100-year flood flow estimate (29,300 cfs) is within the guideline confidence limits.

Based these considerations, therefore, Barr concludes that:

1) The graphical plot technique that relies on the plotting positions is the preferred method for establishing the “with dams” discharge frequency curve for the Fargo/Moorhead situation. This method would result in a 100-year discharge value of about 29,500 cfs; and

2) There is insufficient justification for changing the previously adopted value of 29,300 cfs for the 100-year flood. FEMA guidance indicates that if the previously established discharge values are within the confidence limits of the revised analysis, the previously established values should not be revised. The results of both the Draft Interim Report revised hydrologic analysis and several alternative hydrologic analyses presented in this report indicate that the previously established discharge values fall within the confidence limits guidelines.

I. Introduction and Overview

The report, *Hydrologic Analyses for Flood Insurance Studies, The Red River of the North Main Stem, From Wahpeton/Breckenridge to Emerson, Manitoba, Revised Draft Interim Report* (Draft Interim Report), dated May 2000, was published on behalf of the Federal Emergency Management Agency (FEMA) by the St. Paul District, U.S. Army Corps of Engineers. The Draft Interim Report presents proposed revised values for regulatory flood discharges to be used in updating the Flood Insurance Studies. The Draft Interim Report was intended for review by potentially affected state and local agencies. Barr Engineering Company (Barr) reviewed the report on behalf of the cities of Fargo ND and Moorhead MN. The findings of Barr’s review are presented in this report to the two cities.
The Draft Interim Report proposes revised values for the 100-year and 500-year flood discharges (31,600 cfs and 57,400 cfs respectively) for the Red River of the North at Fargo/Moorhead. These values are higher than the previously-adopted and FEMA-approved values (29,300 cfs and 50,000 cfs respectively) that are now being used by the Cities of Fargo and Moorhead.

An upward revision from the previously-adopted flood discharges would have significant adverse impacts on the cities of Fargo and Moorhead. The cities’ flood protection strategies would have to be revisited and revised; the increase in the regulatory discharge would result in significant expenses both for planning and for required physical modifications of existing municipal infrastructure. These increased costs, through cost-sharing agreements, would also be felt by state and federal taxpayers. Additional financial burden would be placed on local residents that would be newly considered to be within the (expanded) floodplain. These residents would now be forced to buy flood insurance. These changes are likely to cause considerable discontent and

disruption of the affected neighborhoods.
Flood flow estimates are based on records of past floods. Clearly, any estimate of a 100-year or 500-year flood flow will depend on the assumptions and methodology used in the analysis of the existing flow data; changing the assumptions and methodology can either increase or decrease the resulting flood flow estimates.
For this report, Barr conducted an extensive and thorough analysis of the assumptions and methodology used in arriving at the proposed flood flow revisions. In particular, Barr focused on three aspects of the Draft Interim Report:

1. The use of historic (non-gaged) flow estimates
2. The method of dealing with the effects of upstream reservoirs
3. The approach to the statistical analysis of the existing flow data

In reviewing these areas of the Draft Interim Report, Barr encountered several items of concern. In these areas, alternate approaches to the analysis can be suggested. These alternate approaches are all at least as technically valid—within the range of commonly accepted scientific practice—as the approaches presented in the Draft Interim Report. In most cases, using the alternate approaches appears to be preferable for technical reasons—by making use of them the accuracy of the flood flow estimate could be improved. The alternate approaches, when applied to the flood flow analysis process, are likely to lower the proposed revised flood flow estimates for the 100-year and possibly the 500-year flood.
Barr's report lists the items of concern with respect to the Draft Interim Report and discusses them briefly. An observation regarding each area of concern is presented and then followed by a discussion. (Two technical appendices (attached to this report) give greater detail regarding the specifics of the analysis of the assumptions and methodology).
For reference, Barr's principal observations and conclusions regarding the Draft Interim Report are summarized below:

- **Observation 1: The estimates of flow for the 1882 and 1897 historic floods at Fargo seem reasonable, but are not as accurate as the data obtained since the USGS gage was installed.**

- **Observation 2: The 1882 historic flood discharge is the seventh largest flood, and using it does not add accuracy or reliability to the flood frequency analysis.**

- **Observation 3: The historic floods should not be used in the analysis of the "with dams" conditions because the estimate of the effects of the dams on these floods is very approximate and all other floods greater than 8,000 cfs (about a 5-year flood) have occurred with Lake Traverse in operation.**

- **Observation 4: Orwell Dam and Lake Traverse have a pronounced effect on flood flows at Fargo/ Moorhead, with Lake Traverse having a much greater effect than Orwell Dam.**

- **Observation 5: The "with dams" discharge frequency analysis at Fargo/Moorhead cannot appropriately rely on standard analytical methods. A graphical technique is appropriate.**

- **Observation 6: The accuracy of estimating "without dams" flows using the HEC-5 model could be improved. One of the ways to improve the model would be assuring there are no negative inflows into Orwell Dam or Lake Traverse.**

- **Observation 7: The "with dams" discharge frequency curve should either rely on the plotting positions for actual recorded large flood events or a revised analysis that more accurately reflects the effects of the dams. For Fargo/Moorhead, relying on the plotting positions provides a more reasonable and reliable analysis.**

- **Observation 8: A linear regression analysis to estimate the effects of the dams should be limited to the range of flows that are similarly affected by the reservoirs.**

- **Observation 9: The 1997 flood hydrograph has an unusual shape at Fargo/Moorhead due to the effect of the blizzard that occurred during the flood. If the 1997 flood is to be used in a linear regression analysis, it should be adjusted to remove the effect of the blizzard.**

- **Observation 10: The analysis of the "without dams" data can be used to determine a peak flow value for the 500-year flood event. The 500-year flood can also be estimated using the volume frequency analysis and this method may be appropriate for the Fargo/Moorhead situation.**

- **Observation 11: The Weibull plotting position formula appears to provide a more reasonable fit to the data than the median plotting position formula if the 1997 flood is not considered to be an unusual event.**

Summary Conclusions:

- Conclusion: For the Fargo/Moorhead situation, the graphical plot technique that relies on the plotting positions is the preferred method for establishing the "with dams" discharge frequency curve. This method would result in a 100-year discharge value of about 29,500 cfs.
- Conclusion: FEMA guidance indicates that if the previously established discharge values are within the confidence limits of the revised analysis, the previously established values should not be revised. The results of both the Draft Interim Report revised hydrologic analysis and several alternative hydrologic analyses presented in this report indicate that the previously established discharge values fall within the confidence limits guidelines. There is insufficient justification for changing the previously adopted value of 29,300 cfs for the 100-year flood.

II. Use of Historic Floods:

Two historic floods from the 1800s (1882 and 1897) were used in the Fargo/Moorhead analysis in the Draft Interim Report. Barr has reached the following three observations regarding the use of these estimated historic floods in the discharge-frequency analysis at Fargo/Moorhead:

Observation 1:

The estimates of flow for the 1882 and 1897 historic floods at Fargo seem reasonable, but are not as accurate as the data obtained since the USGS gage was installed. The documentation of the 1882 and the 1897 floods at Fargo/Moorhead is based on recorded peak flood elevations at that location. The reliability of the documentation of these two events is very good compared to estimates of historic events at other locations along the Red River of the North, and the estimates of the flow for these two historic floods at Fargo/Moorhead appears to be reasonable.

Discussion:

Fargo/Moorhead has a long period of stream gaging records: 95 years, from 1902 to 1997. In addition to the events covered during this period, information on two historic floods (1882 and 1897) was also used in the Draft Interim Report analysis. The information on the 1882 and the 1897 floods is published by the U.S. Geological Survey (USGS). The actual data obtained on these flood events at Fargo/Moorhead is the peak flood elevation. This elevation information has been adjusted to reflect changes in gage location and changes in the geodetic datum. From the elevation, the peak flow for each event was estimated. At other locations along the Red River, such as Grand Forks, peak flood flows for the historic floods of 1826, 1852, and 1861 were estimated from information transferred from Winnipeg using drainage area ratios and other computational methods. The reliability of the estimate of the 1882 and 1897 peak flows at Fargo is much greater than the reliability of the historic floods flows used at Grand Forks.

The actual recorded peak flood flows for the period of station record and the estimated peak flows for the two historic floods indicate that the 1882 and 1897 floods at Fargo/Moorhead are the third and fourth highest floods (unadjusted data). When comparing the flood information at Fargo/Moorhead with the flood information at Grand Forks, we find that the 1882 and 1897 floods were the second and fourth highest at Grand Forks since gaging records were started in Grand Forks in 1882. Historical floods at Grand Forks were estimated for events in 1826, 1852, and 1861 based primarily on information in Winnipeg with no firm information at Grand Forks. Since there is a continuous record at Grand Forks starting in 1882 and the ranking of these floods is very similar for the same period, and since there are specific elevations obtained for these events at Fargo/Moorhead, the reliability of the estimated flows for these two events at Fargo/ Moorhead can be considered to provide a reasonable estimate of the historic flood flows. Although these estimates of the historic flood flows may be reasonable, their reliability does not compare with the data obtained for recent floods.

Observation 2:

The 1882 historic flood discharge is the seventh largest flood, when considering the adjusted records for both the "without dams" and the "with dams" conditions, and using it does not add accuracy or reliability to the flood frequency analysis. Using the 1882 flood as either a historic or as a systematic flood does not add accuracy to the upper end of the discharge frequency curve.

Discussion:

The flood flows estimated for the historical events in 1882 and 1897 occurred with the basin in a "natural" condition, before any upstream flood control dams were constructed. Two flood control dams were constructed upstream of Fargo/Moorhead in the mid-1900s. White Rock Dam (Lake Traverse) was constructed in 1942 and Orwell Dam was constructed in 1953. Both of these dams are operated to reduce downstream flooding. Although the flood control operation of both dams is aimed primarily at reducing flood stages at Wahpeton/Breckenridge, there is an effect on flood flows further downstream at Fargo/ Moorhead. The effect on peak flood flows at Fargo/Moorhead can be substantial, especially for the larger floods. Therefore, flow data gathered after the dams were constructed comprise a different data set than the flows recorded prior to the dams. Analysis of peak flood flows at Fargo/Moorhead should recognize the effects of the dams by adjusting all data to either a "without dams" condition or a "with dams" condition.

The peak flow data for the top ten floods at Fargo/Moorhead for actual recorded values and for adjusted peak values recognizing the effects of the dams is presented in Table 1. When considering the adjusted peak values, the 1897 flood retains the number 3 rank that it has in the actual recorded values. However, the 1882 flood drops from the fourth largest flood to the seventh largest flood in both of the adjusted peak flow comparisons. Using a historic flood which is the seventh largest at the station does not add accuracy to the analysis. Historical data is used when it represents a complete group of all events that exceed a certain threshold. The inclusion of the 1897 event as historic data meets this criteria. The 1882 event does not meet this criteria because there are six floods that are higher, including five recorded events and one historic event. The five recorded floods were determined based on data with a much higher degree of accuracy and reliability. Also, the 1882 flood was treated in the Draft Interim Report analysis as a "systematic" event, which in essence results in extending the Fargo/Moorhead record by 20 years. This is inappropriate for a historic flood that is the seventh largest event.

Observation 3:

The historic floods should not be used in the analysis of the "with dams" conditions because the estimate of the effects of the dams on these floods is very approximate and all other floods greater than 8,000 cfs (about a 5-year flood) have occurred with Lake Traverse in operation. It may be appropriate to use the 1897 flood as an historic event to help define the upper end of the discharge frequency analysis for the "without dams" condition. However, estimating the adjusted value of the 1897 flood for the "with dams" condition is very approximate and inclusion of the adjusted "with dams" value for the 1897 event does not add accuracy or reliability to the discharge frequency analysis.

Discussion:

Reliable data to estimate the effect of the dams on these two historic events is not available. Since the dams were constructed, flow data at the dams, at Wahpeton/Breckenridge, and at Fargo/Moorhead are all available and the effect of the dams on the peak flood flows at Fargo/Moorhead for floods that occurred after the dams were built can be estimated. Therefore, a data set for the peak flood flows for the "without dams" condition which includes the period when the dams were in operation can be developed and can be used for statistical comparisons. However, to estimate what effects the dams might have had on the flood flows prior to the construction of the dams is very approximate, because flow data at all locations is not available. To estimate the effect of the dams on the 1897 flood, the "estimated" flow for the 1897 flood needs to be adjusted by an "estimated average" effect of the dams on actual recorded floods. The Draft Interim Report analysis used a linear regression relationship to estimate this effect. This linear relationship is approximate and has a wide range of variability for floods larger than 10,000 cfs. The effect of these two factors does provide a value for the 1897 event "with dams" that is not anywhere near the reliability of the actual recorded large flood events. Therefore, adding the adjusted 1897 "with dams" flood flow does not add accuracy to the analysis of the "with dams" condition.

However, since the 1897 flood is the third largest event, since it occurred only five years before the continuous records started, and since it is substantially higher than the next four large floods, it may be appropriate to include it in the "without dams" analysis, as it may add accuracy to the upper end of the "without dams" discharge frequency curve.

III. Effects of Upstream Dams:

There are two major dams upstream of Fargo/Moorhead that are operated to reduce downstream flood levels. Reliably determining the effects of these dams on peak flood flows at Fargo/Moorhead can significantly affect the estimated value of the 100-year flood value used for flood insurance purposes. The Draft Interim Report describes the several-step analytical methodology that was used to incorporate the effects of the upstream dams into the discharge frequency analysis. This analytical methodology is a complex process with many assumptions.

The following are Barr's observations relating to the effects of the dams on flood flows and the discharge frequency curve at Fargo/Moorhead.

Observation 4:

Orwell Dam and Lake Traverse have a pronounced effect on flood flows at Fargo/Moorhead, with Lake Traverse having a much greater effect than Orwell Dam. This effect varies depending on the specific runoff characteristics of each individual flood and with the magnitude of the flood.

