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INVESTIGATION OF THE EFFECTS OF CHIPPEWA RIVER EROSION AND SILT REDUCTION MEASURES

Prepared for

U.S. Army Engineer District
St. Paul, Minnesota

Prepared by

Civil Engineering Department
Engineering Research Center
Colorado State University
Fort Collins, Colorado

D.B. Simons
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FORWARD

This study was performed under Contract No. DACW37-76-C-0221 titled "Investigation of the Effects of Chippewa River Erosion and Silt Reduction Measures - Phase I," between the U.S. Army Engineer District, St. Paul, Minnesota and Colorado State University.

The study was supervised by George W. Skene, Chief, General Investigations Section, Planning Branch, Engineering Division and by Al Bjorkquist, Study Manager. Dr. D. B. Simons of Colorado State University was the principal investigator. He was assisted by Dr. Y. H. Chen, Mr. Kyoung Yoon Park and Mr. Ta-Chung Fang, Civil Engineering Department. The period of agreement was from September 1976 to June 1977.

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Chapter 1

INTRODUCTION

1.1 Introduction

The Upper Mississippi River is part of the main riverine artery of the United States. Its utilization both commercially and recreationally is an important aspect of the national economy. Therefore, the river must be protected and its efficiency maintained if it is to continue to be of major economic importance.

In the St. Paul District, the Chippewa River is a major source of coarse sediment that contributes to Mississippi River dredging problems. The Chippewa sediment is estimated to be responsible for about 20 percent of all maintenance dredging along the Mississippi River within the St. Paul District (U.S. Army Engineer District, St. Paul, 1974a). The source of much of the sediment reaching the Mississippi River originates from erosion of the channel and banks of the Chippewa River below Eau Claire (U.S. Army Engineer District, St. Paul, 1976; Simons, et al., 1976). It is necessary to reduce the flow of sediment from the Chippewa to lessen dredging requirements and associated adverse impacts along the Mississippi. The primary purpose of this study is (1) to examine identified alternatives to determine how effectively they reduce sediment supply from the Chippewa River to the Mississippi River navigation channel and backwater areas, and (2) to investigate the effects of each alternative on aggradation and degradation in the Chippewa River. A map showing the location of study reaches is given in Figure 1.

1.2 Description of the Problems

Erosion and deposition have long been recognized as severe problems along the Chippewa River, especially in the lower reaches

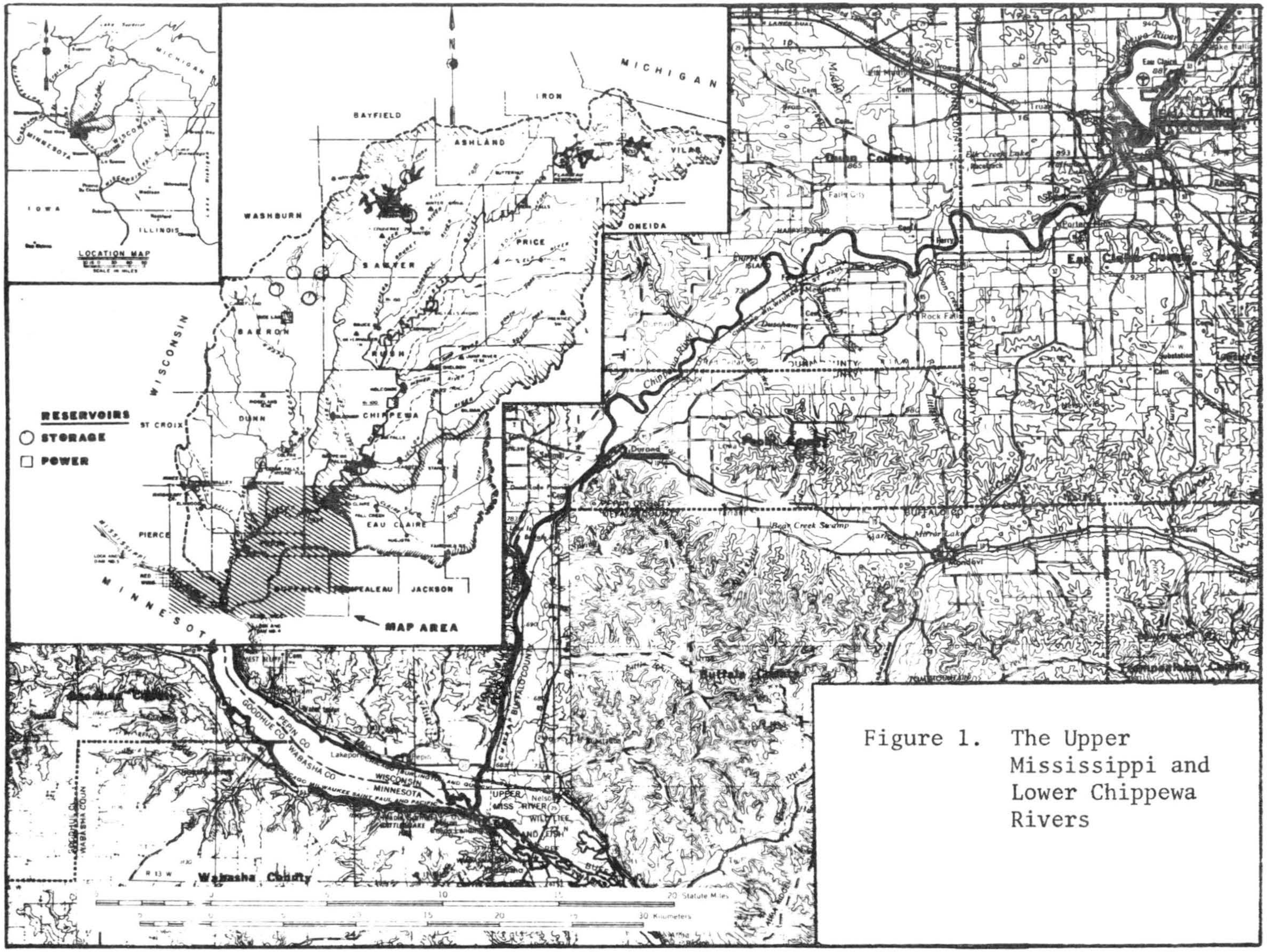


Figure 1. The Upper Mississippi and Lower Chippewa Rivers

below Eau Claire. River banks composed of sand and fine gravel erode undermining of the toe of the bank causing the bank material to slide into the channel, resulting in some loss of floodplain. Much of this sediment is ultimately transported to the Mississippi River. The amount of sediment delivered exceeds the transport capacity of the Mississippi causing aggradation. It is necessary to dredge the deposits of excess sediment to provide adequate water depth for navigation. The difficulty encountered is not in the dredging itself, but in its disposal. The dredged material is generally disposed of in the river environment. Although dredging itself has some effects upon water quality, channel benthos, fish, and other environmental components, most of the attention to date has focused on the adverse effects associated with the disposal of dredged material.

Several alternatives to dredge disposal in the river environment are possible: (1) the dredged material might be placed in areas where the disruption of wildlife is minimal or where use of the material serves a recreational or commercial purpose, e.g., beaches, landfills, etc., (2) the dredged material may be placed in portions of the thalweg where there is sufficient energy to transport the excess sediment downstream and (3) the sediment output of the tributaries may be controlled. If the sediment from tributaries can be reduced to the extent that the Mississippi can transport the remainder and maintain a navigable thalweg, then dredging can be drastically reduced and the disposal problem will be minimal. It is this alternative that the present study addresses.

1.3 Objectives and Procedures

The study is designed to evaluate and identify the most feasible alternatives to: (1) reduce the flow of sediment from the Chippewa to the Mississippi River, (2) minimize the time required to achieve this reduction in sediment load and (3) identify areas that would benefit in terms of reduced dredging requirements in the Mississippi.

There are two major objectives. The first is to examine alternative measures to determine their adequacy in reducing sediment supply from the Chippewa River to the Mississippi River navigation channel and backwater areas. The second objective is to investigate aggradation and degradation in the Chippewa River for each alternative.

Evaluation of alternatives was accomplished as follows. The hydrologic, hydraulic, geologic, geomorphic and dredging data and aerial photographs were analyzed to identify the most promosing alternative measures. Then a one-dimensional mathematical model developed for Pool 4 in the Upper Mississippi and Lower Chippewa River (Simons and Chen, 1976) was used to evaluate each alternative.

1.4 Organization of the Report

The report presents a description of the present geomorphology, surface water hydrology and sedimentation problems of the pertinent river reaches in Chapter 2. Also, the future characteristics of the study area are assessed in Chapter 2 considering the present system. Chapter 3 documents the alternative measures tested and their impacts on the rivers. These impacts are summarized and the most feasible alternative measures are identified in Chapter 4. A suggested program for future studies is presented in Chapter 5.

Chapter 2

THE PHYSICAL ENVIRONMENT

2.1 Physical Aspects of Study Area

2.1.1 Geomorphology

The Upper Mississippi River consists of a network of channels, numerous alluvial islands and sub-channels. Improvement of the Upper Mississippi River for navigation has been underway for almost 150 years. The first undertakings to improve conditions were to remove snags hazardous to navigation. Later dikes were constructed to confine low flow to a narrow channel, thus increasing the depth of flow. At the same time, revetments were placed along caving banklines to hold the channel alignment. In the 1930's the navigation channel depth was increased to 9 feet by constructing a series of locks and dams in the Upper Mississippi River. Since that time the navigation channel has been maintained by these structures and supplemental dredging.

Pool 4 is 44.1 miles long, the longest pool in the St. Paul District. Lake Pepin, a natural river lake formed by the Chippewa delta, comprises over one-half the length of Pool 4.
Prior to the creation of the 9-foot navigation channel, the floodplain land below Lake Pepin adjacent to the Upper Mississippi River was heavily wooded. Lakes, ponds, and deep sloughs were scattered through the wooded area. The lakes and marshes were flooded during the spring but dried out in the summer and fall. Much of the floodplain area was changed with the creation of the navigation pool. The relatively stable water levels in the navigation pool converted the lower portion of the floodplain from wooded islands and dry marshes into

excellent marsh and aquatic habitat. Two major backwater areas are Robinson Lake and Big Lake.