Discussion:

A review of the data presented in the Draft Interim Report shows substantial reductions in peak flows at Fargo/Moorhead for the larger floods with the dams in operation. This data is summarized in Table 2, Summary of Effects of Upstream Flood Control Reservoirs on Peak Flood Flows on the Red River of the North at Fargo/Moorhead. For example, a reduction of 6,400 cfs is shown for the 1969 flood, 4,200 cfs for the 1978 flood, 3,500 cfs for the 1952 flood, and 3,000 cfs for the 1997 flood. The hydrographs shown on Figure 1 compare the effects of the upstream dams for the 1969 and the 1997 floods at Fargo/Moorhead. A review of the 1997 hydrograph shows that without the dams the peak discharge would have occurred about one week earlier than the actual observed peak, with the maximum effect of the dams being a reduction of about 11,000 cfs about one week before the actual peak. The shape of the flood hydrograph for 1997 was extended due to the effects of the blizzard which delayed the flood peak at Fargo/Moorhead. The 1997 flood hydrograph is somewhat atypical of a standard flood hydrograph. For the 1969 flood, the without dams peak discharge would have occurred on the same day as the actual observed peak discharge with the dams in operation.

The relative effects of Orwell Dam and Lake Traverse are illustrated in the spreadsheet analysis of the 1997 and 1969 floods presented in Tables 3 and 4. For the 1997 flood, the maximum difference between inflows and outflows from Orwell Dam (at the dam site) is a reduction of about 1,600 cfs, whereas the maximum difference from Lake Traverse (at the dam site) is a reduction of about 15,000 cfs. For the 1969 flood, Orwell Dam showed a maximum reduction of about 1,500 cfs and Lake Traverse a reduction of about 13,000 cfs. These were the maximum effects at the dam sites; the magnitude of these effects is reduced as the flows proceed downstream. The maximum potential effect of these reservoirs at Fargo/Moorhead is shown in Tables 3 and 4. The effects presented in Tables 3 and 4 are based on a 4-day travel time from the dam sites to Fargo/Moorhead. These maximum potential effects show reductions of about 9,000 cfs for the 1997 flood and about 11,700 cfs for the 1969 flood. However, the actual effects at Fargo/Moorhead need to be determined using a properly calibrated HEC-1, HEC-5, or other hydrologic model, and the actual reductions would be less than the maximum potential effects shown in Tables 3 and 4.

Observation 5:

The "with dams" discharge frequency analysis at Fargo/Moorhead cannot appropriately rely on standard analytical methods. A graphical technique is appropriate.

Discussion:

Based on the fact that the upstream dams have a significant effect on the flood flows at Fargo/Moorhead, the standard analytical methods will not appropriately analyze the discharge frequency relationship for the existing conditions with the dams in operation. According to EM 1110-2-1415, USACE Hydrologic Frequency Analysis (Corps of Engineers Manual for Hydrologic Frequency Analysis), the frequency for flows downstream of a reservoir should be obtained by constructing a frequency curve of the regulated flow by graphical techniques, or by constructing a graph of with-reservoir versus without-reservoir flows which can then be used in conjunction with a frequency curve of without dams flows to construct a frequency curve of with dams flows.

The Draft Interim Report used the second method. The first method, the graphical technique which uses the plotting positions, was not presented in the Draft Interim Report.

Observation 6:

The accuracy of estimating "without dams" flows using the HEC-5 model could be improved. One of the ways to improve the model would be through assuring there are no negative inflows into Orwell Dam or Lake Traverse.

Discussion:

A review of the effects of the dams on peak flows at Fargo/Moorhead for the period since 1942 through 1997 (as presented in Table 2) shows that there are sixteen floods for which the HEC-5 model shows an increase in peak discharge due to the dams. Although this can be possible, it is not a normal situation downstream of a flood control dam. A closer inspection of three of those events (1945, 1953, and 1975) was done to determine if operation of the dams had actually resulted in higher flows than if the dams were not in place. The relative effect of Orwell Dam and Lake Traverse on these three events is summarized in Tables 5, 6 and 7, and is discussed below.

Information on the 1975 flood is presented in Table 5 and shows that Orwell Dam was essentially releasing inflows, with the outflows varying plus or minus 100 cfs of the inflow. However, at Lake Traverse, the maximum release from the dam in 1975 was about 400 cfs while the peak inflows were as high as 2,000 cfs. Therefore Lake Traverse was reducing the flows by somewhere between 1,000 and 1,800 cfs. The net effect of Lake Traverse and Orwell Dam should be a net decrease in the peak flows at Fargo. Although the maximum potential reduction of about 1,800 cfs is probably not realistic, a properly operating hydrologic model of the dams should show a reduction in flow due to the dams and not an increase.

Information on the 1953 flood is presented in Table 6 and shows that Orwell Dam was not yet in operation and that only Lake Traverse was in operation during flood. Prior to the flood peak, there were no releases from Lake Traverse and, after the flood peak, releases of only 20 cfs were made. The inflow data to the dam however shows many days of negative inflow. To reflect this in Table 6, on the days when the Draft Interim Report flow data shows a negative inflow, a value of zero inflow was entered. Negative inflows can be computed at the dam for several reasons however they are usually due to the wind effect on the reservoir pool level. Negative inflow values do not mean that a zero release from the reservoir on a day of negative inflow would result in the dam increasing flows downstream. However, when the hydrologic model does not correct for these negative inflow values, the effect of the dam on downstream flood flows is not being accurately represented. Although Table 6 shows a potential maximum reduction of 2,300 cfs at Lake Traverse, this number is inaccurate due to similar computational problems that caused the negative flow values. A more detailed analysis of the inflow during the 1953 flood would be required to determine the actual effect of the dam. However, the dam would have reduced flood levels downstream, and would not have caused an increase.

Information on the 1945 flood is presented in Table 7. The data shows that Orwell Dam was not yet constructed and that only Lake Traverse was in operation. During the entire period near the flood peak there was zero release from Lake Traverse, while inflows of up to 1,500 cfs were computed. The effect of Lake Traverse on downstream flood flows for the 1945 flood would cause a reduction and not cause an increase.

A review of how the HEC-5 model handles the inflow for several other flood events is presented in Appendix A, Reservoir Analysis. The wide variation in inflow values and the existence of negative inflow values indicates that the actual inflow values which occurred are not accurately represented in the model. Based on the discrepancies evident for the flood hydrographs that were reviewed, it appears that all inflow hydrographs for both Orwell Dam and Lake Traverse should be reviewed to assure that there are no negative inflow values entered and that the data accurately represents the best possible estimate of the actual inflows to the dams. (Note: The Orwell Dam inflows from 1942 to 1953 for without dams conditions should be revised as discussed in Appendix A.)

Observation 7:

The "with dams" discharge frequency curve should either rely on the plotting positions for actual recorded large flood events or a revised analysis that more accurately reflects the effects of the dams. For the Fargo/Moorhead situation, the graphical plot relying on the plotting positions provides a more reasonable and reliable analysis.

Discussion:

The discharge frequency curve for the "with dams" conditions at Fargo/Moorhead as presented in Figure 7 of the Draft Interim Report shows the plotting positions for the "with dams" data and a computed "with dams" curve of estimated dam effects for floods greater than the 10-year flood

(flood flows of greater than 11,000 cfs). This computed "with dams" curve is recommended in the Draft Interim Report as the revised curve.

A discharge frequency curve that would rely on the "with dams" plotting positions for a graphical plot is illustrated on Figures 2 and 3, which is Figure 7 of the Draft Interim Report annotated with an additional graphical plot that relies more heavily on the plotting positions. Figure 2 shows the entire range of the discharge frequency curve and Figure 3 shows an enlargement of only the upper end of the discharge frequency curve which is of greatest interest for flood insurance purposes. The 500-year flow for the graphical plot relying on the plotting positions was selected based on the volume frequency curve presented in the Draft Interim Report for Fargo/Moorhead (Figure 10 of the Draft Interim Report).
All of the plotting points shown on Figures 2 and 3 above 8,000 cfs are from actual observed flows with the dams in operation, except for the two historic events which were included in the Draft Interim Report analysis.

The Draft Interim Report adopted "with dams" curve appears to be a linear plot from the 10-year event to the 500-year event, and only passes through one of the plotting points above the 10-year event. This adopted "with dams" curve is very unusual for a frequency curve that is affected by flood control dams, as in the case of Fargo/Moorhead. The Draft Interim Report adopted "with dams" curve is higher than the plotting points for all four of the highest flood events; this is also unusual.

The graphical plot illustrated on Figures 2 and 3 that relies more heavily on the plotting positions would result in a 100-year flood value of about 29,500 cfs. This graphical plot would provide a reasonable shape for the discharge frequency curve that is affected by flood control dams. A frequent criticism of graphical plots that rely on plotting positions is that different individuals could develop a discharge frequency curve that would vary widely from one individual to the next. However, based on the data for Fargo/Moorhead, the plotting positions are well distributed and would lead most individuals familiar with reservoir affected relationships to develop essentially identical curves. Most of the plotting positions are used in this plot, whereas the "with dams" curve presented in the Draft Interim Report only passes through one of the plotting positions for the larger floods. In the graphical plot shown in Figures 2 and 3, the curve does not give significant weight to the plotting position for the 1997 flood, which is the largest recorded flood at Fargo/Moorhead. Although the plotting frequency for the 1997 flood appears reasonable at about the 160-year frequency, a more typical hydrograph shape for a flood of the same volume would likely be considerably higher than the 28,000 cfs recorded.

If the analytical approach presented in the Draft Interim Report is to be used to estimate the "with dams" condition, the accuracy and reliability of the hydrologic model used to estimate the reservoir effects should be significantly improved and the relationship between the "with dams" and the "without dams" flows should be reevaluated. The results from the analytical approach should also be compared to the results from the graphical approach which uses the plotting positions and the rationale for using the analytical approach should be fully justified.

Observation 8:

A linear regression analysis to estimate the effects of the dams should be limited to the range of flows that are similarly affected by the reservoirs.

Discussion:

The linear regression analysis presented in the Draft Interim Report uses one linear relationship over the entire range of flows through the 100-year flood. This includes the flow range between zero through 31,600 cfs for the “with dams” condition and zero through 38,000 cfs for the “without dams” condition. There are several concerns with this application of the linear relationship. It assumes the same linear relationship exists over the full range of flows. It extrapolates beyond the highest recorded flows, an area where there is limited data. The two data points for the floods above the 50-year frequency are widely separated on the plot, these are the 1969 and the 1997 floods. The Draft Interim Report’s linear regression analysis splits the difference between these two points, giving similar weight to both floods in determining the reservoir effects. However, a review of the 1997 flood hydrograph shows an atypical shape at Fargo/Moorhead due to the blizzard effect, and consequently the effects of the dams on the 1997 flood hydrograph were not representative of what might have occurred with a more normally-shaped flood hydrograph with a peak flow of 28,000 cfs.

Use of a linear regression analysis might be appropriate if used over narrower ranges of flows where similar dam operating situations are more likely to occur. Also extrapolation beyond the observed data points should be used very carefully.

IV. Statistical Analysis:

Observation 9:

The 1997 flood hydrograph has an unusual shape at Fargo/Moorhead due to the effect of the blizzard that occurred during the flood. The volume of the flood would give it a return frequency of about 200 years, but the actual peak discharge observed would have a lower return frequency. If the 1997 flood is to be used in a linear regression analysis, it should be adjusted to remove the effect of the blizzard.

Discussion:

The 1997 flood hydrograph at Fargo/Moorhead, illustrated in Figure 1, shows that the flood flows at Fargo/Moorhead climbed very steeply from April 4 until April 10 and then stayed at about the same level for about 4 days until the steep climb resumed and then culminated in a peak flow occurring on April 17. This sudden flattening of the hydrograph was caused by a blizzard which put a layer of ice on the floodwaters and dramatically reduced and delayed the peak flow at Fargo/Moorhead.

The linear regression analysis used to determine the relationship between “with dams” and “without dams” for the larger floods was particularly sensitive to the treatment of the 1997 flood. If the 1997 flood is not used in analysis of floods larger than 8,000 cfs, the linear relationship shows a greater effect of the dams on the larger flood flows. Using the volume frequency curves for Fargo/Moorhead in the Draft Interim Report, the 60-day volume for the 1997 flood is approximately the 200-year event. If the blizzard/ice effect were removed from the 1997 flood hydrograph, the peak flood discharge at Fargo/ Moorhead for a flood of that volume would have been higher than the 28,000 cfs peak value that was recorded. The effects of the dams would likely have been greater on reducing the peak flows for a 200-year volume flood without the blizzard/ice effect. If the 1997 flood is used in a linear regression analysis, it should be adjusted to remove the effect of the blizzard. Using it as just another plotting point in the analysis does not recognize the unusual runoff circumstances which occurred during the 1997 flood. Additional discussion on this topic is presented in Appendix B, Statistical Analysis.

Observation 10:

The analysis of the “without dams” data can be used to determine a peak flow value for the 500-year flood event for the “without dams” condition which could then be adjusted through computations to arrive at the “with dams” condition. The 500-year flood for the “with dams” condition can also be estimated using the volume frequency analysis and this method may be appropriate for the Fargo/Moorhead situation.

Discussion:

The value of the 500-year flood flow greatly exceeds the experienced ranges of recorded or historic flood events at Fargo/Moorhead. The 500-year flood can be estimated using several methods. The method presented in the Draft Interim Report analysis uses the “without dams” condition, which can then include the entire period of data collected at the USGS gaging station at Fargo/Moorhead. The “without dams” condition however relies very heavily on accurately estimating the effects of the dams on all flood events that were recorded since the dams were constructed and placed in operation. The 500-year value for the “without dams” condition must then be adjusted to determine the effects of the dams on the 500-year event. The Draft Interim Report presents the value of the “without dams” 500-year flood to be 63,400 cfs and then, using the HEC-5 hydrologic model to estimate the effects of the dams, presents a value “with dams” of 57,400 cfs. The shape of the “without dams” discharge frequency curve is also affected by the method used to determine the plotting positions, whether or not historic floods are incorporated and the manner in which they are incorporated, and the skew factors adopted for use. For example, using the recorded flows for 1902-1941, adjusted flows for 1942-1997, the 1897 flood and the regional skew factor of –0.22, a 500-year flood value of 56,000 cfs was obtained for the “without dams” condition. And, then when the linear regression equations were used to compute the effects of the dams, a 500-year flood value between 45,000 cfs and 47,000 cfs was obtained for the “with dams” condition, depending on whether the 1997 flood was used in the regression analysis. This sensitivity analysis is discussed further in Appendix B. Thus, although the same method is used, slightly different assumptions can significantly affect the value of the 500-year flood for the "with dams" condition.