The effect of navigation channel development on geomorphology of Pool 4 below Lake Pepin was investigated by Simons, et al. (1976). The findings are summarized below:

1. The position of the Upper Mississippi River in the study reach has remained essentially unchanged from 1850 to the present.

2. In response to dike construction during 1878-1929, the river surface area of the Upper Mississippi decreased. After the construction of Lock and Dam 4, the river surface increased.

3. The number and area of islands increased from 1878 to 1929 in response to the construction of dikes. After the construction of Lock and Dam 4 in 1935 both the number of islands and the total island area increased. The new islands were created by inundation of low floodplain areas, creating new chutes. This increase was greatest in the lower two-thirds of Pool 4 below Lake Pepin.

4. The average width of the Upper Mississippi River in Pool 4 below Lake Pepin decreased in the period from 1878 to 1929. The response to the operation of Lock and Dam 4 was to increase the width in the lower two-thirds of the pool and to narrow it in the upper one-third.

5. In response to the constriction of the channel by dikes, the Upper Mississippi degraded its riverbed in the period 1878 to 1929. Between 1938 and 1972, the riverbed aggraded due to the decreased sediment transport ability after the construction of Lock and Dam 4.

Both the navigation channel and backwater areas have sedimentation problems. Ninety percent of the total amount of sediment entering Pool 4 is trapped by Lake Pepin. This deposition is slowly reducing the capacity of the lake. The Great River Environmental Action Team (GREAT I) is investigating the significance of shoaling in Lake Pepin.

The sediment which is discharged from Lake Pepin is very fine and causes little or no dredging problems in the navigation channel downstream but some of this fine sediment is deposited in backwater areas. In constrast, the Chippewa River, transports a large amount of coarse sediment to the Mississippi River which contributes to dredging requirements as far downstream as Pool 5A.

The Chippewa River Basin extends 175 miles from Upper Michigan through northwestern Wisconsin. The Chippewa River drains 9,435 square miles and enters the Mississippi River just below Lake Pepin. The basin comprises 17 percent of the State of Wisconsin. Major land uses in the basin are recreation, forest management, and agriculture. In the north, there is wood harvesting and related manufacturing. Agriculture is dominant in the south because the growing season is longer and soils are less sandy and infertile.

The Chippewa basin is relatively flat with numerous lakes and swamps in the headwaters region, and rolling farmlands and cutover wooded areas in the middle and lower reaches. The topography was formed by glacial activity which left thick sedimentary deposits in the lower portion of the basin that thin out toward the northeast. The glacial drift forms an almost continuous mantle, as thick as 150 feet over the bedrock. Drift in the basin is composed of ground moraines, and outwash materials. Permeable sand and fine gravel outwash, which was deposited by meltwater streams from stagnating glaciers, forms the valley bottom on the Lower Chippewa River, making its banks highly erodible.

From its confluence with the Mississippi River to the town of Durand 16 miles up the valley, the Chippewa River is essentailly a braided river with a sinuosity of 1.06. The main channel is characteristically broad and shallow and contains shifting sandbars and sand islands. The average channel width is 700 feet and the average depth is about 3 feet. The bank full width is approximately 1,000 feet. Channel slope for this river reach is 1.76 feet per mile. Upstream from Durand to Eau Claire at river mile 61, the Chippewa River has a meandering configuration with sinuosity of 1.49. This reach is characterized by eroding sand and gravel banks. The channel width is somewhat less than that below Durand, averaging about 600 feet. The channel slope for this reach is about 1.5 feet per mile.

A geomorphic study of the Chippewa River indicates that erosion of steep high banks is evident at several locations between Eau Claire and Durand. They include Yellow Bank at river mile 20.5, right bank of the Chippewa near Happy Island at river mile 35.5, and left bank of the Lower Elk Creek entering the Chippewa near river mile 45.5 (see Figure 2). These banks are more than 100 feet in height and they are being eroded at their toes which causes the sandy bank material to slide into the channel resulting in failure of the flat surfaces at the toe of the bluffs. In certain instances local residents state that as much as 100 horizontal feet have been eroded from the land at the bluff top within the last 10 years (U.S. Army Engineer District, St. Paul, 1976). However, after comparing the 1928 and 1972 river patterns, this statement is doubtful. As far as can be determined from the topographic maps and aerial photographs, these bank areas have not noticeably retreated in the past 40 years.