The Draft Interim Report volume frequency analysis at Fargo shows a maximum mean daily flow value of slightly less than 50,000 cfs, which would imply that the maximum peak flow value would be only slightly greater than 50,000 cfs. This volume frequency analysis approach produces a 500-year flow value very close to the previously adopted 500-year value of 50,000 cfs.

Observation 11:

The Weibull plotting position formula appears to provide a more reasonable fit to the data than the median plotting position formula if the 1997 flood is not consider to be an unusual event.

Discussion:

The Draft Interim Report used the median plotting position formula for plotting the individual data points for the discharge frequency relationship. This plot produced erratic plots for flows greater than 10,000 cfs. Three other plotting position formulas were tested for their ability to reduce the erraticness of the plots. The Weibull plotting position formula did reduce the erratic nature of the plotting points. Both the Weibull and the median plotting position formulas are acceptable as presented in Bulletin 17B guidelines. Use of the graphical plotting method with the plotting points from the Weibull formula and using the 1997 flood plotting point as any other plotting point resulted in a 100-year discharge of about 29,000 cfs. Figure 4 illustrates a "with dams" discharge frequency curve using the Weibull plotting points. The "without dams" discharge frequency curve shown on Figure 4 was used to provide a value for the 500-year flood which was then adjusted for reservoir effects to give the plotting point for the 500-year flood "with dams" condition.

V. Summary Conclusion:

After comparing the results of the technical analysis considering the above discussed observations, the following summary conclusions have been reached.

Conclusion:

For the Fargo/Moorhead situation, the graphical plot technique that relies on the plotting positions is the preferred method for establishing the "with dams" discharge frequency curve. This method would result in a 100-year discharge value of about 29,500 cfs.

Discussion:

For the Fargo/Moorhead analysis, the graphical approach which uses the plotting positions is preferred over the analytical approach for the following reasons:

- All of the gaged recorded high flows events above 8,000 cfs have occurred with the dams in operation. The effects of the dams on these floods at Fargo/Moorhead are most accurately determined based on the observed flows from actual operation rather than relying on reconstructed computed flows.

- The potential effects of the dams on the two historic floods can be estimated only very approximately. These two historic floods should not be used as plotting points in the "with dams" discharge frequency analysis.

- A graphical plot relying on the plotting positions produces a very reasonable, justifiable and understandable curve. The variations between the curve and the plotting points can be explained and supported. Although in some circumstances using the plotting positions as the basis for developing the discharge frequency curve can produce very different results depending on the individual drawing the curve and thus result in uncertainty, in the present Fargo/Moorhead situation, the plotting positions would lead most individuals familiar with reservoir affected flow conditions to develop essentially identical curves and the level of confidence in the resulting curve could be considered high.

- The analytical approach used in the Draft Interim Report is a complex process with several steps that can introduce significant uncertainty into the analysis and the results. The HEC-5 model used to compute what the flows at Fargo/Moorhead would have been over the period 1942 through 1997 if the upstream flood control dams had not been in place does not reproduce actual observed flood hydrographs in key areas and produces questionable results for a number of floods. The linear regression which was then developed from the HEC-5 model results used one linear relationship over the entire range of flows; this introduces additional uncertainty, especially at the higher flood flows. The high flow portion of the discharge frequency curve, which is of greatest significance in the regulation of the floodplain and has the greatest potential effects on the cities of Fargo and Moorhead, is also the area where the analytical method used in the Draft Interim Report has the greatest degree of uncertainty.

Conclusion:

FEMA guidance indicates that if the previously established discharge values are within the confidence limits of the revised analysis, the previously established values should not be revised. The results of both the Draft Interim Report revised hydrologic analysis and the several alternative hydrologic analyses presented in this report indicate that the previously established discharge values fall within the confidence limits guidelines. There is insufficient justification for changing the previously adopted value of 29,300 cfs for the 100-year flood.

Discussion:

FEMA guidelines for reanalysis of hydrology for flood insurance studies states that proposed discharge values must be compatible with those used in previously completed studies on the same watercourse. Discharge values from a later flood flow frequency analysis that disagree with previously used discharges should be considered only when the later discharges can be shown to be significantly different statistically from the previous discharges. The test for significance shall be based on the confidence limits of the latest analysis: the latest discharges should be used if the previously established discharges do not fall within the 95- and 5-percent confidence limits of the most recent estimates; the previously established discharges should be used if they fall within the 75- and 25 percent confidence limits of the most recent estimates.

The Draft Interim Report presents 95- and 5-percent confidence limits for the “without dams” condition at Fargo/Moorhead but not for the “with dams” condition. For the 100-year flood for the “without dams” condition, these confidence limits result in a range of discharge values between 28,100 cfs and 53,200 cfs. Development of comparable confidence limits for the “with dams” condition would result in lower values for the range. Calculations based on the information presented in the Draft Interim Report results in the following estimates for the “with dams” conditions:

- -5% confidence limit 44,900 cfs
- -25% confidence limit 36,300 cfs
- -75% confidence limit 28,000 cfs
- -95% confidence limit 23,900 cfs

The previously established discharge for the 100-year flood is 29,300 cfs which falls within the 25- and 75- percent confidence limits of the recent Draft Interim Report analysis for the “with dams” condition. Meeting this test would support using the previously established discharge value of 29,300 cfs.

The alternate methods analyzed by Barr using updated data provide an estimate of the 100-year flood that is very close to the previous estimates. Several technical analysis options that appropriately represent the effect of the dams on the flood flows at Fargo/Moorhead result in a 100-year discharge between 29,000 and 30,000 cfs, including the graphical plot method that relies on the plotting positions. The method used in the Draft Interim Report results in 100-year and 500-year discharges slightly higher than the results from the alternate methods evaluated by Barr, however, the results from all of these methods would indicate that the previously established values should not be changed.

APPENDIX J

MEETING NOTES AND MEMORANDA

CEMVP-ED-H (1110-2-1403) 24 July 2000
Zien/trz/5714

MEMORANDUM FOR RECORD

SUBJECT: Response to Barr Engineering's review comments on the revised Draft Interim Report, Hydrologic Analyses for Flood Insurance Studies, The Red River of the North Main Stem, from Wahpeton/Breckenridge to Emerson, Manitoba, May 2000.

The following comments in Italics were received from Barr Engineering on 20 July 2000, with regards to the discharge-frequency curve at Grand Forks, North Dakota. A meeting was held at the offices of the St. Paul District on 21 July 2000 to address the comments. In attendance were Terry Engel, Robert Engelstad and Terry R. Zien from the Corps of Engineers and William Spychalla and Suzanne Jiwani from Barr Engineering.

It should be noted that the data and assumptions that were used to derive the discharge-frequency curve for the Red River of the North at Grand Forks were discussed and agreed upon at a meeting at the Minnesota State Capitol building in June of 1997. Technical experts from the Corps of Engineers, Minnesota and North Dakota U.S. Geological Survey districts, the Minnesota Department of Natural Resources, FEMA Regions 5 and 8, and the North Dakota State Water Commission were present. The current study checked the data and assumptions in great detail and did not change anything.

1) Use of Historic Values

The period of record is substantial without the three historical values. How does including them affect the frequency curve? What are the 100-year and 500-year peak discharges without the historic values? The report states that 1861 was treated as part of the systematic record. Why was 1861 handled this way? What is the effect if it is handled as a historic value?

It is the opinion of the U.S. Army Corps of Engineers that discharge-frequency curve computations are greatly improved by the inclusion of historic flood events, even for gage locations that have a relatively long period of record. The estimated historic flows must be deemed reasonable and appropriate. The historic flood events transferred to Emerson and then to Grand Forks from Winnipeg, Manitoba, for 1826, 1852 and 1861 were deemed reasonable and appropriate for inclusion in the analysis for Grand Forks based on historic accounts of the events.

MEMORANDUM FOR RECORD

SUBJECT: Response to Barr Engineering's review comments on the revised Draft Interim Report, Hydrologic Analyses for Flood Insurance Studies, The Red River of the North Main Stem, from Wahpeton/Breckenridge to Emerson, Manitoba, May 2000.

The 1861 event was treated as a systematic event instead of a historic event for two reasons. The first reason was that there was some uncertainty that there was not a flood larger than 1861 during the period from 1826 through 1881 at Grand Forks for the years without observed records. The systematic record begins in 1882. The estimated flood flow for the 1861 event at Grand Forks was 65,000 cubic feet per second (cfs).

The second reason was that the use of the 1861 flood as a historic event results in seven high outliers to be identified in the log-Pearson Type III (Bulletin 17B) discharge-frequency analysis. This occurred because all flood flows larger than the lowest historic event were treated as high outliers by Bulletin 17B criteria. This was not considered reasonable for the observed data set because there were four floods larger than 1861 in the systematic record. These are 1882 (75,000 cfs), 1979 (82,000 cfs), 1897 (85,000 cfs) and 1997 (137,000 cfs).

There were several permutations and combinations of historic events that could have been used in computing the discharge-frequency curve for the Red River of the North at Grand Forks. These would have had varying impacts on the computed curve. The combination judged to be most reasonable was used.

2) Mixing of Summer and Spring Events
Sixteen of the values used in the analysis are for summer flooding events. Mixing summer with spring snowmelt events means that the data is nonhomogeneous. The values for these sixteen events should be substituted with the peak snowmelt values for the given year. This will decrease the mean. It will also change the standard deviation and skew factor. Have the analyses been conducted with only springtime events?

The analysis performed for the Red River at Grand Forks was for the set of annual independent instantaneous peak flows, which is a homogeneous data set by definition regardless of season or source of flooding. The resulting plotting positions of the annual peaks show a very good fit to the analytical discharge-frequency curve. Further investigation into the need for separation of the seasonal peaks was, by definition, not appropriate.

Bulletin 17B and Corps of Engineers EM 1110-2-1415 discuss the fit of the annual peaks to the log-Pearson Type III distribution as a criterion for separation of the data into two sub-sets. The plotted data must exhibit a break in slope or other significant anomaly with an abnormally high computed skew that shows the presence of two distinct populations to justify data separation. This was not the case for the set of annual peak flows for Grand Forks. Another consideration for data separation is ice-affected peak stage not occurring at the time of the peak flow. This was not a concern at Grand Forks.

3) Skew Factor

A range of skew factors was used in the analyses. These factors are different from the regional skew factor published in Bulletin 17B. Were sensitivity analyses with respect to the skew factor conducted? What criteria were used to determine when to adjust the skew factor and what skew factor to adopt?

The regional skew coefficients presented in Bulletin 17B were developed from gages with drainage areas of 3000 square miles or less and from limited data sets through water year 1973, and were not computed with the recommended procedures described in Bulletin 17B. The coefficients on the map remained unchanged from Bulletin 17 (1976). In addition to being outdated, the skew coefficients would not be appropriate to use for the Red River main stem gage locations that have drainage areas greater than 3,000 square miles and relatively long periods of record.

Computed station skew was used for Halstad, Grand Forks and Emerson. The station skew at Fargo was weighted with a regional skew coefficient from a recent U.S. Geological Survey (Minnesota District) regional skew study, which had drainage areas up to 6,000 square miles (Fargo's contributing drainage area is about 4,600 square miles). The unadjusted skew coefficient for Fargo was very inconsistent with other Red River main stem gaging stations. The statistics (including skew) were adjusted for the

MEMORANDUM FOR RECORD

SUBJECT: Response to Barr Engineering's review comments on the revised Draft Interim Report, Hydrologic Analyses for Flood Insurance Studies, The Red River of the North Main Stem, from Wahpeton/Breckenridge to Emerson, Manitoba, May 2000.

Drayton gage to be regionally consistent with the long record stations at Grand Forks and Emerson.

4) Convergence of Curves at Emerson, Drayton, and Grand Forks
The frequency curves for Emerson, Drayton, and Grand Forks gauging stations for frequencies above 1%. The skew factor at Drayton was adjusted so the frequency curves did not cross. Because of the large increase in drainage area, it seems logical that the discharges at Drayton and Emerson would be larger than at Grand Forks. Were analyses conducted adjusting the skew factors so that the frequency curves at the three gauging stations would be nested rather the converged?

The skew coefficients at Grand Forks and Emerson were not adjusted. The mean, standard deviation and skew for Drayton were adjusted as described in the report to be regionally consistent with Grand Forks and Emerson. The curves do tend to converge at the upper end, for the more rare flood events. Factors that contribute to this are upper basin storage (primarily the swamps of northwestern Minnesota) and overbank storage (sectional flooding) downstream of Grand Forks. Annual flood peaks are not always larger at Emerson than they are at Grand Forks, even though the contributing drainage area increases from 21,445 to 31,445 square miles. This is true for large and small floods throughout the systematic record.

TERRY R. ZIEN, P.E.

Hydraulic Engineer
Hydraulic and Hydrologic Engineering Branch

RED RIVER OF THE NORTH AT FARGO/MOORHEAD TECHNICAL REVIEW OF CORPS HYDROLOGIC ANALYSES

SUMMARY OF DISCUSSION AT MEETING WITH THE CORPS OF ENGINEERS – NOVEMBER 16, 2000

Submitted by Barr Engineering
to the Cities of Fargo, ND and Moorhead, MN

(Revised on 12/26/00 in accordance with comments from the St. Paul District Corps of Engineers:
Terry Zien, Dan Reinartz, Aaron Buesing, and Bob Engelstad)

This discussion was planned to provide an interpretation of the study and results as shown in the *Hydrologic Analysis for Flood Insurance Studies, the Red River of the North Main Stem From Wahpeton/Breckenridge to Emerson, Manitoba, Revised Draft Interim Report, May 2000.* A list of questions was developed and forwarded to all attendees prior to this meeting. This summary of the November 16, 2000 meeting does not necessarily follow the presentation outline exactly: portions were rearranged to ensure continuity in the discussion on each topic. This summary primarily presents the material as stated by the Corps of Engineers, and is not necessarily the views of the other attendees.

There were approximately 20 attendees from the Corps of Engineers, Minnesota Department of Natural Resources, North Dakota State Water Commission (NDSWC), City of Fargo, City of Moorhead, Ulteig Engineering, Moore Engineering, Houston Engineering, and Barr Engineering. The list of attendees is attached.

Introduction by Terry Engel

The meeting began with a presentation by Terry Engel regarding general information and scheduled dates for the project. He noted that he expected to receive comments regarding the Fargo hydrologic analysis by the end of January. There is no funding to address the comments that are submitted, and any revisions would likely have to wait until mid-year 2001. The Corps will make revisions after the comment period as soon as funds are received. The FIS restudy is scheduled to be completed by September 30, 2001. This deadline may have to be extended if there are major revisions and the funding is not available until mid-year. In January 2000, the Interagency Hydrology Review Committee met with representatives from the NDSWC, the MNDNR, FEMA Regions V and VIII, and the ND USGS to review the Fargo hydrologic report, and there was acceptance of the methodology and results presented in the report.

He noted that Aaron Busing was continuing to work on the HEC-RAS model for the Red River basin. It is taking longer than expected, but Aaron was at the meeting to review his progress and answer any preliminary questions. Aaron needed to make modifications to the current HEC-2 model to calibrate it to the 1997 flood event. One of the concerns was that the floodway run is currently resulting in a stage increase of greater than 0.75 feet in several areas (0.75 feet increase is the standard for the Red River of the North that was agreed upon by both States). None of the areas with floodway concerns is in Fargo, but there are some problems immediately downstream of Fargo. This issue is outstanding and needs to be resolved.

Overview and Addressing of Questions by Terry Zien

Terry began with a presentation of the general methodology, and weaved in the answers to various questions in this presentation. He then followed with a question-by-question review and the respective answer(s). The existing flood frequency curve for the City of Fargo was developed in 1970 as part of a regional flood analysis. This analysis used the gage data as observed, with no adjustment to define the potential effects of the upstream reservoirs. Additional background information was not available for review. The procedures used Water Resources Council Bulletin #15 (1967), which listed current standards and procedures for definition of flood frequency curves. There have been many changes to the flood frequency analysis methodology since 1967, and the current standard that is used by the Corps of Engineers and others is Bulletin 17B (March 1982 version). Although the Fargo Flood Insurance Study (FIS) was updated in about 1995 and 1997, there were no revisions to the hydrology since the 1970 study. The 100-year Effective flow listed in the FIS is 29,300 cfs.

Flood Frequency Analysis (FFA)

Gaging records for Fargo were available for 1882, 1897, and 1902 through 1997, however the data set is not homogeneous. The reservoir at Lake Traverse was constructed in 1942 and at Orwell in 1953. Since this set of data does not represent similar conditions in the river, Bulletin 17B indicates that a straight analysis of the observed data is not accurate. Therefore, they did not want to use the mixed set of data and a more complicated analysis was completed that attempts to make the entire data set homogeneous. As a sensitivity analysis and to look at preliminary results, the entire gage data set was run through Bulletin 17B to define an "observed data" flood frequency curve (with no adjustments made to correct for the non-homogeneous data set). This analysis predicted a peak 100-year flow of 34,300 cfs at Fargo (skew was computed at –0.02). However, they did not feel that this "observed data" analysis reflected the reservoir effects at Fargo. The peak inflow to Traverse was estimated to be between 13,000 and 15,000 cfs during the 1997 event: The peak outflow from Traverse was estimated to be between 7,000 and 8,700 cfs (depending on who's measurement you take – USGS or Corps).

The published USGS gage data for Fargo includes peak stage and estimated flow data for both the 1882 and 1897 events. These flows are based on high water marks, and were confirmed with a separate contract for North Dakota USGS review of their historical database. Inclusion of these events in the flood frequency analysis was discussed briefly. Bulletin 17B defines historic events as floods that occur outside the period of systematic record. These historic floods determine which events in the systematic record are considered to be high outliers (all events with flows greater than the historic flood flows).

- The 1882 flood (20,000 cfs) was considered as a systematic event, which extends the period of record back to 1882. It was not considered historic because it is only the 7th largest flood and doing so would have included 4 other events as high outliers, which did not seem appropriate for this analysis. Cannot use as a historic event because it is not certain that there were no larger floods in the record that are not recorded (1893 peak flows may have been a bit larger than 1882 peak flows). The only other options would be to leave it out or consider it part of a broken period of record. The Corps did not leave it out because it is a large event. Even if you don't include the point, you would extend the period of record to include back to 1882 because you know there were no floods of historic proportions between 1882 and 1896.

- The 1897 flood (25,000 cfs) was considered as a historic event.

The computed station skew for Fargo was compared to the adopted skews for other gaging stations along the Red River to ensure a regionally consistent set of numbers for the main stem of the Red River. These were station skews except for Wahpeton, which was a station skew weighted with a regional skew.   A graph was shown that compared the adopted skews to the mean log at each station.   At Fargo, the influence of station skew in the weighting with regional skew needs to be considered because of the long period of record. The adopted skews were a compromise between regional and computed values for Fargo and Drayton.

A sensitivity analysis was performed using the "observed data" set. Approximately 18 runs were completed using HEC-FFA, nine of which were for Fargo. Using the regional skew with the original data predicted a 100-year flow of 33,100 cfs. Using only the regulated flow years (1942 – 1997) the peak flow was computed to be about 37,000 cfs. Using the original data with the 1997 flood as a natural (no dams) flow predicted a peak 100-year flow of about 34,900 cfs. Using the original data with a 1997 flood flow of 23,000 cfs (as sensitivity to the measured 1997 peak flows, subtracting the dam outflows from the peak) predicted a peak 100-year flow of about 33,600 cfs. A Gumbell analysis was also completed, but the points did not fit the Gumbell distribution therefore it was not considered further. The computed line was much flatter than the Log Pearson Type III line. The Corps will send a copy of the sensitivity analysis for review.

The low outlier test in Bulletin 17B tests for what is considered unusual low flows. The computed low outlier value was about 150 cfs for Fargo in the various FFA runs. The lowest flow in the period of record is 300 cfs. One criticism of the Log Pearson analysis is that low events can affect the upper end of the curve. If you take the low flows out of the analysis, the skew would be more positive (making the upper flows higher).

Although the four largest floods are below the computed curve, there is scatter throughout the curve. The adopted curve is very close to 3 of the 4 top floods – it is considered a good match. The highest flood is 1997. Although it appears that the curve basically ignores the 1997 point, one point does not heavily influence a curve that is developed using a long period of record.

There was no comparison done between the FFA for observed flows for Wahpeton/Breckenridge and the Fargo data. The FIS study for Wahpeton was completed before this study began. A stage-frequency analysis was completed for the Wahpeton study due to the ice effects (28 out of 56 years). Nor was there any comparison between the FFA for observed flows for Hickson and Fargo. Generally short-term stations are compared to long-term stations not vice versa. They focused on consistency of the main stem, not on tributaries. There would be some value to a tributary study.

The effect of reservoirs on a FFA is typically shown as a deviation from the normal curve. For a FFA just below the reservoir, the deviated curve typically remains flat when it first diverges, reflecting the reservoir's operation of releasing maximum outflow without exceeding restrictive channel capacity (typically at about the 10-20 year flood), and then jumps back to the normal curve as the outflows start to approach the inflows (after the emergency spillway begins to operate – at about the 100-200 year flood). This prominent divergence, or "dip" in the curve, is not seen at Fargo for 2 reasons: 1) there is no emergency spillway at Traverse and therefore outflows never approach inflows and 2) the effect of Traverse on peak flows is not as prominent as you go downstream (this is probably why there has not previously been an adjustment at Fargo to reflect the reservoir effects). There is no peak inflow point above which the Traverse peak inflows equal peak outflows – because of the restricted outlet capacity. The outflow is limited by the physical configuration of the outlet works and the height of White Rock Dam. The embankment is high, and restricts the outflows. The shape of the divergence curve is a function of storage in the reservoir – you can't predict at what level the inflows will equal the outflows. Even up to the SPF flows, there is a reduction in the peak. The reservoirs reduced the peak flow in Fargo by about 3,000 cfs during 1997.

Explanation of the FFA curve shown on Figure 7: The top line with triangles is an analytical curve based on natural flow conditions (Figure 6 – without dams using 1882, 1897 and 1902 – 1941 data unadjusted and 1942 – 1997 data adjusted back to natural conditions). The bottom line with circles is a graphical curve based on the linear regression reduction (described below) for the respective flows for the 10-, 50-, and 100-year events. The 500-year point was anchored using the volume-duration-frequency analysis (described below). You can't do an analytical curve with dams, because of the divergence portion of the curve from the effect of dams.

The curve with circles (from Figure 7) was the final flood frequency curve used for the lower frequency events. The higher frequency flows on the final flood frequency curve (flows less than the 10-year event) were developed using analytical techniques. There is not a lot of difference between the with- and without-dams conditions for these high frequency events.

Effect of Reservoirs

The effects of the upstream reservoirs was analyzed to define a homogeneous data set for the FFA. More data was available for the period 1942 – 1997, and therefore this period of data was adjusted to a non-regulated condition. There was not enough data to adjust the data prior to 1942 to a regulated condition (the gages at the reservoirs were installed when the dams were constructed). The effect of the reservoirs was accomplished using the HEC-5 computer model. The HEC-5 model has 5 basic variables: reservoir inflows, reservoir operation, reservoir pool elevations, river flows, and routing parameters. The model uses available data to solve for the unknown data.

The analysis considered three basic areas that contribute flow to Fargo:

1. Local watersheds downstream of the reservoirs.
2. Wild Rice River watershed.
3. Traverse and Orwell reservoirs.

The timing and magnitude of the peaks from each of these three areas affect the peak flows at

Fargo. Each one can have a significant impact on the peak. The Orwell reservoir does not have big outflows, and does not affect the peaks. Up until 1997, there were no significant outflows from Traverse and Orwell reservoirs that contributed to the peaks at Fargo.

Although the text states that the peak flows at Fargo from 1942 – 1996 were considered to be from local flows, with no significant addition to peak flows at Fargo from the upstream reservoirs, if the reservoirs were not constructed the peaks in Fargo would have been larger than observed. The peak "natural" conditions flows would have included flows from the reservoir areas. The reservoirs have less impact for lower flows. Local flows are typically higher than reservoir outflows during these low flow events.

The process for adjusting the 1942 – 1997 data to non-regulated conditions follows:

1. The observed reservoir data (dam operations, tail water gages, and pool elevations at the reservoirs) was used to compute the reservoir inflows from the areas upstream of the dams using reverse routing. The local and incremental inflows at Fargo and Wahpeton were computed with HEC-5 using the observed gage data for the Red River. All flows were computed as mean daily values.

2. Model the natural (non-regulated) conditions flows for 1942 – 1997 by removing the reservoirs (shut off the reservoirs in the model). Figure 6 shows the FFA using the non-regulated set of data for the entire period of record. The 100-year peak flow was 37,300 cfs and the computed skew was +0.03.

   The model used a Wahpeton flood stage criteria of 12' for Traverse operation for the entire record. Using a 10' flood stage criteria from 1942 – 1980's would not have made much difference at Fargo.

The model was calibrated to define the timing between the gages: the 1997 flood was used to calibrate the model. The calibration model was verified using the 1969 flood.

The storage error in the model (Question 2.2.6) was not reviewed further. The pool elevation during the 1997 flood got up to elevation 981-982, therefore the error may not be great because of the low elevation where it occurred.

The routing from Wahpeton to Fargo was computed to be about 3 days using the model. There could be some variation with this parameter from year to year and for different storms. The timing was probably longer during 1997 than in 1969 and other years. The HEC-5 model is run using daily time steps, so differences of several hours are not computed. A different routing may change the peak flow at Fargo by a couple hundred cfs. The Straddle-Stagger routing method is used in HEC-5. The routing accounts for storage and timing.

3. Develop linear regression analysis to account for the effect of the reservoirs. The linear regression analysis was based on the data from 1942 – 1997. The linear regression provides a correlation between the with-dam flows and the without-dam flows. If you don't use linear regression, you must rely on the plotting position and supplement with data on larger flows. The linear regression correlation was used to define the final flood frequency curve for the 10-, 50-, and 100-year flows. The linear regression line had a good R squared value for the data analyzed.

The 500-year flow must account for the increase in flows from the reservoir because the assumption is that there will be significant outflow at rare high flood events. The more rare flood events must include more flow from Lake Traverse to account for the reservoir being at capacity. There are 2 possible ways to anchor the 500-year flow: 1) develop a rainfall-runoff model or 2) use reservoir data to do a volume frequency analysis. A rainfall-runoff model would have been too expensive and was not completed. A volume-frequency analysis was the selected method.

4. Develop a volume-duration-frequency analysis. The elevations were smoothed by taking a 5-day centered moving average of each daily value to eliminate wind effects. The maximum flow periods for each year (1942 – 1996) were located for each duration (based on gage data at Traverse, Orwell, and Fargo). And a FFA was completed for each duration (1-, 3-, 5-, 7-, 15-, 30-, 60-, and 90-day).

5. The volume frequencies for the 500-year flood for various durations were input into HEC-1 and used to develop a balanced hydrograph. The shape of the hydrograph was also input to HEC-1. The shape of the top 5 flood hydrographs was reviewed and determined to be very similar. The model computes a simulated/balanced 500-year hydrograph at Fargo under with dam conditions.

6. The HEC-1 balanced hydrograph for the 500-year flood was input into the HEC-5 model to compute the predicted peak flow under natural without dam conditions. The peak discharge was computed to be the approximate flow at about the 670-year event. But this was computed using a truncated portion of the record (1942 – 1997, the higher period). The difference in flows was used as the reduction from the natural conditions 500-year flow to the with dam condition 500-year flow. This flood was titled the "Index Flood".

The data from the HEC-5 runs were compared to gage data from various gages (including the Wahpeton gage), and it seems to compares well.

1997 Flood

The computed frequency of the 1997 flood was compared for the various stations based on flow:

Wahpeton	140-year flood
Fargo	70-year flood
Halstad	140-year flood
Grand Forks	210-year flood
Drayton	140-year flood
Emerson	170-year flood

The statistics of the frequency event versus the change of actually occurring in a given period was discussed. There is a 63% chance of the 100-year flood occurring during a 100-year period. There is a 75% chance of a 70-year flood occurring during a 100-year period.