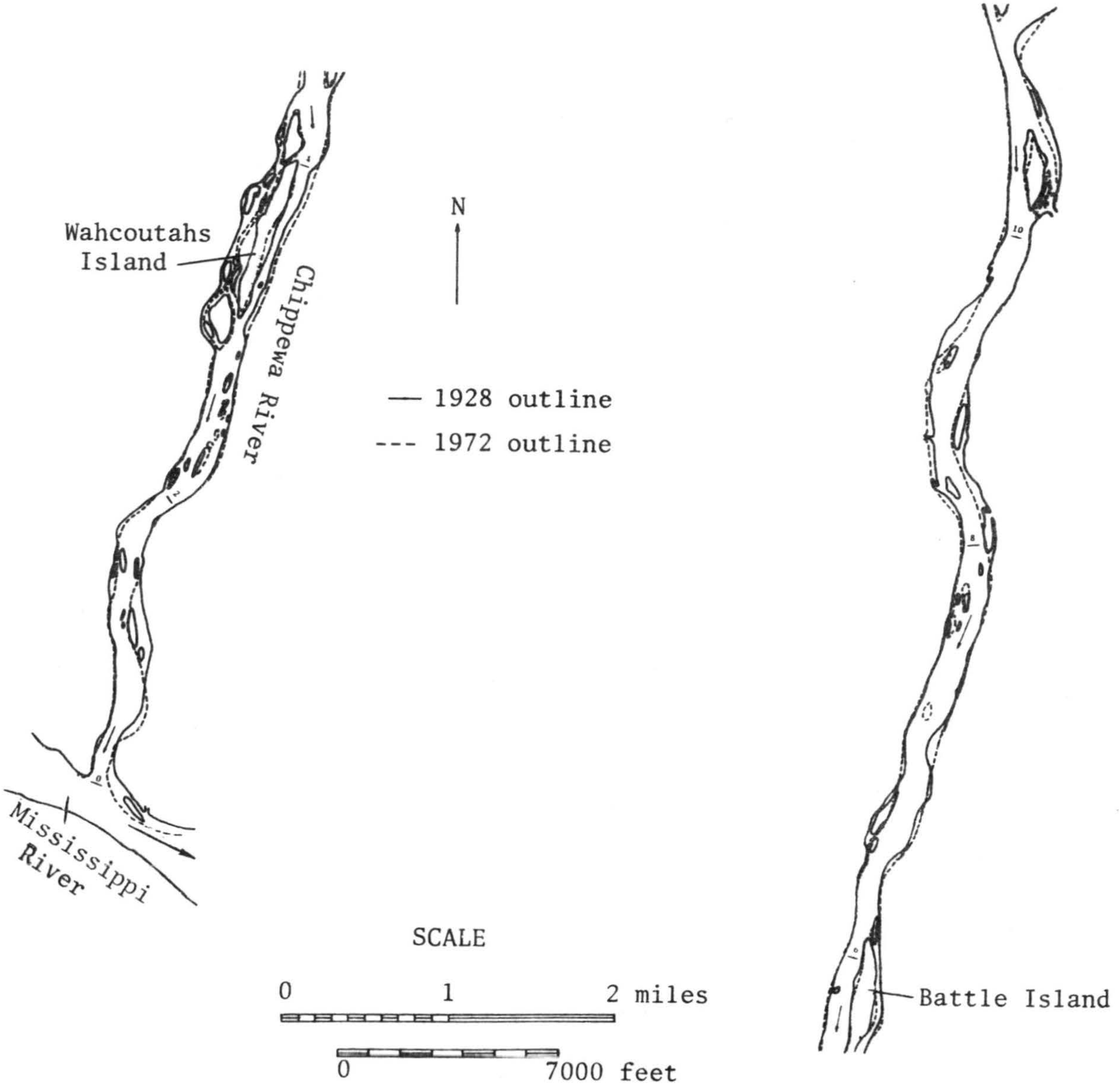


Figure 2a. The Lower Chippewa River

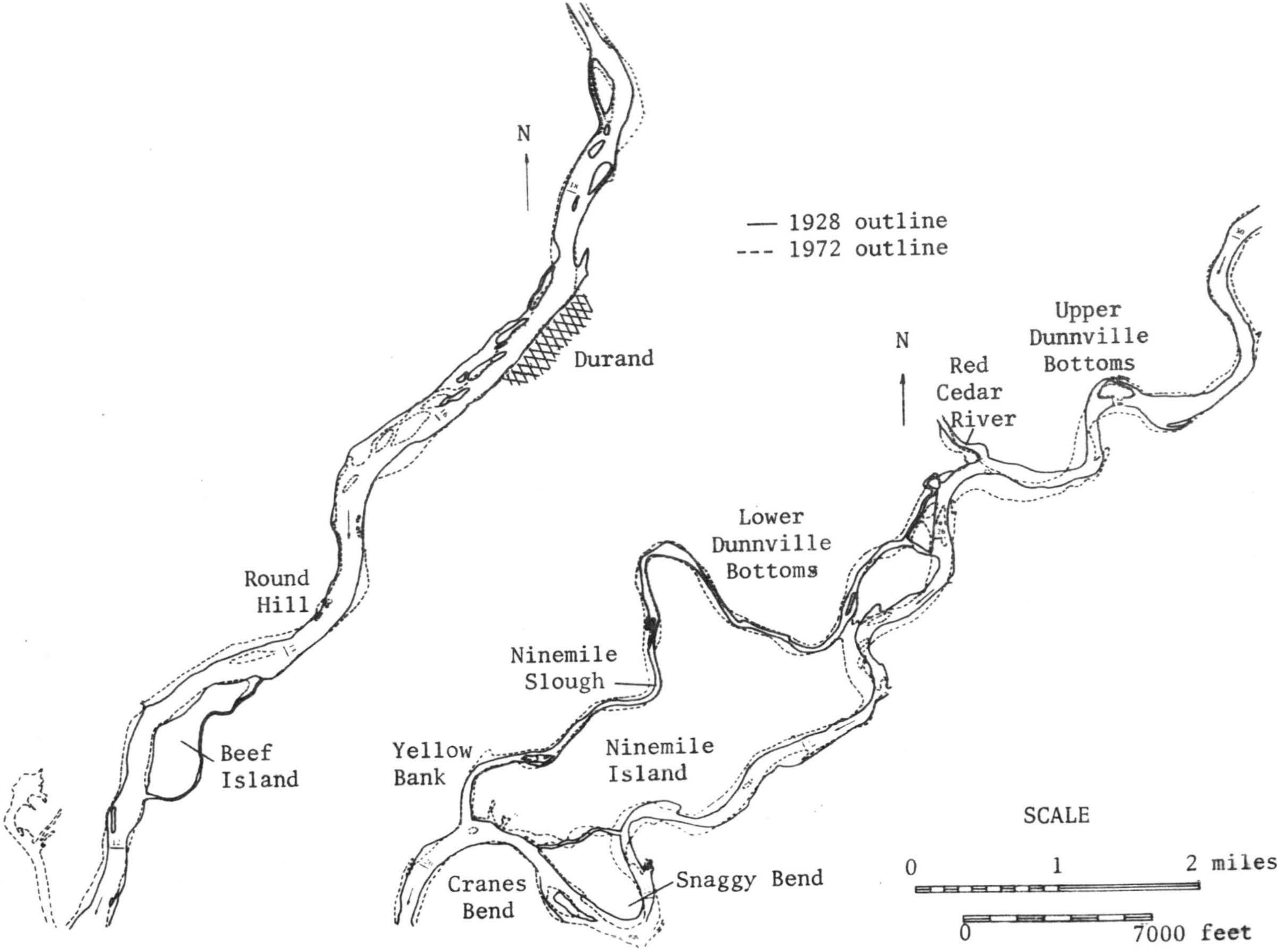


Figure 2b. The Lower Chippewa River

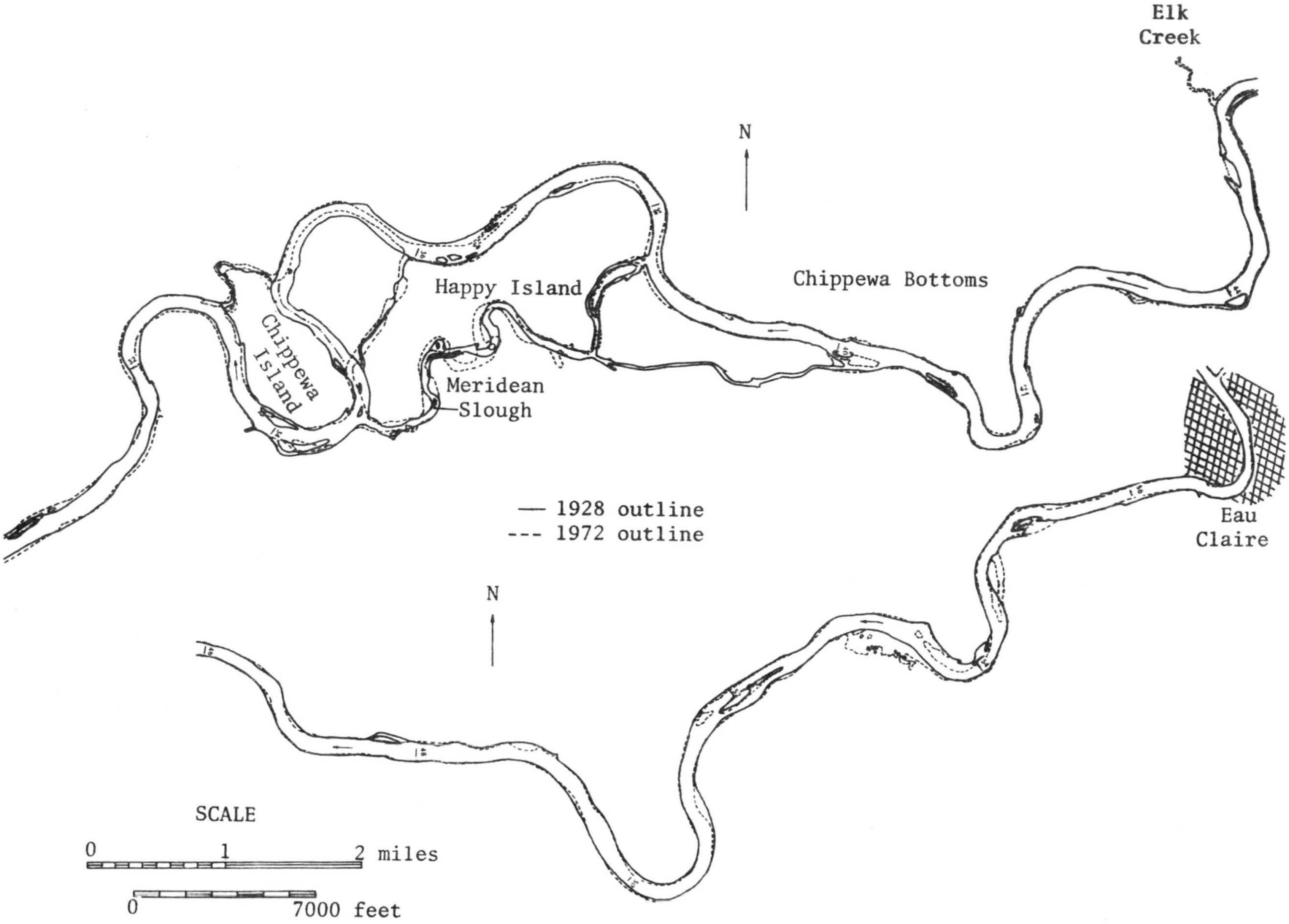


Figure 2c. The Lower Chippewa River

Many of the sandy banks averaging 10 to 15 feet in height above average low water level are being eroded. Comparison of the 1928 and 1972 river patterns (Figure 2) shows that during this period severely eroded low banks include the banks: (1) between river mile 3 and 4; (2) between river mile 8 and 9; (3) between river mile 11.5 and 14; (4) near river mile 14.5, 15.7 and 18.5; (5) between river mile 20 and 30; (6) at the natural cutoff on Happy Island near river mile 36, and (7) near river mile 53 and 55. In some locations, river banks were eroded 500 feet. However, deposition also occurred in many locations in the Chippewa River. An estimation of surface area and width changes that have occurred in the Chippewa River is given in Table 1.

Examination of Figure 2 and Table 1 verify that the Chippewa River banks are being eroded:

1. Sediment eroded from banks between river mile 52 and 56 were mainly deposited between river mile 36 and 52.

2. That part of sediment entering the Mississippi River due to bank erosion probably originates from erosion of low banks between river miles 18 and 32. Changes of high bank lines were relatively minor. The eroded bank area between 1928 and 1972 in this reach of river totaled about 288 acres. The average river width increased by 170 feet. Assuming that the average bank height is 15 feet above the riverbed and the unit weight of sand bank material is 100 lbs/ft^3, then the weight of eroded sediment per year between 1928 and 1972 was approximately 210,000 tons/year. A portion of this sediment was deposited on riverbed. Excess sediment transported downstream from the eroded bank is estimated to be 185,000 tons/year.

By using Toffaleti's method (1969), a sediment transport relation was derived:

$$Q_s = 0.000122\ Q^{1.8}$$

Table 1. Changes of Surface Areas and widths in the Chippewa River between 1928 and 1972

River Mile	Surface Area Changes (acres)	River Width Changes (ft)	River Mile	Surface Area Changes (acres)	River Width Changes (ft)
0-2	-17	-70	30-32	+14	+60
2-4	- 7	-30	32-34	~ 0	0
4-6	~ 0	0	34-36	~ 0	0
6-8	+ 5	+20	36-38	-10	-40
8-10	+26	+110	38-40	~ 0	0
10-12	+ 5	+20	40-42	- 7	-30
12-14	+40	+160	42-44	+ 5	+20
14-16	- 9	- 40	44-46	- 6	-25
16-18	-50	-210	46-48	- 3	-10
18-20	+37	+150	48-50	- 7	-30
20-22	+32	+132	50-52	- 9	-40
22-24	+70	+290	52-54	+27	+110
24-26	+43	+180	54-56	+18	+ 75
26-28	+53	+220			
28-30	+39	+160			

* Negative values indicate a decrease in surface area and width (deposition), and positive values indicate an increase in surface area and width (erosion).

where Q_s is the bed material discharge in tons/day and Q is the water discharge in cfs. This relation was verified using the measured sediment discharge collected at Durand (see Figure 3). From this transport relation and the mean flow duration curve in the Chippewa River at Durand (Upper Mississippi River Basin Coordinating Committee, 1972)

$Q \text{ (cfs)} = 14{,}000\ e^{-2.08t}$ (t is the percentage of time, between 0 and 1)

the annual transport rate was estimated to be 380,000 tons/year. This indicates that the sediment eroded from the Chippewa banks between river mile 18 and 32 contributed about 50 percent of sediment entering the Mississippi River, causing sedimentation problems in the navigation channel and backwater areas of the Upper Mississippi River.