Using the no adjustment flood frequency curve, the 1997 flood at Fargo is the 50-year flood. The peaks from the three contributing areas can each be higher frequency than the peak at Fargo, the timing of the peaks affects the peak at Fargo. The 1989 event had a freeze that affected the runoff after Fargo reached its peak discharge but before the 2nd half of the basin began to runoff. The 1997 flood also had a freeze that affected the peak in Fargo. The flows would have been larger if there was no freeze to slow the flows. The Fargo flood was unique (anomaly) compared to the other floods along the Red River in 1997. They did not compare the volume-frequency of the 1997 flood for the various stations along the Red River. On April 5, basin temperatures dipped well below freezing, thereby completely arresting the runoff process. The only water that was flowing was the flow already in the major river channels. This occurred on the rising limb of the Fargo hydrograph. Thus, Fargo's peak was delayed. The hydrograph responded by attenuation until April 11 when basin temperatures again rose above freezing. Runoff commenced and flows then began to increase at Fargo as shown on the hydrograph, thereby continuing the rising limb of the hydrograph until it reached its peak discharge on April 17. (This flood characteristic is more pronounced at Wahpeton. See figure below). One can make a rough estimate of what the peak could have been without the effect of the temperatures by estimating a recession for the first portion of the hydrograph, separating it from the total to estimate the second portion of the hydrograph, and then shift the second portion back in time to commence runoff on April 5. Adding the two hydrographs will estimate the total runoff hydrograph that could have occurred. Although Fargo experienced a major event, it did not experience a catastrophic event, as did Grand Forks. Had the below freezing temperatures not occurred when they did, Fargo could very well have experienced the same degree of flood as Grand Forks. The first portion of runoff continued downstream and then coincided with the local runoff that began after April 11 thereby exacerbating flood conditions downstream. When Fargo neared its peak discharge (April 17), Halstad (April 19) and Grand Forks (April 18) were nearing their peak discharges, which complicated runoff predictions for the NWS because the whole basin appeared to be peaking at the same time. Typically, Fargo peaks and then is routed downstream to cause a peak at Grand Forks. Typically, Grand Forks does not peak until days later.

The accuracy of the flow measurements was discussed. The Corps has asked the USGS several times about the accuracy of the 1997 measurements, and they are very confident about the peak flows reported at the gages. They will provide back-up data if it is requested. The Corps found it difficult to calibrate the HEC-RAS model to high water marks using 28,000 cfs (the discharge measured at the gage) as the peak discharge throughout the city. Local inflow totalling 1,500 cfs was added downstream of the gage in order to get good calibration results. The total river flow of 29,500 cfs used at the downstream end of town compares well to the 30,000 cfs used by Ulteig Engineering in its study of Oakport. The USGS agrees with this idea of added local inflows downstream of the gage.

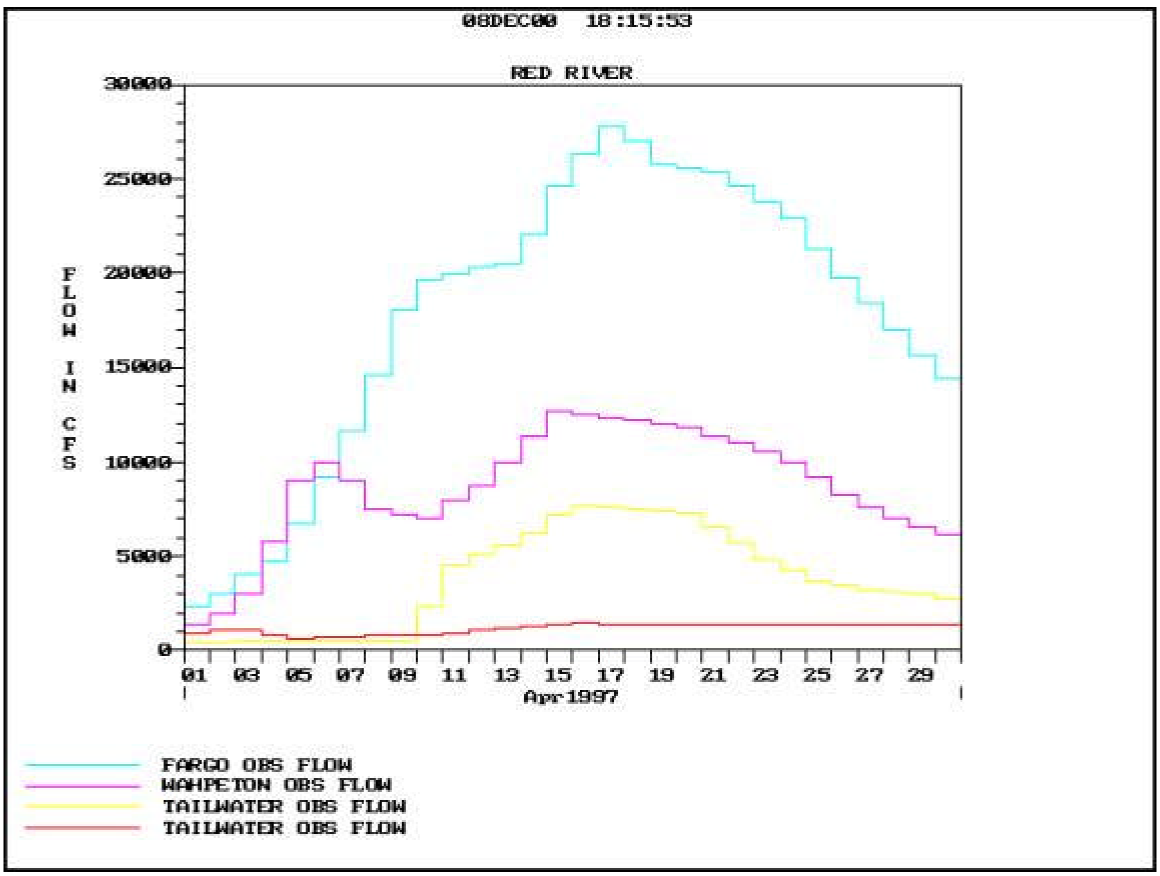
Overland flows from the Sheyenne and other tributaries were not taken into consideration directly.

Input in the following section was from a variety of attendees regarding the 1997 flood:
The hydrologic and hydraulic analyses need to match. A peak flow of 30,000 cfs matches the hydraulics better, it should maybe be used in the hydrologic analysis too. It would also be easier to sell to constituents in Fargo/Moorhead. The Corps did some of these runs using the no adjustment data set: The peak 100-year flood would be about 34,300 cfs.

Although the blizzard did reduce the peak flow, the FFA does not know that there was a blizzard in 1997. You can't make a physical interpretation of a statistical data point. The Corps notes that this is why the detailed analyses of the dam/reservoir impacts were so important, and it doesn't seem to follow the trend of the rest of the data because of the temperature effects as discussed above.

The linear regression line only has data points up to the 1997 flood. The line is extrapolated in the critical area where the reservoir would affect the flows. Isn't curvilinear regression better?

There is a very small drainage area between Wahpeton and Fargo, primarily the Wild Rice River. The frequency of the 1997 Wild Rice River flows at Abercrombie was about the 50-year flood (9,470 cfs). The 100-year frequency flood at Abercrombie is about 12,990 cfs. The peak in Abercrombie was on 4/16, and the peak in Fargo was on 4/17. There was breakout flow in 1997 on the Wild Rice. Breakout flows occurred from the Red River to the Wild Rice River, from the Wild Rice to the Red (sometimes at the same locations, on different days) and from the Sheyenne River to the Wild Rice. It was a very dynamic situation that would be extremely difficult to model. The increase in flows between the Hickson gage and the Fargo gage was about 16,000 cfs – this is primarily the inflow from the Wild Rice. The Wahpeton peak was very flat, with multiple peaks: The flow was greater than the 100-year for a long time.



ATTENDANCE ROSTER

SUBJECT: **Red River of the North @ Fargo/Moorhead, Hydrology Update -**

Review Comment Meeting

Date: **16 Nov 2000**

	NAME	REPRESENTING	TELEPHONE NO.
1	William Spychalla	Barr Engineering	(952) 832-2666
2	Nancy Johnson Dent	Barr Engineering	(952) 832-2806
3	Suzanne Jiwani	Barr Engineering	(952) 832-2706
4	Tim Fay	ND State Water Commission	(701) 328-4956
5	Gregg Thielman	Houston Engineering	(701) 237-5065
6	Lawrence Woodbury	Houston Engineering	(701) 237-5065
7	Terry Zien	Corps of Engineers	(651) 290-5714
8	Robert Engelstad	Corps of Engineers	(651) 290-5610
9	Pat Foley	Corps of Engineers	(651) 290-5630
10	Terry Engel	Corps of Engineers	(651) 290-5287
11	Aaron Buesing	Corps of Engineers	(651) 290-5627
12	Bob Martin	City of Moorhead	(218) 299-5393
13	Mark Bittner	City of Fargo	(701) 241-1572
14	Bob Zimmerman	City of Moorhead	
15	Bob Merritt	Minnesota DNR	(218) 847-1580
16	Jeff Volk	Moore Engineering	(701) 282-4692
17	Bruce Langness	Ulteig Engineering	(701) 237-3211
18	Chuck Spitzack	Corps of Engineers	(651) 290-5307
19	Chuck Crist	Corps of Engineers	(651) 290-5298
20	Mike Knoff	Corps of Engineers	(651) 290-5600
21.	Daniel Reinartz	Corps of Engineers	(651) 290-5613

Memorandum for Record 21March01

from: David Goldman, Hydrologic Engineering Center, U.S. Army Corps of Engineers

to: Terry Zien, St. Paul District, U.S. Army Corps of Engineers

Purpose: Recommendations with regard to estimating regulated frequency curves.

1. Introduction

The accepted and most appropriate method for estimating regulated frequency curves of maximum annual peak flows is to transform an estimated unregulated frequency curve to a regulated frequency curve using an unregulated versus regulated relationship for the dam. Corps guidance (Hydrologic Frequency Analysis, EM 1110-2-1415, 1993, pg. 3-26) suggesta also employing a graphical analysis tied to plotting positions for estimating regulated frequency curves. However, the graphical curve should only be used to check the regulated curve obtained from transforming the unregulated curve for analysis errors. The graphical frequency curve should not be used as a final estimate of the regulated curve, particularly for infrequent quantiles (flows) where plotting positions are known to suffer from extreme sampling error and are very inaccurate.

Note that most recent Corps studies obtain the regulated frequency curve by transforming an unregulated curve using the unregulated versus regulated relationship for the dam. Most recently, the Corps recent major effort to estimate regulated frequency curves on the Upper Mississippi (i.e., the Missouri River, Illinois River and Mississippi River above St. Louis) used this methodology. This methodology was considered to be superior to a graphical analysis in a review by technical and interagency advisory groups comprised of experts from universities, private practice and within the federal government.

The purpose of this memorandum is to briefly describe the basis for using the unregulated versus regulated relationship approach and its advantages over a graphical approach to obtain the regulated frequency curve of maximum annual peak flows. In section 2, the general superiority of employing probability distributions to obtain unregulated frequency curve estimates over graphical approaches tied to plotting positions is described. As part of this description, the appropriate plotting position to use for comparison with the estimated probability distribution is discussed. The advantage of using probability distribution estimates of the unregulated frequency curve also results in better estimates of the regulated frequency curves than can be obtained with regulated curves as is described in section 3.

2. Estimating unregulated frequency curves

Estimating a probability distribution from the annual series of maximum flow has long been recognized as a statistically more accurate method for estimating flow-frequency curves than using plotting positions. The sampling error, or uncertainty in the estimate, of a flood quantile (e.g., the 100-year flow) due to the limitations of record length, is much greater for the plotting position than obtained with distribution estimates. The problem, of course, is in determining an adequate distribution for estimating the flood frequency curve. The Water Resources Council (see Interagency Advisory Committee on Water Data (IACWD) 1982, Guidelines for determining flood flow frequency, Bulletin 17B, U.S. Department of the Interior, Geological Survey, Office of Water Data Collection, Reston, VA) investigated this problem and found that the log-Pearson III distribution estimated using the method of moments, together with the use of regional skew, provide reasonable estimates of flood quantiles when tested at over 300 gage sites. Consequently, the council recommended that this distribution be used by federal agencies in estimating flood frequency curve unless it could be shown that some other distribution provides better estimates in a regional study of annual flood data.

Estimating a flood frequency curve using a distribution has other advantages over plotting positions. Probability distribution can incorporate regional information (e.g. regional skew), there analytic computation can be consistently applied, and can be extrapolated for regulatory purposes (e.g., estimate the 1/500 year annual exceedance flood).

Uncertainty, of course, still exists with regard to the estimate of the frequency curve. Confidence limits provide a measure of the likely difference between the estimated distribution and the true or "population" estimate. Within the confidence limits different estimates of the flood distribution might be used compute the frequency curve. FEMA uses a median curve estimate, referred to as the computed curve, for regulatory purposes where there is a 50% chance the population value will exceed the curve. The Corps of Engineers uses an expected probability estimate of the frequency curve which corresponds to the population number of exceedances or floods that can be expected to occur over a very large number of projects. This expected probability estimate is considered to provide the appropriate estimate of future flood risk for evaluating the economics of Corps flood damage reduction projects.

As in the case of the flood distribution, different estimates of plotting positions can be used for comparison of the frequency curve. The median plotting position, as the name suggests, corresponds to a 50% chance that the population exceedance is greater than the plotting position estimate for a particular ranked flood. The Weibull plotting position provides the expected or average exceedance for a particular ranked flood (see Handbook of Hydrology, editor David Maidment, pg. 18.24, McGraw Hill, 1992). Note that the median and Weibull plotting position formulas provide these estimate independent of distributional assumptions; and consequently, are applicable independent of the underlying distribution. Consequently, when comparing plotting positions to flood frequency distributions, the median plotting position should be used with the FEMA computed log-Pearson III, and the Weibull plotting position should be compared to the Corps, expected probability estimate.

3. Regulated frequency curves

Regulated frequency curves are estimated by transforming the unregulated flow frequency probability distribution rather than directly employing a graphical analysis of the regulated flow plotting positions to take advantage of the increased statistical accuracy obtained from using the distribution as described in the previous section. Estimating the regulated frequency curve based on a graphical analysis suffers from the significant statistical sampling error associated with plotting positions. Furthermore, transforming the unregulated frequency curve gains the same advantages over graphical frequency analysis as in the unregulated case: 1) the estimates will benefit from regional information on flood frequency, 2) the method can be more consistently applied, and 3) the frequency curve can be extrapolated for regulatory purposes (e.g., estimate the 1/500 regulated flow). Consequently, transforming an unregulated frequency curve using an unregulated versus regulated relationship has significant advantages over that of graphical analysis from a statistical accuracy point of view.

When comparing plotting positions and regulated flood frequency distributions, the same principles should be followed as in the unregulated case. If the computed unregulated frequency curve is used to compute the regulated frequency curve, the plotting position should be should be computed with Median plotting position formula. Correspondingly, the Weibull formula should be used when the unregulated expected probability curve is employed.

Memo for Record

From: Terry J. Engel

Subject: Update of Red River of the North Hydrologic Data, Agency Coordination Meetings – March 21/22, 2001

Date: March 22, 2001

1. Subject coordination meetings were convened by Mr. Ogbazghi Sium, chair of the State of Minnesota Hydrologic Review Committee. The meetings were arranged to discuss Corps-developed Red River hydrology data, address local hydrology review comments, discuss Red River hydraulic aspects of the work, and discuss application of state/FEMA floodway criteria to the update. The meeting was not a closed meeting. However, only agencies and firms working under contract to the agencies were invited to attend.

2. Meeting attendees:

Ms. Sally Magee	FEMA	Mr. Ogbazghi Sium	MN DNR
Mr. Ken Hinterlong	FEMA	Mr. Jim Solstad	MN DNR
Dr. John Liou	FEMA	Mr. Bob Merritt	MN DNR
Mr. Mike DePue	PBS&J	Mr. Tom Lutgen	MN DNR (2)
Mr. Greg Thielman	Houston Eng.	Mr. Tim Fay	ND SWC
Mr. Gregg Wiche	ND USGS (1)	Mr. Bob Engelstad	COE
Mr. Skip Vecchia	ND USGS (1)	Mr. Pat Foley	COE
Mr. Terry Zien	COE	Mr. Terry Engel	COE
Mr. Aaron Buesing	COE		

(1) Attended the March 21 session only
(2) Attended the March 22 session only

3. The meetings commenced the afternoon of March 21. A brief history of the hydrologic update was presented by Mr. Engel. Technical presentations by the Corps and ND USGS followed:

a. **Corps:** Mr. Terry Zien discussed the general development of the Corps hydrology and response to local review comments. Topics discussed:

- Bulletin 17B methodology;
- Flow data used;
- Assumptions;
- Derivation of historic peak flow values for the 1826, 1852 and 1861 floods at Grand Forks and coordination with the ND USGS;
- Presentation of the development of the discharge-frequency curves at the six main stem gaging stations with greater detail on the Grand Forks curve and the Fargo graphical curve with reservoir analysis;
- Discussion of public comments received from Fargo, Moorhead, Grand Forks and East Grand Forks developed by Barr Engineering.

A panel discussion of Grand Forks hydrology with regard to historic events and the proper flow to use for the 1997 flood followed Mr. Zien's presentation. The ND USGS recommended that the Corps use 114,000 cfs for the 1997 annual peak flow (Open File Report 00-344, October 2000) instead of the 137,000 cfs value considered valid at the time of the Corps draft report (May 2000).

Attendees agreed that the Corps should develop a revised curve for Grand Forks based on the following parameters:

- All agencies agreed to use 114,000 cfs for the 1997 flood;
- The historic floods for 1826 and 1852 would be used (the values would be an average of the Corps derived values and the USGS derived values), but not 1861;
- New curves would be developed for the other main stem gages influenced by the Grand Forks curve;
- A new curve for Emerson would also be developed with the same assumptions.

The panel discussion continued with the Fargo/Moorhead discharge-frequency curve.

b. **ND USGS:** Mr. Skip Vecchia presented a statistical analysis from Mr. Ken Wahl (USGS regional office in Denver) of the 20 largest annual flood peaks for the Fargo USGS gage (Mr. Wahl participated by speaker phone). Further panel discussion of the Fargo curve focused on uncertainties in the Corps analysis. The effective FIS discharge-frequency curve was within the approximated 90% confidence interval of the new graphical curve.

The meeting adjourned at 5:15 p.m. It was agreed to continue/complete the hydrology discussion the next morning.

4. The morning of March 22 hydrology discussions continued. Terry Zien presented a summary of the discussion from the previous afternoon, emphasizing the complex hydrologic situation at Fargo. He noted that the graphical discharge-frequency curve developed for Fargo represented the use of applied hydrology as well as statistical analyses, incorporating observations of real flow events and basin storage conditions. The Corps' opinion remained that this curve more accurately represented the flood risk to Fargo than the effective FIS curve.

5. At the end of the Fargo/Moorhead hydrology discussion meeting attendees were "polled" - what should be used as the regulatory discharge at Fargo/Moorhead? FEMA and the ND State Water Commission indicated that even though they felt that the Corps' analysis was very sound there were a number of points of hydrologic uncertainty. Therefore they opted to keep the effective 29,300 cfs Fargo/Moorhead Red River regulatory discharge. (Since the ND USGS was not in attendance the second day of the meetings I called them March 28. The ND USGS supported keeping the effective 29,300 cfs discharge for flood plain management purposes). The state of Minnesota supported the Corps' number but deferred to FEMA. The Corps supported using its 31,600 cfs discharge.

Majority rules - when the Fargo/Moorhead flood insurance studies are updated a regulatory discharge of 29,300 cfs will be used.

The Corps has no flood plain management authority for areas other than lands it owns. The Red River basin flood plain management regulatory authority resides in the hands of local interests, the state, and FEMA. We will support the 29,300 cfs discharge for FEMA and state floodplain management activity.

6. The hydraulic portion of the meetings was initiated immediately after the hydrology discussions. Mr. Aaron Buesing presented draft hydraulic data. Among the items presented were:

a. **Study Limits**:

- Study limits extend from the Canadian border upstream to the downstream end of Grand Forks where the study ties into the effort being conducted for the cities of Grand Forks and East Grand Forks;
- The study continues from west of Eldred, MN, upstream through Fargo, ND, where it ties into the effort being conducted by Houston Engineering;
- The study continues from the upstream end of the Houston Engineering study at the Cass County (ND) / Richland County (ND) line upstream to the downstream end of the Wahpeton/Breckenridge Flood Insurance Study.

b. **Calibration:**

- All events were calibrated using one set of Manning's n values;
- In the past Manning's n values were lower for larger flood events, but this is avoided by properly defining the effective flow limits;
- The 1969, 1978, 1979, 1989, and 1997 floods were used for calibration;
- The results of the calibration were shown on profile charts for the study limits, except upstream of Fargo, which still needs to be completed.

c. **Cross section geometry:**

- Old HEC-2 cross-section data was compared to new survey information obtained by Houston Engineering for their effort;
- The data comparison indicates cross-section geometry upstream of Fargo has not changed much in 25 years;
- There is no evidence that old cross-section data should not be used for this study.

d. **Comparison to effective FIS profiles:**

- Profile charts were provided that show how the new 10-, 50-, 100-, and 500-yr profiles compare to the effective profiles, except upstream of Fargo, which still needs to be completed;

- In some areas the proposed and effective profiles are about the same, but in other areas they are quite different;
- The new 100-yr profile is within one foot of the 1997 profile (based on high water mark data) for the entire study.

e. **Floodways:**

- The effective floodways have been modeled, but no additional floodway work will be done under this study (not in the scope of work);
- Contrary to the published effective FIS, the effective floodways in the rural areas cause greater than a 0.75 ft increase in the base flood elevation (the effective flow limits were not modeled correctly in the effective FIS);
- The effective floodway downstream of Fargo is of particular concern – it causes stage increases of over 2 feet.

7. FEMA has directed us (as the study contractor FEMA "hired" to perform the work) to schedule mid-June 2001 local coordination meetings to discuss the hydrology, responses to the review comments, final discharges, and aspects of the hydraulic work.

8. Our schedule provides for us to complete all our work by the end of September 2001. We will then provide the draft data to FEMA for review and further work (development of floodway alignments, plotting of flooded outlines, etc.).

9. Shortly we will provide a letter to basin interests discussing the outcome of our coordination meeting. I'll copy the letter to meeting attendees.

10. If you need additional information, have comments pertaining to this memo for record, etc., please give me a call or email me.

Terry J. Engel
Project Manager

CEMVP-ED-H (1110-2-1403) 10 May 2001
Zien/trz/5714

MEMORANDUM FOR RECORD

SUBJECT: Response to interagency meeting comments from 21 and 22 March 2001 on the final Draft Interim Report, Hydrologic Analyses for Flood Insurance Studies, The Red River of the North Main Stem, From Wahpeton/Breckenridge to Emerson, Manitoba, with regard to the discharge-frequency curve for Grand Forks, ND.

1. The comments suggested by the interagency review group were incorporated into the derivation of the discharge-frequency curve for Grand Forks, North Dakota. Specifically, those comments were:

A. Use a peak flow value for the 1997 flood of 114,000 cfs instead of 137,000, as recommended by the North Dakota office of the USGS. The value of 137,000 cfs is not to be used in discharge-frequency analyses.

B. Eliminate the 1861 flood event from the analysis.

C. Retain the 1826 and 1852 flood events and use them as historic events. The values of these events were averaged between the USGS estimated values and the newer Corps values estimated in the referenced report, as recommended by the review committee. Both estimation efforts used 114,000 cfs for the 1997 flood. The resulting flows were 144,000 cfs for the 1826 flood and 97,000 cfs for the 1852 flood. Manitoba Water Resources has estimated the 1826 flood peak at Grand Forks to be 145,000 cfs.

D. The same assumptions will be applied to the discharge-frequency curve for Emerson, Manitoba when we receive the estimated historic events from the USGS.

2. Another modification that was incorporated into the analysis was to add data for the years 1998 through 2001. This was considered prudent to keep the discharge-frequency curve as current as possible. These years will also be added to the other discharge-frequency curves in the main stem study.

SUBJECT: Response to interagency meeting comments from 21 and 22 March 2001 on the final Draft Interim Report, Hydrologic Analyses for Flood Insurance Studies, The Red River of the North Main Stem, From Wahpeton/Breckenridge to Emerson, Manitoba, with regard to the discharge-frequency curve for Grand Forks, ND.

3. The resulting discharge-frequency curve for Grand Forks was as follows (computed probability without expected probability adjustment, median plotting positions):

Q10 = 47,700 cfs
Q50 = 87,600 cfs
Q100 = 108,000 cfs
Q500 = 161,000 cfs

Mean Log = 4.1889
Standard deviation = 0.3903
Adopted (Station) Skew = -0.2247

4. The discharge-frequency curve for Grand Forks presented in the final Draft Interim Report is not considered to be incorrect by the Corps of Engineers. However, it is recommended to adopt the curve presented in Paragraph 3 above, in accordance with the interagency review group comments.

5. A final Interim Hydrology Report will be provided after all of the discharge-frequency curves are updated as appropriate.

Respectfully submitted,

Terry R. Zien, P.E.
Hydraulic Engineer

U.S. Army Corps of Engineers
St. Paul District

APPENDIX K

CORRESPONDENCE

January 29, 2001

Terry Engel
St. Paul District
US Army Corps of Engineers
190 5th St. East
St. Paul, MN 55101

Re: May 2000 Hydrologic Analysis for
Flood Insurance Studies
Grand Forks/East Grand Forks

Dear Terry,

The City of East Grand Forks requested Floan-Sanders, Inc. to review the above referenced report and provide comments to FEMA and the Corps. In an August 18, 2000 letter (see attached first page of letter) to John Liou, FEMA, Region 8 and Terry Reuss Fell, FEMA, Region 5, we requested additional information and analysis on the inclusion of three historic floods (1826, 1852 and 1861) which were only documented at Winnipeg. Our concern is the data from these three floods is very inaccurate compared to our 1882-2000 gage records. During the fall I met with the City of Grand Forks Engineering staff a number of times to further discuss the hydrologic analysis. The City of Grand Forks retained Barr Engineering to prepare a report to evaluate the hydrologic analysis to see if it is technically sound and reasonable. Al Grasser, Acting City Engineer for Grand Forks provided us with a copy of the preliminary Barr report which was also provided to the Corps. Based on our past review of the hydrologic analysis and the preliminary results of the Barr study, we feel a technically sound case can be made for a 100 year flood discharge in the range of 95,600 to 105,000 cfs. Accordingly we would respectfully request FEMA and the Corps to modify their analysis to include the following:

The peak flow value used for the 1997 flood at East Grand Forks should be 114,000 cfs instead of the 137,000 cfs value which was used in your analysis. The 114,000 cfs value is published in a USGS report as the peak discharge value which should be used for flood insurance purposes.

We feel the historic floods of 1826, 1852 and 1861 at East Grand Forks should not be used in the analysis. The methods used to estimate these flows at East Grand Forks are very approximate and are not of comparable accuracy to the 116 years of recorded gage data. This 116 year period of flow records at East Grand Forks is one of the longest in this region and includes several large floods since 1950, including the 1997 record flood. If there is any reason to use a historic flood, it should only be the 1826 flood as that appears to have potentially been larger than the 1997 flood.

We appreciate the opportunity to review this report and provide comments. Flood damage reduction is a top priority for East Grand Forks and we are working very hard with the Corps to reduce the flood risk to our community in the shortest time frame possible. While supporting the need for the flood insurance studies we are concerned that any revisions be based on technically sound, supportable, reasonable and accurate information. Because of our flat topography, even minor changes to the 100 year flood levels can result in significant change to the 100 year flood plain map which directly effects our businesses and residents. We believe that by incorporating the above revisions and comments into your analysis it will provide a more technically sound and supportable 100 year flood level which the City of East Grand Forks and our residents can fully support.

If there are any questions or if you need additional information, please contact our office.

Respectfully yours,
Floan-Sanders, Inc.

Dean Wieland

Dean R. Wieland, P.E.