2.1.2 Surface Water Hydrology

Topographic conditions and climatic variations in temperature and precipitation in the Chippewa River Basin cause extreme variation in stream runoff. A system of 8 water storage reservoirs have been constructed near the headwaters of the Chippewa, Flambeau, and Red Cedar River. These dams reduce flood peaks and provide a more uniform flow. In 1952, 19 hydroelectric generating plants were operated on the Chippewa, Flambeau, and Red Cedar Rivers. Two plants operated at Dells Dam in Eau Claire, Wisconsin. This dam is the last to control the Chippewa River and is located about 60 miles above the mouth of the Chippewa River. These dams and reservoirs affect the stage and discharge in the river system. The mean annual discharge at Durand, Wisconsin, 17.4 miles above the Chippewa mouth, is about 7,000 cfs (cubic feet per second). The enlargement of flow areas between river mile 18 and 32 during the period of 1928 to 1972 lowered the normal flow level by about 2 feet. A natural cutoff occurred at Happy Island during the same period

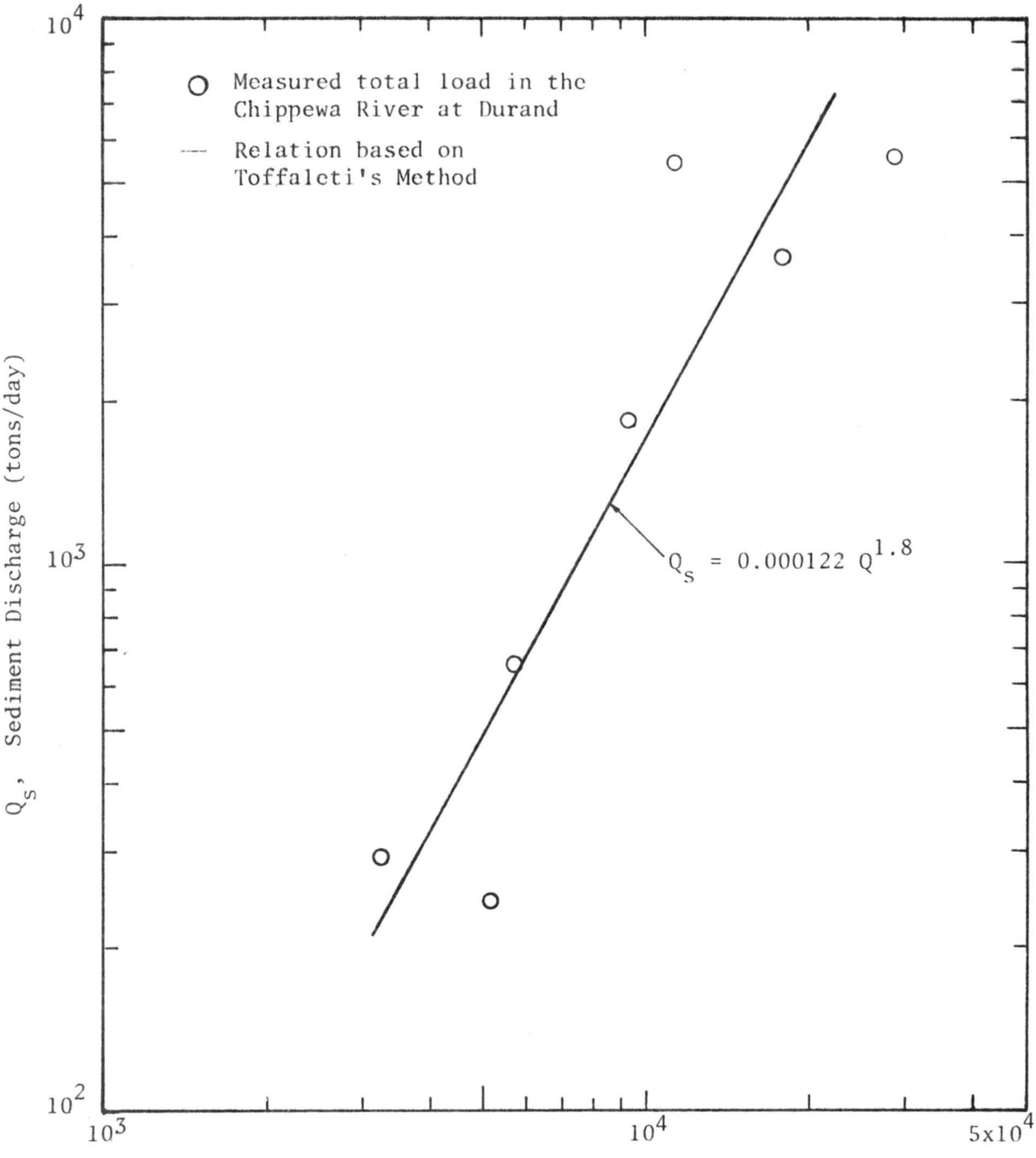


Figure 3. Sediment Rating Curve for the Chippewa River at Durand

had a similar effect on the water level.

Water and sediment moving through the Mississippi and Chippewa Rivers are affected by Lock and Dam 4. At low and intermediate flows, the dam raises the pool level above the natural river level. This increases the flow depth in Pool 4 of the Upper Mississippi and the Lower Chippewa River. The backwater of Pool 4 can affect the Chippewa River up to 6 miles above its mouth, decreasing the ability of this river reach to transport sediment. The result is deposition in the lower reach of the Chippewa at low and intermediate flows.

When flood flows occur, the gates at Lock and Dam 4 are opened and flow conditions approach the natural river state. During floods, the sediment deposited during periods of low and intermediate flow on the Chippewa bed is flushed downstream to the Mississippi. The amount often exceeds the sediment transport capacity of the Mississippi River. This results in deposition in Pool 4 below Lake Pepin and to a lesser degree further downstream. It is these areas of excessive deposition that require recurrent dredging to maintain the navigation channel. The erosion and deposition is highly dependent on the relative magnitudes of the Mississippi and Chippewa River flows.

2.1.3 Dredging

Dredging records for the Pool 4 reach in the Upper Mississippi River indicate that the most troublesome crossings that require frequent dredging are between river miles 762.4 to 763.8 near the mouth of the Chippewa, between river miles 758.9 and 759.6 above Hershey (Crats) Island, and between river miles 757.1 and 758 near Teepeeota Point. The dredged volumes in these three reaches were 2,120,000, 3,188,000 and 2,473,000 cubic yards respectively between 1936 and 1972. These reaches are straight and the flow is divided by alluvial islands. The dredging in these reaches accounted for about 78 percent of the total dredging in Pool 4 downstream of Lake Pepin between 1936 and 1972. The total dredged volume reported in this river reach was 9,913,000 cubic yards during this time. The dredging records were provided by U. S. Army Engineer District, St. Paul, (1974a). Assuming that the unit weight of the dredged material was 100 lbs/ft^3, then the bed material dredged from this river reach weighed an average of about 370,000 tons/year.

It has been verified that the Chippewa River is the major source of coarse sediment contributing to dredging needs in Pool 4. By virtue of its comparatively steep gradient, high velocity, and easily eroded banks, the Chippewa River transports more sediment per unit volume of water than the Mississippi River. In fact, it carries several hundred thousand cubic yards of coarse material to the Mississippi River each year. Based on a rough estimate, the total weight of this coarse material is about 380,000 tons/year. Much of this material is dredged from the Mississippi River to maintain the 9-foot navigation channel. It is estimated that the Chippewa River is responsible for about 20 percent of all maintenance dredging along the Mississippi River within the St. Paul District. Also, it has been estimated that in Pool 4 below Lake Pepin the bed material dredged in a year weighed about 370,000 tons, which is almost equal to total bed-material load transported from the Chippewa into the Mississippi River. Since some of the Chippewa sediment affects the Mississippi River as far downstream as Pool 5A, it is evident that this dredged amound exceeded that actually required to maintain the navigation channel. The practice of overdepth and overwidth dredging plays an important role affecting the dredging quantities.

Other factors that influence dredging requirements include:

1. Extended periods of abnormally low-flow where lack of water in the system becomes a controlling factor.

2. Extended periods of unusually high flow.

3. Effectiveness and efficiency of dredging operations.

The dredged material is pumped through a pipeline and disposed of along the bankline of the river channel, in dike fields, or on islands. This disposed material may be moved again by subsequent floods resulting in additional deposition in sloughs, chute channel and backwater channels. Also, there is the possibility of sterilizing biologically productive habitats by covering them with such material.

2.2 Impact of Operation and Maintenance on the Physical Environment

2.2.1 Impacts on Geomorphology

If the present scheme of operation to maintain the 9-foot navigation channel continues, the Chippewa River will continue to transport excessive sediment to the Mississippi River. Based on a mathematical model study, Simons and Chen (1976) estimated that there would be a 0.7-foot overall aggradation within the main channel of Pool 4 below Lake Pepin during the next ten years. They also estimated that the natural levee along the river banks, on the islands, and near the mouths of backwater areas would grow about 0.5 feet in ten years. The deposition of sediment in the backwater areas will continute to accumulate at an overall averaged rate of about 0.1 inch per year. The bank erosion problem in the Chippewa River will persist especially in those river reaches paralleling Ninemile Island and Happy Island and upstream thereof. Ninemile Slough should continue to increase in size due to increases in its flow rate downstream of the junction of the Chippewa River and Ninemile Slough near river mile 25. This will further erode the banks and possibly accelerate the erosion of Yellow Bank. In addition, lowering of the water level due to the enlargement of this river reach will cause further undercutting of the upstream river banks decreasing the river stability. Also, the natural cutoff in Happy Island should continue to grow, lowering the flow level and pollsibly affecting channel stability. The erosion rates near the severely eroded banks (see Figure 2) can be evaluated if bank stability data are obtained. Table 1 may be used to approximate the erosion rate. There will be some small net aggradation occurring in the lower end of the Chippewa River.

2.2.2 Impacts on Surface Water Hydrology

According to an analysis of the hydrologic data it is expected that the surface water hydrology in the next 20 years will be similar to what it is today.

2.2.3 Impacts on Dredging Requirements

If the river system is not modified it is expected that dredging will be necessary to maintain the navigation channel. The dredging requirements may be changed after a better understanding of the river system is obtained and an improved dredging policy is established. This improved dredging policy can also be applied to maintain the navigation channel in the Upper Mississippi River should alternative measures be implemented to improve the Chippewa River. Colorado State University is conducting a two-dimensional mathematical model study in this river reach. This study will provide useful information on the river system to evaluate dredging requirements and to establish a better dredging policy. Also, the controversy regarding the disposal of dredged material may be minimized after a better disposal policy is established and better disposal sites are identified.

Chapter 3

ALTERNATIVE MEASURES

3.1 Description of Alternative Measures to Reduce the Flow of Sediment from the Chippewa to the Mississippi River

The alternatives investigated include:

1. Increase storage of existing flood control dams in the Chippewa River Basin to reduce downstream flood discharges.
2. Dredge a sedimentation trap at the lower end of the Chippewa River.
3. Establish a meander pattern in the Chippewa River below Durand.
4. Divert a portion of the Chippewa River flow into Lake Pepin with and without dredging.
5. Divert a portion of the Chippewa River into a sedimentation basin formed by the backwater of Pool 4 with and without dredging.
6. Construct a low-head dam at the lower end of the Chippewa River.
7. Construct a series of low-head dams on the lower Chippewa to reduce channel gradient.
8. Establish streambank erosion controls and supplemental sediment controls.

3.2 Evaluation of Alternative Measures

3.2.1 Alternative 1: Increase Storage of Existing Flood Control Dams in the Chippewa River Basin.

Numerous storage reservoirs and power generation dams have been constructed in the Chippewa River Basin (see Figure 4). These dams are generally drawn down starting in the Fall to provide flood control during the following Spring runoff season. They can be operated to further reduce downstream flood discharges, and thereby reduce the Chippewa erosion and the sediment supply to the Mississippi River.

A study of this alternative shows that the discharge of sediment from the Chippewa can be reduced by increasing the storage capacity of the six existing dams (Chippewa Dam, Holcombe Dam, Cornell Dam, Wissota Dam,

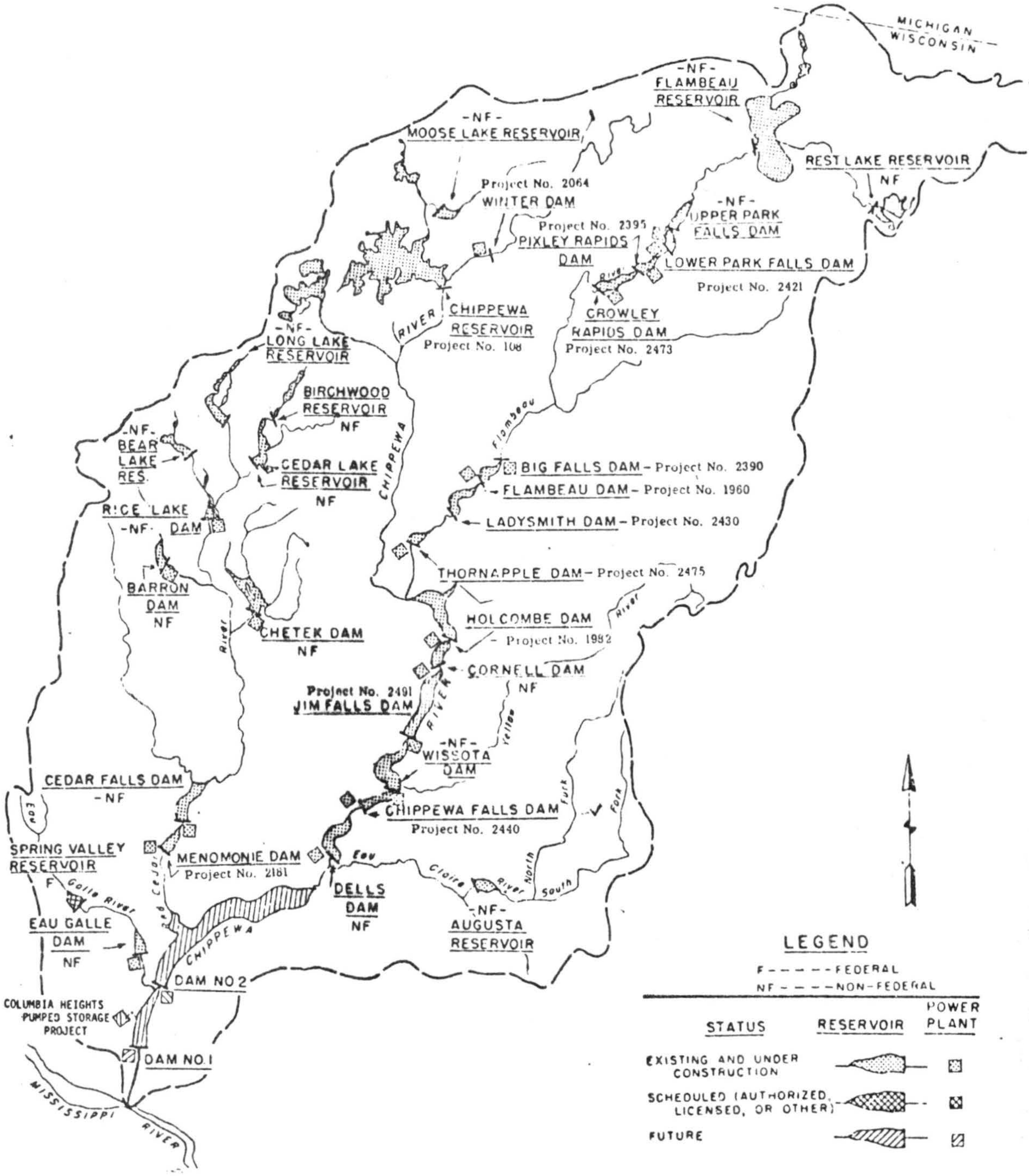


Figure 4. Reservoirs in the Chippewa River Basin.

Chippewa Falls Dam, and Dells Dam) by increasing the Fall drawdown or by increasing the reservoir stages for flooding or both. The surface areas of Chippewa, Holcombe, Cornell, Wissota, Chippewa Falls and Dells Reservoirs are respectively about 15,000, 3,000, 600, 6,000, 110 and 600 acres. If the power pools of these reservoirs were lowered to provide an additional 5 feet for flood control storage, an extra storage of 126,600 acre-feet would result. This extra storage would be sufficient to reduce the flood peak discharge by about 6,000 cfs for a ten day period if the reservoirs could be properly operated. A hydrograph similar to the 1965 hydrograph (5-year recurrence interval) was modified in this way as shown in Figure 5 to evaluate the effects of increasing reservoir storages. By routing the original and modified hydrographs through the mathematical model and comparing the differences in the stages and sediment supply to the Mississippi River, the effect of this alternative measure was evaluated. This increase in storage would lower the flood stage in the Chippewa River about 1.5 feet and reduce the sediment supply to the Mississippi River about 15 to 20 percent (or about 60,000-80,000 tons/year) based on the results of the mathematical model. A similar reduction in flood stage due to a decrease in flood discharge could be estimated from the rating curve at Durand (Figure 6). If these dams were modified to increase their storage capacity 50 percent of the above case, the flood stage in the Chippewa would be lowered about 1 foot and the sediment supply to the Mississippi would be reduced by 10 to 15 percent. This alternative would result in an immediate reduction in sediment supply in the Mississippi.

The effects of the reduction in sediment supply would propagate downstream through Pool 4 and other downstream pools at a rate of about

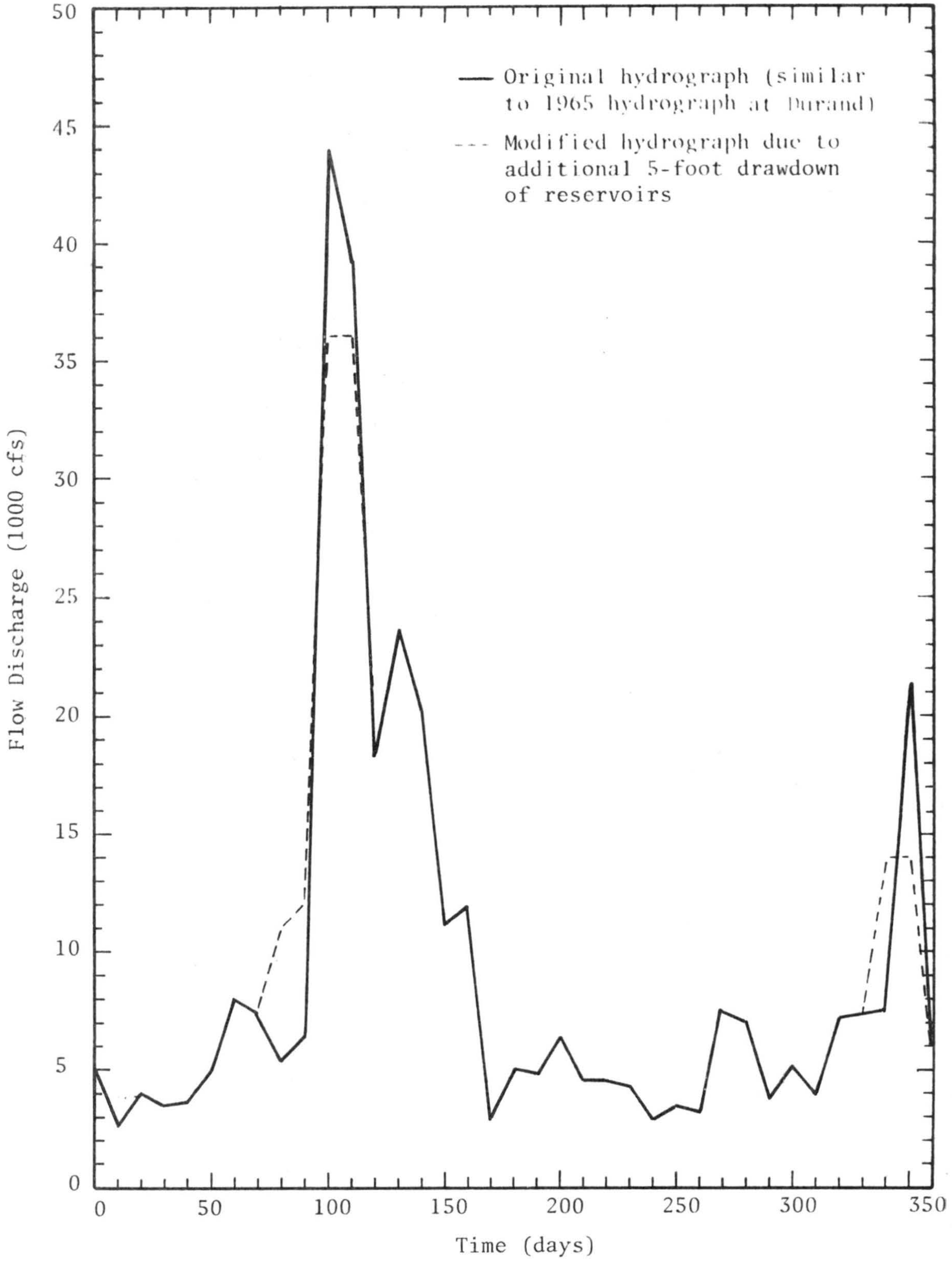


Figure 5. Hydrographs Used in the Mathematical Model to Evaluate Response of Rivers to Development