DRW:sw

cc: Terry Reuss Fell - FEMA
John Liou - FEMA
Ogbazghi Sium - MN DNR
Al Grasser - City of Grand Forks
Gary Sanders
Dave Mack
Jerry Skyberg
Senator Paul Wellstone
Senator Mark Dayton
Congressman Collin Peterson

GRAND FORKS
City of Grand Forks
Engineering Department
255 North Fourth Street • P.O. Box 5200 • Grand Forks, ND 58206-5200
(701) 746-2640
Fax: (701) 746-2514

January 29, 2001

Terry Engel
St. Paul District
US Army Corps of Engineers
190 Fifth Street East
St. Paul, MN 55101-1638

RE: Comments on Hydrologic Analysis for Flood Insurance Studies, Red River of the North

Dear Terry:

This is in response to your request for review and comments on the report entitled "Hydrologic Analyses for Flood Insurance Studies, The Red River of the North Main Stem, From Wahpeton/Breckenridge to Emerson, Manitoba, Revised Draft Interim Report", dated May 2000. To assist us in our evaluation, the City retained Barr Engineering to review the information and provide a report on their findings. I am attaching a copy of that report which forms the basis of our comments.

Barr's evaluations show the determination of the 100 year regulatory flood discharge is sensitive to a number of assumptions, including the value of the 1997 peak flood discharge and the use of the historic floods in the analysis. The sensitivity analysis that they conducted showed that values for the 100 year flood ranging from 95,600 cfs to 105,000 cfs would be technically sound, supportable and reasonable, and that the difference in the range related primarily to the use of historic floods.

We feel the peak flow value used for the 1997 flood at Grand Forks should be 114,000 cfs instead of the 137,000 cfs value which was used the study analysis. The 114,000 cfs value is published in a USGS report as the peak discharge value which should be used for flood insurance purposes.

The historic floods of 1826, 1852 and 1861 at Grand Forks should not be used in the analysis. The methods used to estimate these flows at Grand Forks are very approximate and are not of comparable accuracy to the 116 years of recorded flow data measured at Grand Forks. This 116 year period of flow records at Grand Forks is one of the longest in this region and includes several large floods since 1950, including the 1997 record flood. If there is any reason to use a historic flood, it should only be the 1826 flood as that appears to have potentially been larger than the 1997 flood.

We appreciate the opportunity to review this report and provide comments. Flood damage reduction is a top priority for Grand Forks, and we are working very hard with the Corps to complete a flood protection project to reduce the flood risk to our community in the shortest timeframe possible. While supporting the need for the flood insurance studies we are concerned that any revisions be based on the most technically sound, supportable, reasonable and accurate information available. Because of our flat topography, even minor changes to the 100 year flood levels can result in significant change to the 100 year flood plain map which directly effects our businesses and residents. We believe that by incorporating the above revisions and comments into your analysis it will provide a more technically sound and supportable 100 year flood level which the City of Grand Forks and our residents can fully support.

To help ensure the most technically sound product with the greatest basis of consensus is obtained, I am forwarding under separate cover, a copy of the Barr Report and this letter to the ND State Water Commission and the ND USGS for their input. I would request that they be given some time to evaluate all the data and provide comments. Please let us know if you would prefer to work with them directly, or if you wish the City of Grand Forks to consolidate and forward their comments.

Thank you for the opportunity and time to carefully review the study document. If you have any questions on our review, please call me at 701-746-2645.

Sincerely,

Allen R. Grasser, P.E.
Acting City Engineer

ARG/tmw

Cc: John Liou, FEMA w/attachments
Senator Dorgan
Senator Conrad
Congressman Pomeroy
Dean Wieland, Floan-Sanders
Mayor Brown
Richard Warne
Charles Grotte

City of Fargo

ENGINEERING DEPARTMENT

200 North 3rd Street / Fargo, ND 58102 / Phone 701-241-1545 / Fax 701-241-8101 / E-mail feng@ci.fargo.nd.us

February 1, 2001

Mr. Terry J. Engel
Project Manager
US Army Corps of Engineers
190 5th Street East
St. Paul, MN 55101-1638

Re: Red River Hydrologic Analysis

Dear Mr. Engel:

The Cities of Fargo and Moorhead have retained the services of Barr Engineering to review your report on the Hydrologic Analysis of the Red River. The Barr review report will be finalized for City review on February 14. Due to the importance of this issue, the City Commission and Councils of Fargo and Moorhead, respectively, will review the report at their regular meetings on February 20, 2001. Following their review, the Barr report and City comments will be forwarded to you by February 23, 2001.

We are slightly behind the schedule previously submitted to you and ask that you extend the comment period to accommodate submittal of Fargo/Moorhead comments.

We are interested in receiving an explanation of the process that will be used to evaluate and respond to comments received concerning the hydrologic report. Due to the critical importance of decisions regarding hydrology and flood plain issues, we request the opportunity to be present at interagency meetings when these issues are discussed.

Sincerely,

Mark H. Bittner

Mark H. Bittner
City Engineer

MHB/jmg

C: Bob Martin
Bill Spychalla

United States Department of the Interior

U.S. GEOLOGICAL SURVEY
Water Resources Division
821 East Interstate Avenue
Bismarck, ND 58503

February 15, 2001

Allen R. Grasser, P.E.
Acting City Engineer
255 North Fourth Street
P.O. Box 5200
Grand Forks, ND 58206-5200

Dear Allen:

I received your January 30, 2001, letter regarding the Barr Engineering Hydrologic Review of the FIS study, and I have a few comments related to the flood frequency analyses for the Red River at Grand Forks. First, I want to thank you and your staff for inviting us to the January 18 meeting at your office to discuss the Barr Engineering Report. I believe that the frank, open dialogue we had at the meeting has helped lead to a better understanding of hydrologic issues related to flood peaks and flood frequency for the Red River at Grand Forks.

Our office reviewed the Corps of Engineers Draft Interim Report dated May 2000, and, although we may have done some parts of the analyses differently, we are in general agreement with the flood discharges determined in that draft. Because of the excellent systematic and historical discharge information at Grand Forks, the Grand Forks gage was used as the anchor for much of the entire main stem. Therefore, because any change in the 100-year flood discharge at Grand Forks from 110,000 cfs will have an effect on the entire basin analysis, we believe that lowering the discharge at Grand Forks should be done only if compelling reasons exist for such a change. We also believe that all historical information, including the 1826, 1852, and 1861 floods should be used in the analysis. Although 116 years of recorded flow at Grand Forks is a long record, we feel that hydrologic conditions in the basin that exist today are more comparable to those that existed during the 1800's then those that existed during much of the dry period of the early 1900's.

You indicate that based on discussions at our meeting Bill Spycalla would do some additional sensitivity analyses based on a USGS and SWC suggestion of a 151,000 cfs historic 1826 flood peak. Apparently, the 151,000 cfs flood peak for 1826 was an early estimate by Terry Zien. Since our meeting Terry mentioned to me that the 151,000 cfs estimate was not based on the final regression equation. However, a complete sensitivity analysis should be based on all comprehensive flood peak estimates for 1826. The estimates that should be considered are: 135,000 cfs-Corps of Engineers study; 145,000 cfs-Alf Warkentin, Senior Hydrologic Forecaster, Province of Manitoba, hydrologic and hydraulic modeling of 1826 flood on the Red River; and 164,000 cfs-statistical analysis by Skip Vecchia of our office.

We believe the unusual hydraulic conditions associated with the April 18, 1997 discharge of 137,000 cfs should be used as a basis for excluding if from the flood-peak series and instead using 114,000 cfs that more closely represents hydraulic conditions associated with past flood peaks. However, the Corps may have policy or other hydrologic reasons why they chose 137,000 cfs. We believe the floods of 1826, 1852, and 1861 should be used in the analyses. The fact that the values are estimates should not be a reason for excluding them from the analyses.

It is my understanding the Corps is reviewing your comments on the report "Hydrologic Analyses for Flood Insurance Studies, The Red River of the North Main Stem, From Wahpeton/ Breckenridge to Emerson, Manitoba, Revised Interim Report." My staff and I believe that we should allow the Corps to review your comments and make any additional sensitivity runs they deem necessary before supporting any change in the one-percent flood frequency value.

I am sure we all will have a chance in the near future to meet and discuss the Corps' response to your review comments. If you have any questions please call me at (701) 250-7401.

Sincerely,

Gregg J. Wiche

Gregg J. Wiche

cc: Terry Engel, U.S. Army Corps of Engineers
Tim Fay, North Dakota State Water Commission

Colonel Kenneth Kasprisin
District Commander
St. Paul District
U.S. Army Corps of Engineers
190 Fifth Street East
St. Paul, Minnesota 55101-1638

February 20, 2001

RE: Comments on Hydrologic Analysis for Flood Insurance Studies, Red River of the North, Fargo/Moorhead

Dear Colonel Kasprisin:

This is in response to your request for review and comments on the report entitled "Hydrologic Analyses for Flood Insurance Studies, The Red River of the North Main Stem, From Wahpeton/Breckenridge to Emerson, Manitoba, Revised Draft Interim Report", dated May 2000.

We appreciate the opportunity to review this report and provide comments. As you and your staff are very aware, floods are a major concern for Fargo and Moorhead. We are still recovering from and addressing problems related to the 1997 flood on the Red River and also from the rainstorm induced flooding of this past summer. While we understand the need for the reanalysis of the flood insurance studies along the entire main stem of the Red River of the North, we are very concerned that any revisions to the Flood Insurance studies and maps at Fargo/Moorhead be based on technically sound and reliable information and conclusions. Even minor changes in regulatory flood levels can have very significant effects to Fargo, Moorhead and the surrounding area, affecting not only the operations of the cities but also directly impacting our residents and our businesses. We believe that any proposed changes should be fully justified.

The proposed changes to the regulatory flood discharges presented in your Revised Draft Interim Report are of great concern to us. Because of this concern, we have formed a joint floodplain task force and a joint technical review committee to address these floodplain issues, and we have contracted with Barr Engineering to review the Revised Draft Interim Report analysis at Fargo/Moorhead on our behalf for technical soundness and reasonableness. Barr has provided us with their evaluation which indicates that in several areas of the analysis alternate approaches would be acceptable or even preferable, and that use of the alternate approaches could result in estimates of the 100-year flood flows lower than those presented in the Revised Draft Interim Report. Their report indicates that a 100-year flood flow estimate in the range of 29,000 cfs to 30,000 cfs appears to be reasonable. Attached is a copy of Barr Engineering's report.

Barr's evaluations show that the determination of the 100 year regulatory flood discharge at Fargo/Moorhead is sensitive to a number of assumptions. These assumptions include the method used to estimate the effects of the upstream flood control dams on flood flows at Fargo/Moorhead, the method used to estimate the effects of these dams on the discharge-frequency curve, and the manner in which the 1997 flood and also the historic floods are used in the analysis. For example, Barr's report indicates that all large floods recorded since gaging records were started at Fargo/Moorhead occurred since Lake Traverse has been in operation and that the effect of Lake Traverse on these floods is best reflected in the actual observed data. Use of a graphical analysis method that relies on the plotting positions for the these larger flood events provides a more reasonable and reliable approach to estimating the 100-year flood value. This approach would result in a 100-year flood flow of about 29,500 cfs, which is essentially the same as the currently adopted value of 29,300 cfs.

Barr's report also identifies that FEMA guidance regarding reanalysis of hydrology for flood insurance studies would indicate that the differences between the reanalysis results and the currently adopted values do not provide sufficient justification for revising the 100-year flood flows.

We believe that your analysis and conclusions should be modified to incorporate the observations and conclusions presented in the Barr report, especially the following comments:

1) The discharge-frequency curve for the existing "with dams" condition should be based on a graphical analysis that relies primarily on the observed data and the plotting positions for the larger floods.

2) The results of the revised flood frequency analysis show that the previously adopted regulatory flood flows fall within the FEMA guidelines for confidence limits of the revised analysis values, and that there is not justification to modify the regulatory flood discharge values. The previously established 100-year flood discharge of 29,300 cfs should remain valid.

We believe that a revision in your analysis to incorporate our comments will provide a more reliable and supportable regulatory flood level. This determination is extremely important to our community and we need to assure that we adopt our regulations based on technically sound and reasonable information.

We appreciate the fine work that you and your staff continue to do on behalf of our community, and especially appreciate the cooperation of your staff in explaining the methodology that they used in the analysis and in responding to questions from Barr Engineering and our review committee members. We look forward to continued cooperation as you work toward completion of your hydrologic analysis for the Red River of the North. Because of the great importance of this analysis to our communities, we request that we be able to participate in future meetings that you have with the state and Federal agencies regarding the reanalysis of hydrology and hydraulic relationships of the Red River of the North at Fargo/Moorhead, especially as related to the addressing of our comments and concerns. If you have any questions regarding our comments or concerns, please contact Mr. Mark Bittner, Fargo City Engineer at 701-241-1572 or Mr. Bob Martin, Moorhead Director of Public Works at 218-299-5393.

Sincerely,

Bruce Furness
Mayor, City of Fargo

Morris Lanning
Mayor, City of Moorhead

Enclosure

DEPARTMENT OF THE ARMY
ST. PAUL DISTRICT, CORPS OF ENGINEERS
ARMY CORPS OF ENGINEERS CENTRE
190 FIFTH STREET EAST
ST. PAUL, MN 55101-1638

FEB 28 2001

REPLY TO
ATTENTION OF

Project Management and Development Branch
Planning, Programs and Project Management Division

Honorable Bruce Furness
Mayor of Fargo
200 North Third
P.O. Box 2083
Fargo, North Dakota 58107-2083

Honorable Morris Lanning
Mayor of Moorhead
500 Center Avenue
P.O. Box 7779
Moorhead, Minnesota 56561-0779

Dear Mayor Furness and Mayor Lanning:

We have received your review comments pertaining to the "Hydrologic Analyses for Flood Insurance Studies, The Red River of the North Main Stem, From Wahpeton/Breckenridge to Emerson, Manitoba, Revised Draft Interim Report" prepared by my Engineering Division hydrologic engineers. I have provided your review comments to my Engineering Division staff. We will address each of your review comments in detail.

The State of Minnesota has arranged an agency-only meeting for March 21-22, 2001, to discuss hydrology review comments received from you and the cities of Grand Forks and East Grand Forks. Regions V and VIII of the Federal Emergency Management Agency, the North Dakota State Water Commission, and the North Dakota U.S. Geological Survey have been invited to attend the meeting.