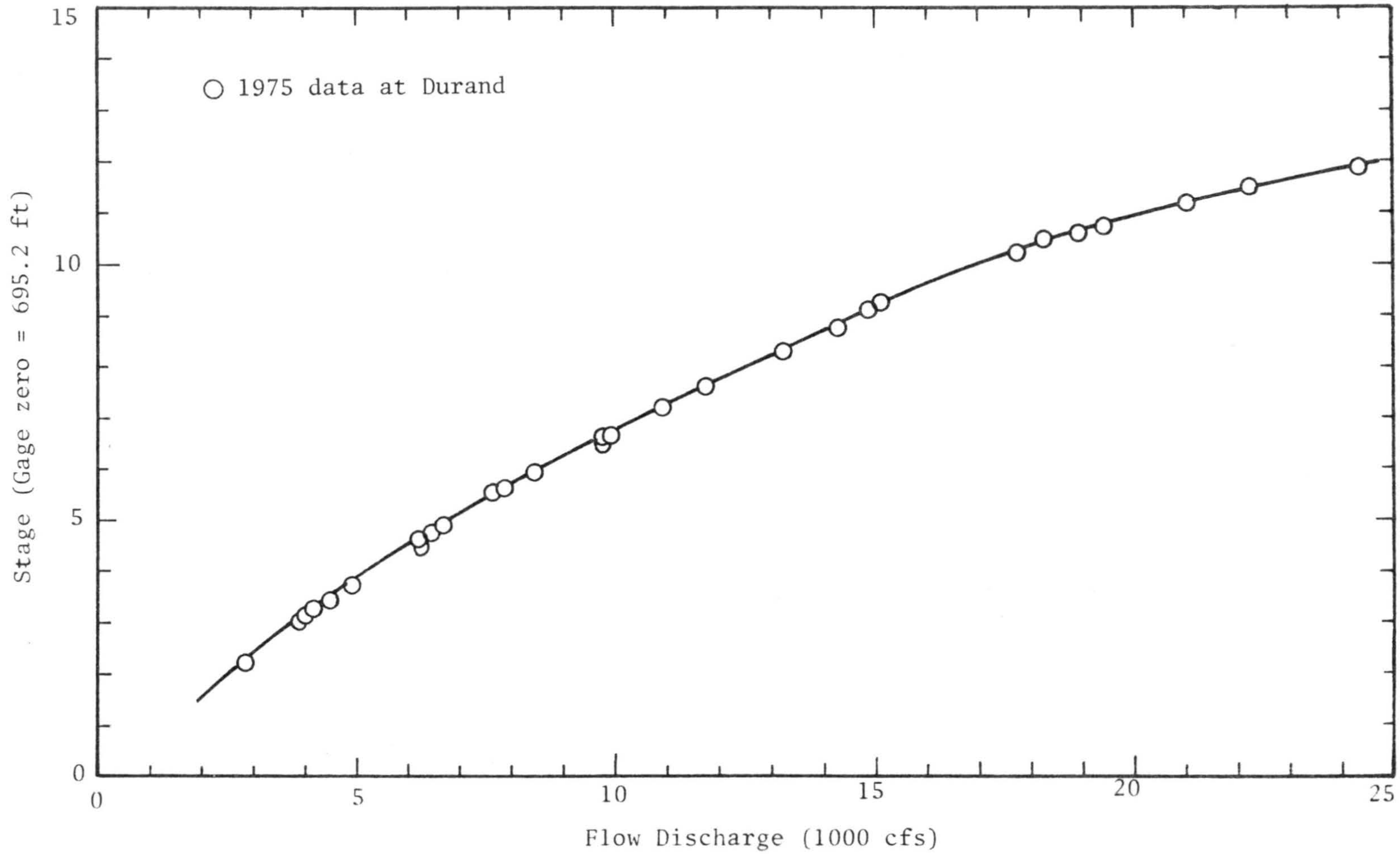


Figure 6. Stage and Discharge relation in the Chippewa River at Durand

one mile per year according to a one-dimensional mathematical model study. Dredging requirements and growth of natural levees would be reduced directly proportional to the reduction of sediment inflow from the Chippewa. This sediment reduction would affect the dredging requirements at the three major problem sites (near Reads Landing, Crats Island, and Teepeeota Point) in the following way.

The dredging requirement near Reads Landing would be reduced about 10 to 20 percent (about the same rate as the sediment reduction in the Chippewa) in the first year after increasing reservoir storage (the reduction rate varies depending on the selected alternative). The reduction would not affect the problem area above Crats Island until about the fourth year after implementing the alternative. The reduction in dredging requirements at this location would be of a lesser degree than the sediment reduction rate in the Chippewa because of the local meandering effect that produces and sustains a point bar along the inner bend. A conservative estimate indicates that the reduction in dredging requirement above Crats Island would be about one-half the estimated sediment reduction in the Chippewa River. The effect of the sediment reduction would result in improved conditions at Teepeeota Point about six years after implementation of the alternative and it would reduce the dredging requirement by about one-half the sediment reduction in the Chippewa.

It is estimated that the sediment reduction from the Chippewa River would become fully effective in Pool 4 below Lake Pepin in about 10 years. This would reduce the dredging requirement by about two thirds of the sediment reduction rate from the Chippewa River. For this alternative, the reduction in dredging volume would be about 20,000-40,000 cubic yards (or 27,000-54,000 tons) in a year after the alternative becomes fully effective (assuming that annual dredging volume was 270,000 cubic yards from the average of 1936-1972 dredging records). Also, the study indicates that even if the Chippewa sediment entering the Mississippi was eliminated completely, dredging would still be required to maintain the navigation channel in Pool 4 because of the effects of the meandering and pools and crossings in the Mississippi River. The effect of implementing this alternative would extend beyond Pool 4.

Figure 7 shows the approximate effect on dredging requirements in the Mississippi River due to sediment reduction in the Chippewa River. The figure is derived considering that:

1. The dredging requirement near Reading Landing would be affected fully by the sediment reduction as stated above.

2. The dredging requirement above Crats Island and above Teepeeota Point would be decreased by about 50 percent of the reduction rate.

3. The effect of the sediment reduction in the Chippewa would extend to Lock and Dam 5A (River Mile 729).

Figure 7 can be used to assess the effect of reduction in the Chippewa sediment on Pool 4 as well as Pools 5 and 5A. The effect on Pool 4 has been discussed above. A similar approach can be used to assess these effects on Pools 5 and 5A. For example, a 20 percent reduction in the Chippewa sediment (a sediment reduction of about 76,000 tons) would decrease the dredging requirement near river mile 748 by 4 percent. If the original dredged volume was 37,000 cubic yards in a year, this reduction would decrease the dredging requirement to 35,000 cubic yards. However, this reduction would not be realized until about 13 years after the reduction of sediment from the Chippewa was accomplished. Figure 7 is also utilized to evaluate other alternatives.

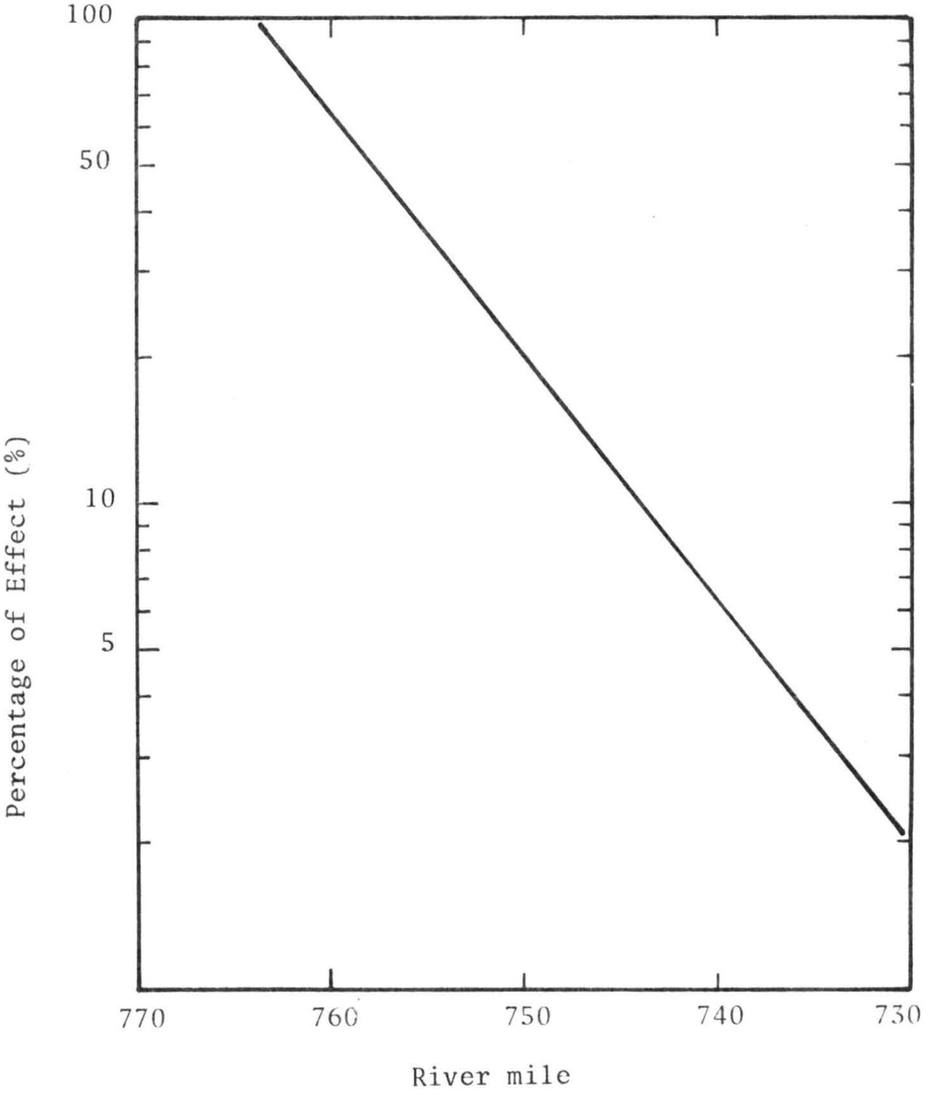


Figure 7. Effect of the Reduction in the Chippewa Sediment Supply on the Dredging Requirement in the Mississippi River

should be implemented to determine size distributions and sedimentation rates in these areas.

As stated in Section 2.2.1, the sediment deposition near the mouths of backwater areas in the existing river system would be about 0.5 feet in ten years. A 20 percent reduction of the Chippewa sediment would reduce this sedimentation rate by 7 percent, or by one-half inch, and would have even less effect on the remote backwater areas.

The basin area of the Chippewa River affected by this alternative would be small. The economic benefits of this alternative should consider the reduction of flood damage and maintenance requirements due to the decrease in peak discharge and sediment supply from the Chippewa. Conversely, there would be a decreased power supply, a reduction in wild rice production, a loss of fish and wildlife resources, and other adverse impacts.

3.2.2 Alternative 2: Dredge a Sedimentation Trap at the Lower End of Chippewa River

The river reach near the lower end of the Chippewa River could be dredged to form a sedimentation trap to reduce the sediment supply to the Mississippi River. The effect of the trap on flood stage would be small and it would be necessary to identify a suitable disposal site for the dredged material.

The ability of the sedimentation trap to achieve sediment reduction would mainly depend upon the size of the trap and its maintenance. The study indicates that the annual reduction rate per year would equal the ratio of the weight of the dredged material to the annual sediment load. For example, a dredged trap 4 feet deep, 600 feet wide and 1,600 feet long located in the bed of the Chippewa River near its mouth (see Figure 8). would reduce the sediment inflow to the Mississippi River by about 50 percent during an average year, or by about 190,000 tons/year. This reduction was determined by routing the 1965 hydrograph through the mathematical model with a dredged sedimentation trap located near the mouth of the Chippewa River. The 50 percent reduction of sediment supply would decrease the dredging requirement in the Mississippi River near Reads Landing about 50 percent (see Figure 9). However, the reduction would only be temporary because the dredged trap would fill up, quite often within a year (see Figure 10). If the sedimentation trap was dredged every year, the effectiveness of this alternative on river dredging requirements would be comparable to Alternative 1, except that dredging requirements would be further reduced. That is, effects of the reduction in sediment supply would propagate downstream through Pool 4 and other downstream pools at a rate of about one mile per year. The dredging requirement near Reads Landing would be reduced about 50 percent (i.e., by 30,000 cubic yards or by 40,000 tons), if the sedimentation trap was reconstructed every year. The reduction would not reduce deposition near Crats Island until about the fourth year after implementation of the alternative. The dredging requirement at this location would be about one-half the sediment reduction from the Chippewa River, that is, about a 25 percent reduction or 34,000 cubic yards (45,000 tons). The effect of the sediment reduction would not reach Teepeeota Point until six years after implementation of the alternative and its effectiveness on the dredging reduction would be about one-half the sediment reduction. In a long run, the dredging volume would be reduced by one-third or about 90,000 cubic yards (or 120,000 tons) per year in Pool 4 below Lake Pepin.

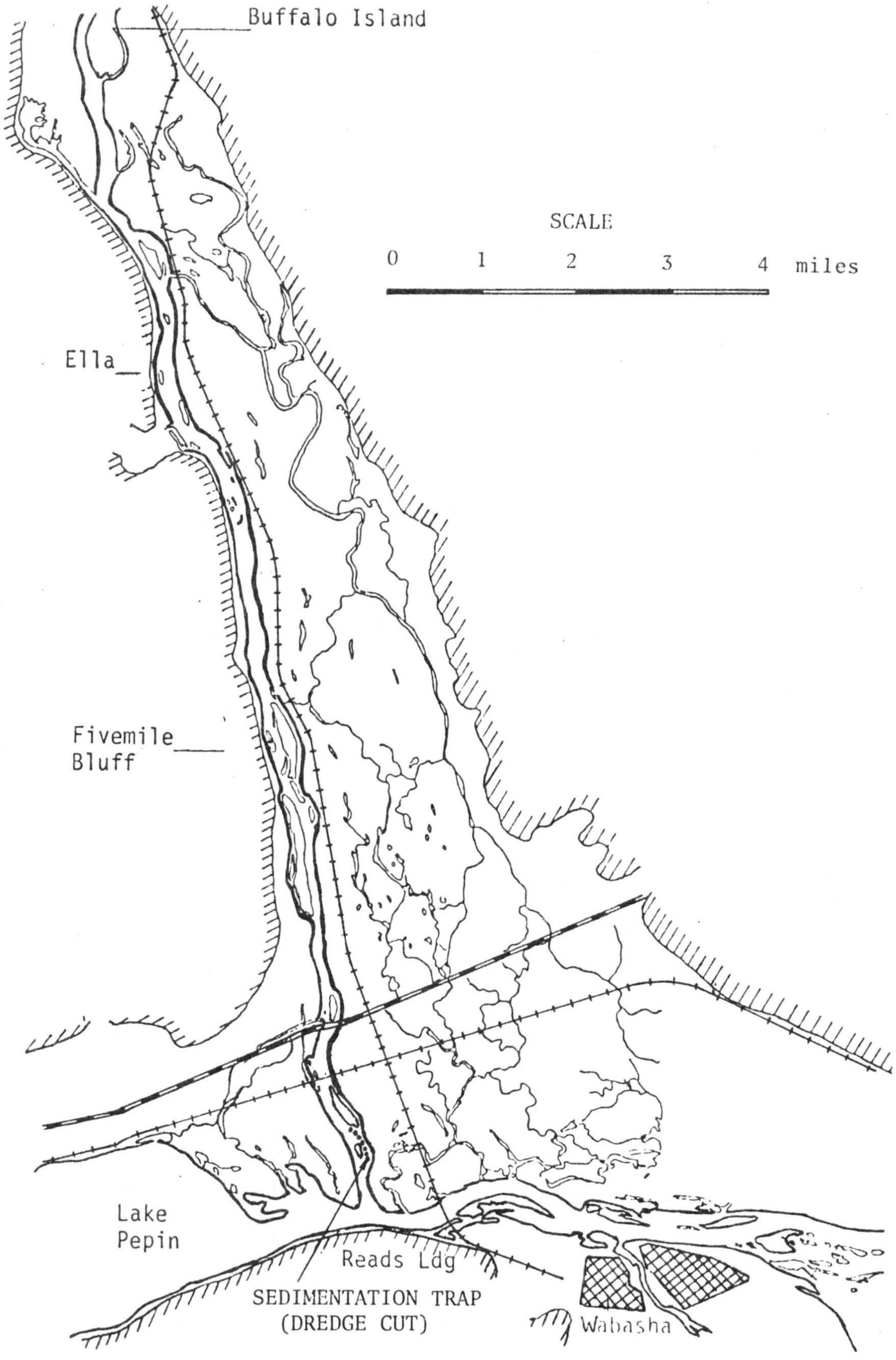


Figure 8. Location of Alternative 2: Dredge a Sedimentation Trap at the Lower End of Chippewa River

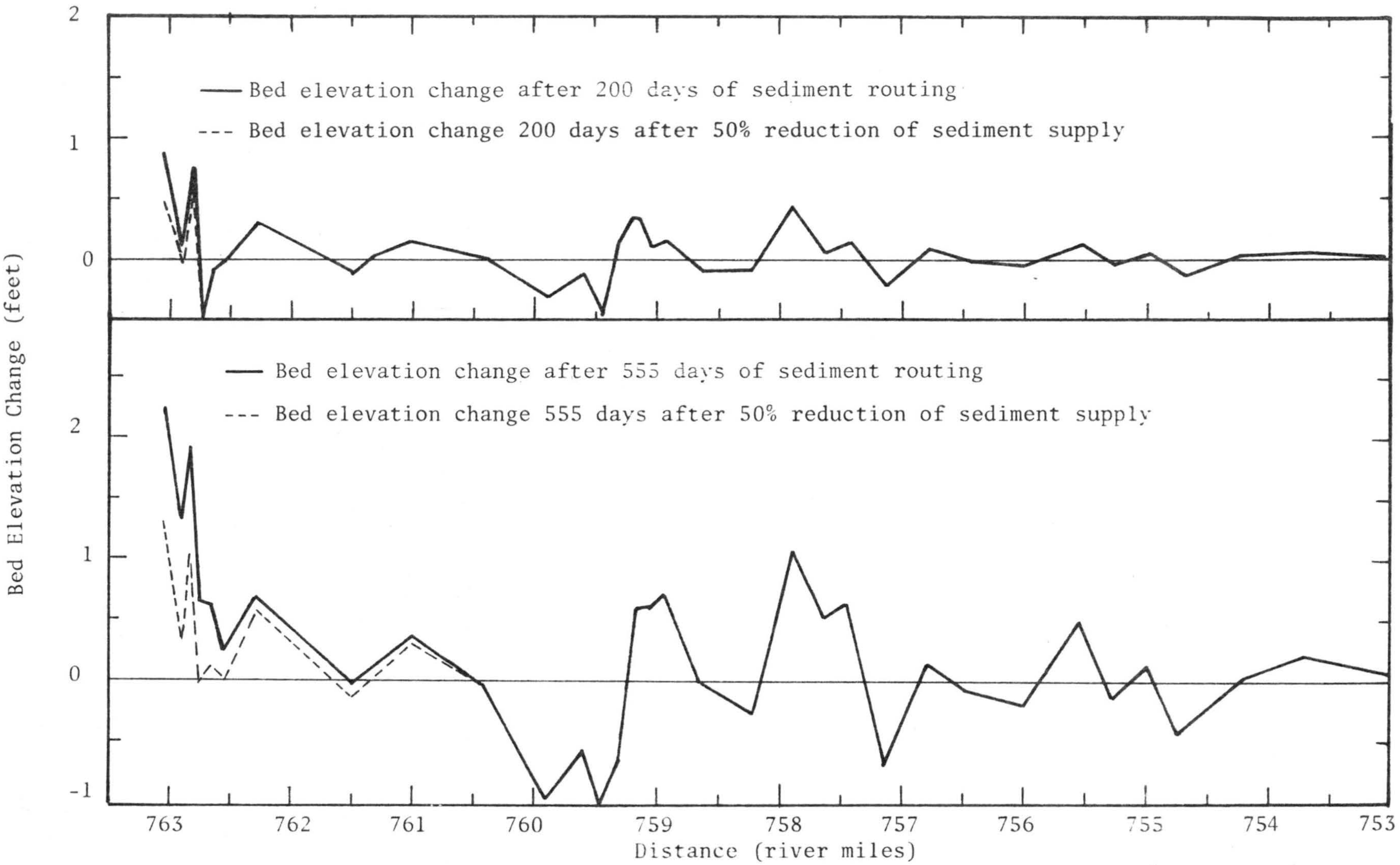


Figure 9. Bed Elevation Changes in Pool 4 with and without 50 percent reduction of sediment supply from the Chippewa River