During the meeting we will discuss the review comments, the Federal Emergency Management Agency's guidelines pertaining to the development of hydrologic data, and the States' floodplain management program criteria. We will also discuss the impacts of the higher regulatory discharges on the Red River Valley communities. At the conclusion of the meeting, we will have developed an agency-coordinated response to the review comments.

We will then schedule meetings with you and other Red River Valley communities to discuss the agency-coordinated responses to the review comments received from you and others.

Sincerely,

Kenneth S. Kasprisin
Colonel, Corps of Engineers
District Engineer

Copy of letter to:

Mr. Mike Eggl
Office of Senator Byron Dorgan
P.O. Box 2579
Bismarck, North Dakota 58502-2579

Mr. Ogbazghi Sium
Minnesota Department of Natural
Resources Waters
500 Lafayette Road
St. Paul, Minnesota 55155

Mr. Kenneth Hinterlong
Federal Emergency Management Agency
Region V - Mitigation Division
536 South Clark Street, 6th Floor
Chicago, Illinois 60605

Dr. John Liou
Federal Emergency Management Agency
Region VIII
Denver Federal Center, Building 710
P.O. Box 25267
Denver, Colorado 80225-0267

Mr. Jeff Klein
North Dakota State Water Commission
900 East Boulevard
Bismarck, North Dakota 58505-0850

DEPARTMENT OF THE ARMY
ST. PAUL DISTRICT, CORPS OF ENGINEERS
ARMY CORPS OF ENGINEERS CENTRE
190 FIFTH STREET EAST
ST. PAUL, MN 55101-1638

March 28, 2001

REPLY TO
ATTENTION OF

Project Management and Development Branch
Planning, Programs and Project Management Division

Mr. Allen R. Grasser, P.E.
City Engineer
City of Grand Forks
255 North Fourth Street
Grand Forks, North Dakota 55101-1638

Dear Mr. Grasser:

Your letter dated January 29, 2001, provided us the City of Grand Forks' technical review comments pertaining to our "Hydrologic Analyses for Flood Insurance Studies, The Red River of the North Main Stem, From Wahpeton/Breckenridge to Emerson, Manitoba, Revised Draft Interim Report."

Members of our staff and an interagency technical committee met on March 21-22, 2001. Your hydrology review comments as well as other local hydrology review comments were discussed in detail. Attending the meeting were the following individuals/agencies:

Ms. Sally Magee	FEMA Washington
Mr. Ken Hinterlong	FEMA Region V
Dr. John Liou	FEMA Region VIII
Mr. Mike DePue	PBS&J
Mr. Greg Thielman	Houston Engineering
Mr. Gregg Wiche	ND USGS
Mr. Skip Vecchia	ND USGS
Mr. Terry Zien	Corps
Mr. Aaron Buesing	Corps
Mr. Ogbazghi Sium	MN DNR
Mr. Jim Solstad	MN DNR
Mr. Bob Merritt	MN DNR
Mr. Tom Lutgen	MN DNR
Mr. Tim Fay	ND SWC
Mr. Bob Engelstad	Corps
Mr. Pat Foley	Corps
Mr. Terry Engel	Corps

FEMA – Federal Emergency Management Agency
ND SWC – North Dakota State Water Commission
MN DNR – Minnesota Department of Natural Resources
Corps – Corps of Engineers
ND USGS – North Dakota U.S. Geological Survey

(Note: Messrs. Thielman and DePue are FEMA study contractors. They are working/will work on the Red River hydrologic update.)

Meeting attendees concurred with the use of 114,000 cubic feet per second as the peak flow discharge for the 1997 Red River flood.

We discussed the historic flood data we used to develop our hydrology. We had developed one set of historic data. The ND USGS had developed another set of data. The consensus of the meeting attendees was that the two sets of data, both defendable, should be averaged and used to revise our draft hydrology.

Early in April 2001, we will initiate revision of our draft hydrology to reflect the discussions/agreements reached at the meeting. We should be able to provide you our revised discharge data (draft) early in May 2001.

The Federal Emergency Management Agency directed us to schedule a local coordination meeting in Grand Forks/East Grand Forks in mid-June 2001. During the coordination meeting, our hydrologic engineers will address our/technical committee response to your review comments in detail. We will also address the calibration of the Red River hydraulic simulation computer model HECRAS.

Our Red River main stem Flood Insurance Study work is scheduled for completion by the end of September 2001. Upon completion of the work, we will submit our draft data to the Federal Emergency Management Agency for review and processing.

If you have any questions concerning the Flood Insurance Study update hydrologic issues, please feel free to contact me at (651) 290-5287.

Sincerely,

Terry J. Engel
Project Manager

Copy of letter to:

Mr. Kirk Johnson
Deputy Legislative Director
Office of Senator Kent Conrad
Washington, D.C. 20510

Mr. Mike Eggl
Office of Senator Byron Dorgan
P.O. Box 2579
Bismarck, North Dakota 58502-2579

Ms. Joan Carlson
Office of Representative Earl Pomeroy
266 Federal Building
657 Second Avenue North
Fargo, North Dakota 58102

Mr. Ogbazghi Sium
Minnesota Department of Natural
Resources Waters
500 Lafayette Road
St. Paul, Minnesota 55155

Mr. Kenneth Hinterlong
Federal Emergency Management Agency
Region V – Mitigation Division
536 South Clark Street, 6th Floor
Chicago, Illinois 60605

Dr. John Liou
Federal Emergency Management Agency
Region VIII
Denver Federal Center, Building 710
P.O. Box 25267
Denver, Colorado 80225-0267

Mr. Jeff Klein
North Dakota State Water Commission
900 East Boulevard
Bismarck, North Dakota 58505-0850

Mr. Tim Fay
North Dakota State Water Commission
900 East Boulevard
Bismarck, North Dakota 58505-0850

Mr. Bill Spychalla
Barr Engineering Company
4700 West 77th Street
Edina, Minnesota 55435

DEPARTMENT OF THE ARMY
ST. PAUL DISTRICT, CORPS OF ENGINEERS
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ST. PAUL, MN 55101-1638

APR 10 2001

REPLY TO
ATTENTION OF

Project Management and Development Branch
Planning, Programs and Project Management Division

Ms. Sarah Neimeyer
Office of Senator Paul Wellstone
136 Hart Senate Office Building
Washington, D.C. 20510-2303

Dear Ms. Neimeyer:

For your information, we are providing a copy of our letter to the City of East Grand Forks, Minnesota, concerning technical review comments on our "Hydrologic Analyses for Flood Insurance Studies, The Red River of the North Main Stem, From Wahpeton/Breckenridge to Emerson, Manitoba, Revised Draft Interim Report." Our letter describes the activities required to complete the study process. The Red River Main Stem Flood Insurance Study work is scheduled for completion in September 2001.

Any questions concerning the study may be addressed to me at (651) 290-5300 or to the project manager, Mr. Terry Engel, at (651) 290-5287.

Sincerely,

Kenneth S. Kasprisin
Colonel, Corps of Engineers
District Engineer

Enclosure

DEPARTMENT OF THE ARMY
ST. PAUL DISTRICT, CORPS OF ENGINEERS
ARMY CORPS OF ENGINEERS CENTRE
190 FIFTH STREET EAST
ST. PAUL, MN 55101-1638

APR 10 2001

REPLY TO
ATTENTION OF

Project Management and Development Branch
Planning, Programs and Project Management Division

Mr. Dean Wieland, P.E.
Floan and Sanders, Inc.
1600 Central Avenue NE
P.O. Box 385
East Grand Forks, Minnesota 56721

Dear Mr. Wieland:

Your letter dated January 29, 2001, provided us the City of East Grand Forks' technical review comments pertaining to our "Hydrologic Analyses for Flood Insurance Studies, The Red River of the North Main Stem, From Wahpeton/Breckenridge to Emerson, Manitoba, Revised Draft Interim Report."

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FEMA – Federal Emergency Management Agency
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ND USGS – North Dakota U.S. Geological Survey

(Note: Messrs. Thielman and DePue are FEMA study contractors. They are working/will work on the Red River hydrologic update.)

Meeting attendees concurred with the use of 114,000 cubic feet per second as the peak flow discharge for the 1997 Red River flood.

We discussed the historic flood data we used to develop our hydrology. We had developed one set of historic data. The ND USGS had developed another set of data. The consensus of the meeting attendees was that the two sets of data, both defendable, should be averaged and used to revise our draft hydrology.

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Our Red River main stem Flood Insurance Study work is scheduled for completion by the end of September 2001. Upon completion of the work, we will submit our draft data to the Federal Emergency Management Agency for review and processing.

If you have any questions concerning the Flood Insurance Study update hydrologic issues, please feel free to contact me at (651) 290-5287.

Sincerely,

Terry J. Engel
Project Manager

Copy of letter to:

Ms. Sarah Neimeyer
Office of Senator Paul Wellstone
136 Hart Senate Office Building
Washington, D.C. 20510-2303

Ms. Laura Wolss
Office of Senator Mark Dayton
Federal Building, Suite 298
Fort Snelling, Minnesota 55111

Mr. Maynard Pick
Office of Representative Collin Peterson
110 South Second Street, Suite 112
Waite Park, Minnesota 56387

Mr. Ogbazghi Sium
Minnesota Department of Natural
Resources Waters
500 Lafayette Road
St. Paul, Minnesota 55155

Mr. Kenneth Hinterlong
Federal Emergency Management Agency
Region V – Mitigation Division
536 South Clark Street, 6th Floor
Chicago, Illinois 60605

Dr. John Liou
Federal Emergency Management Agency
Region VIII
Denver Federal Center, Building 710
P.O. Box 25267
Denver, Colorado 80225-0267

Mr. Jeff Klein
North Dakota State Water Commission
900 East Boulevard
Bismarck, North Dakota 58505-0850

Mr. Tim Fay
North Dakota State Water Commission
900 East Boulevard
Bismarck, North Dakota 58505-0850

Mr. Bill Spychalla
Barr Engineering Company
4700 West 77th Street
Edina, Minnesota 55435

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ST. PAUL, MN 55101-1638

APR 10 2001

REPLY TO
ATTENTION OF

Project Management and Development Branch
Planning, Programs and Project Management Division

Honorable Bruce Furness
Mayor of Fargo
200 North Third
P.O. Box 2083
Fargo, North Dakota 58107-2083

Honorable Morris Lanning
Mayor of Moorhead
500 Center Avenue
P.O. Box 7779
Moorhead, Minnesota 56561-0779

Dear Mayor Furness and Mayor Lanning:

Your joint letter dated February 20, 2001, provided us your technical review comments pertaining to our "Hydrologic Analyses for Flood Insurance Studies, The Red River of the North Main Stem, From Wahpeton/Breckenridge to Emerson, Manitoba, Revised Draft Interim Report." Our letter of February 28, 2001, acknowledged receipt of your comments and further indicated that my staff as well as an interagency technical committee would address your comments.

The members of my staff and an interagency technical committee met on March 21-22, 2001. Attending the meeting were the following individuals/agencies:

Ms. Sally Magee	FEMA Washington
Mr. Ken Hinterlong	FEMA Region V
Dr. John Liou	FEMA Region VIII
Mr. Mike DePue	PBS&J
Mr. Greg Thielman	Houston Engineering
Mr. Gregg Wiche	ND USGS
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FEMA – Federal Emergency Management Agency
ND SWC – North Dakota State Water Commission
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ND USGS – North Dakota U.S. Geological Survey

(Note: Messrs. Thielman and DePue are FEMA study contractors. They are working/will work on the Red River hydrologic update.)

Your hydrology review comments as well as other local hydrology review comments were discussed in detail. The Federal Emergency Management Agency, the North Dakota State Water Commission, and the North Dakota U.S. Geological Survey representatives indicated that even though our hydrology analyses were technically sound, there were a number of points of hydrologic uncertainty in the methodology we used to generate our hydrology. Therefore, they opted to retain the effective regulatory discharge of 29,300 cubic feet per second (cfs) at Fargo/Moorhead. The Minnesota Department of Natural Resources supported the Corps' proposed regulatory discharge of 31,600 cfs but deferred to the Federal Emergency Management Agency.

The Federal Emergency Management Agency has directed us to continue our work and use a Red River of the North regulatory discharge of 29,300 cfs for Fargo/Moorhead Flood Insurance Study update purposes.

The Federal Emergency Management Agency also directed us to schedule a local coordination meeting in Fargo/Moorhead in mid-June 2001. During the coordination meeting, my hydrologic engineers will address your review comments in detail. We will also address the calibration of the Red River hydraulic simulation computer model HECRAS.

Our Flood Insurance Study work is scheduled for completion by the end of September 2001. Upon completion of the work, we will submit our draft data to the Federal Emergency Management Agency for review and processing.

If you have any questions concerning the Flood Insurance Study update hydrologic issues, please feel free to contact me at (651) 290-5300 or Mr. Terry Engel at (651) 290-5287.

Sincerely,

Kenneth S. Kasprisin
Colonel, Corps of Engineers
District Engineer

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Mr. Kirk Johnson
Deputy Legislative Director
Office of Senator Kent Conrad
Washington, D.C. 20510

Mr. Mike Eggl
Office of Senator Byron Dorgan
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REPLY TO
ATTENTION OF

Project Management and Development Branch
Planning, Programs and Project Management Division

Mr. Mike Eggl
Office of Senator Byron Dorgan
P.O. Box 2579
Bismarck, North Dakota 58502-2579

Dear Mr. Eggl:

For your information, we are providing a copy of our letter to the City of Grand Forks, North Dakota, concerning technical review comments on our "Hydrologic Analyses for Flood Insurance Studies, The Red River of the North Main Stem, From Wahpeton/Breckenridge to Emerson, Manitoba, Revised Draft Interim Report." Our letter describes the activities required to complete the study process. The Red River Main Stem Flood Insurance Study work is scheduled for completion in September 2001.

Any questions concerning the study may be addressed to me at (651) 290-5300 or to the project manager, Mr. Terry Engel, at (651) 290-5287.

Sincerely,

for Kenneth S. Kasprisin
Colonel, Corps of Engineers
District Engineer

Enclosure

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