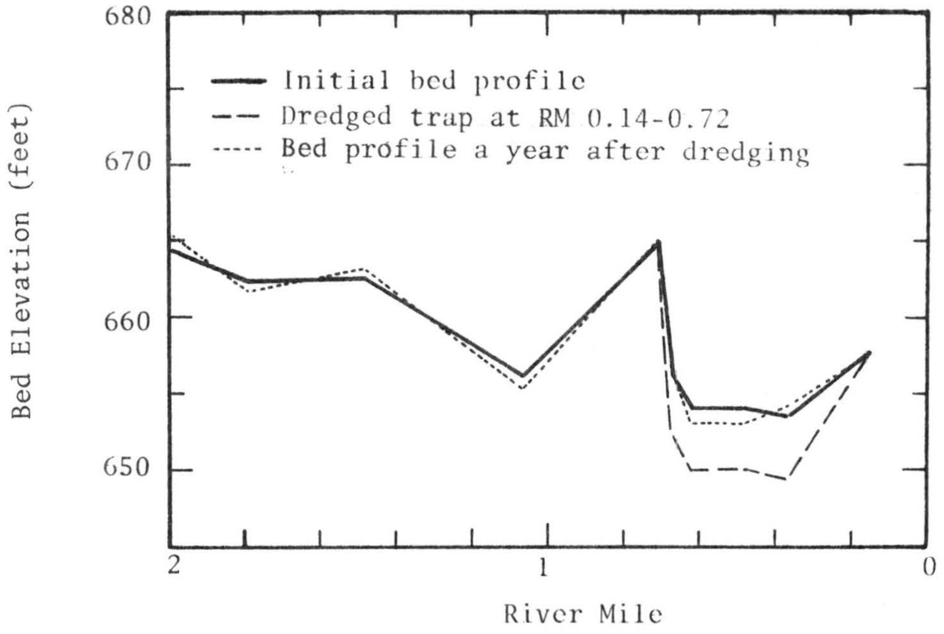


Figure 10. Bed Elevation Changes in the Chippewa River near the Dredged Sedimentation Trap

In summary, this alternative would require re-dredging of the sedimentation trap periodically for it to remain effective. Also, this alternative would not reduce erosion problems in the Chippewa River. This alternative can only be justified if the cost is competitive with that of other alternatives and if the dredged material has commercial value or can be placed in the riverine environment without causing significant adverse impacts therein.

3.2.3 Alternative 3: Establish a Meander Pattern in the Chippewa River below Durand

According to a study of the Chippewa Geomorphology (Simons, et al., 1976), it appears technically and physically feasible to induce a meandering pattern in the Chippewa River below Durand. This would reduce the gradient of the channel, less sediment would be eroded from the banks and more would stay within the channel system. The meandering could be established by artificially placing a meander bend near the location shown at the top of Figure 11. coupled with the construction of wing dams and bank revetment at proper locations.

The development of the meandering river would be a slow process. It would require considerable time to improve conditions in the Mississippi River. To accelerate the establishment of the meandering channel, additional loops could be dredged along the river at proper locations. The established meandering channel would be similar to the one shown in Figure 11. This would increase the sinuosity of the river reach from 1.06 to 1.2 and decrease the slope from 1.76 to 1.55 feet/mile, making this river reach more comparable to the upper river.

With the reduction of slope after development of the meandering river, the flow velocity would decrease. The sediment supply from the Chippewa to the Mississippi River would be reduced by about 10 percent based on routing the 1965 hydrograph through the mathematical model.

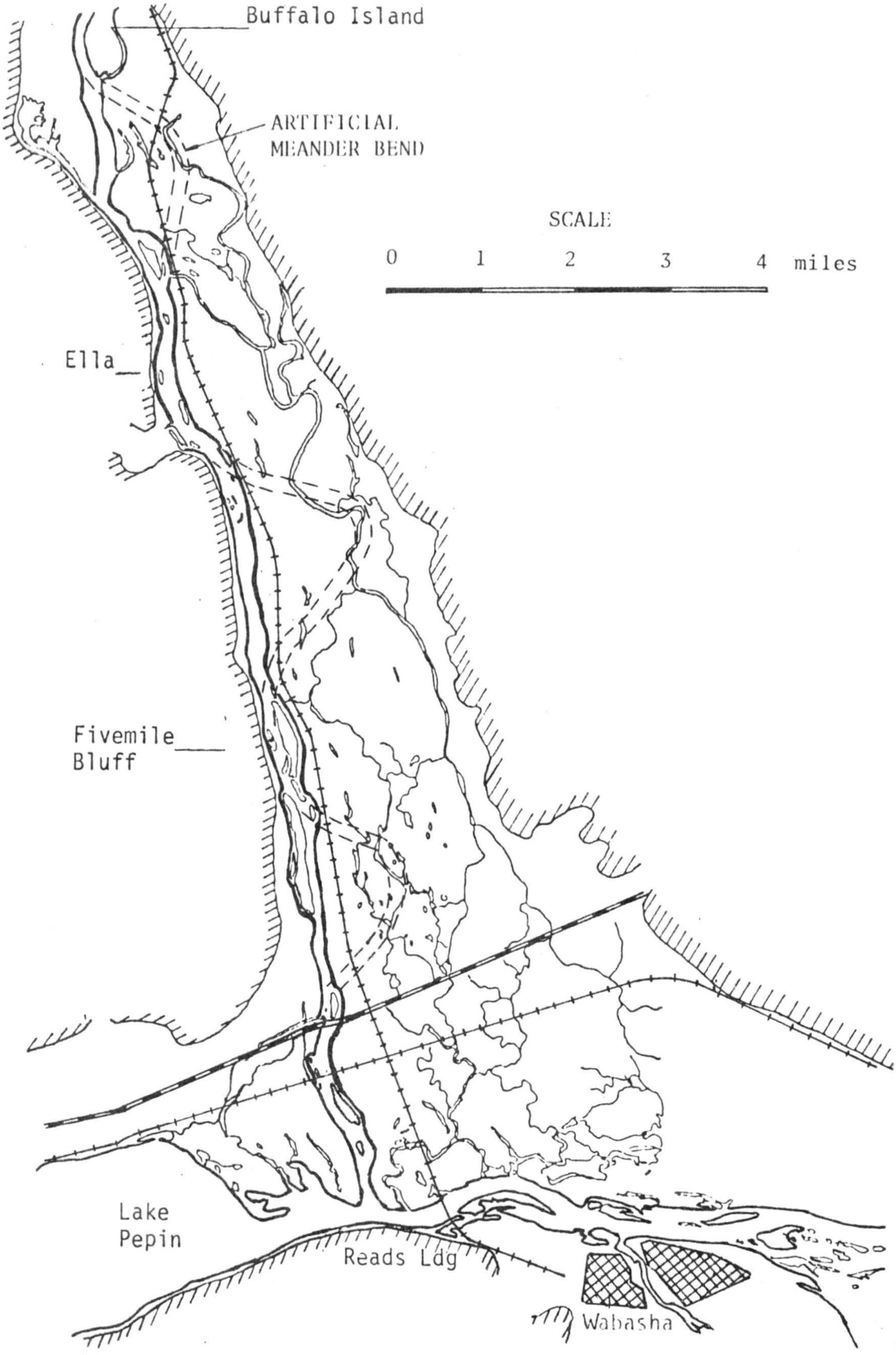


Figure 11. Location of Alternative 3: Establish a Meander Pattern in the Chippewa River below Durand

This reduction would not significantly change the dredging requirements and sedimentation patterns in the Mississippi River. Furthermore, since the sediment load entering this reach from upstream would not be reduced by this alternative, deposition would occur in this reach during and after development of the meandering channel. This could complicate the development and maintenance of the meandering channel.

In summary, the Chippewa floodplain below Durand would be extensively affected. The cost of implementing this alternative would be relatively large. In addition, the railroad located on the east Chippewa floodplain would need to be relocated. This would add to the expense of this alternative. Therefore, considering the costs and benefits, this alternative is not recommended unless environmental improvements within the Chippewa River can justify the cost.

3.2.4 Alternative 4: Divert a Portion of the Chippewa River Flow into Lake Pepin with and withouth dredging

Diversion of a portion of the Chippewa River water and sediment into Lake Pepin would reduce the direct sediment supply from the Chippewa to the Mississippi River. A diversion channel could be constructed by enlargement of an existing stream that connects the Chippewa River near river mile 2.2 and the Lower Lake Pepin as shown in Figure 12. The diversion system should require a diversion dam to control the diversion rate and to help stabilize the riverbed. The dimensions of the diversion channel and diversion dam examined in this study are given in Figure 13. Because the diversion channel would be constructed in the sandy soil, a bank slope of 1:3 was selected. The length of the diversion channel would be about 2.5 miles long with a bed slope of 1.32 feet/mile. Its capacity would be about 10,000 cfs. The diversion dam would provide a control location 670 ft above mean sea level. The resulted diversion system

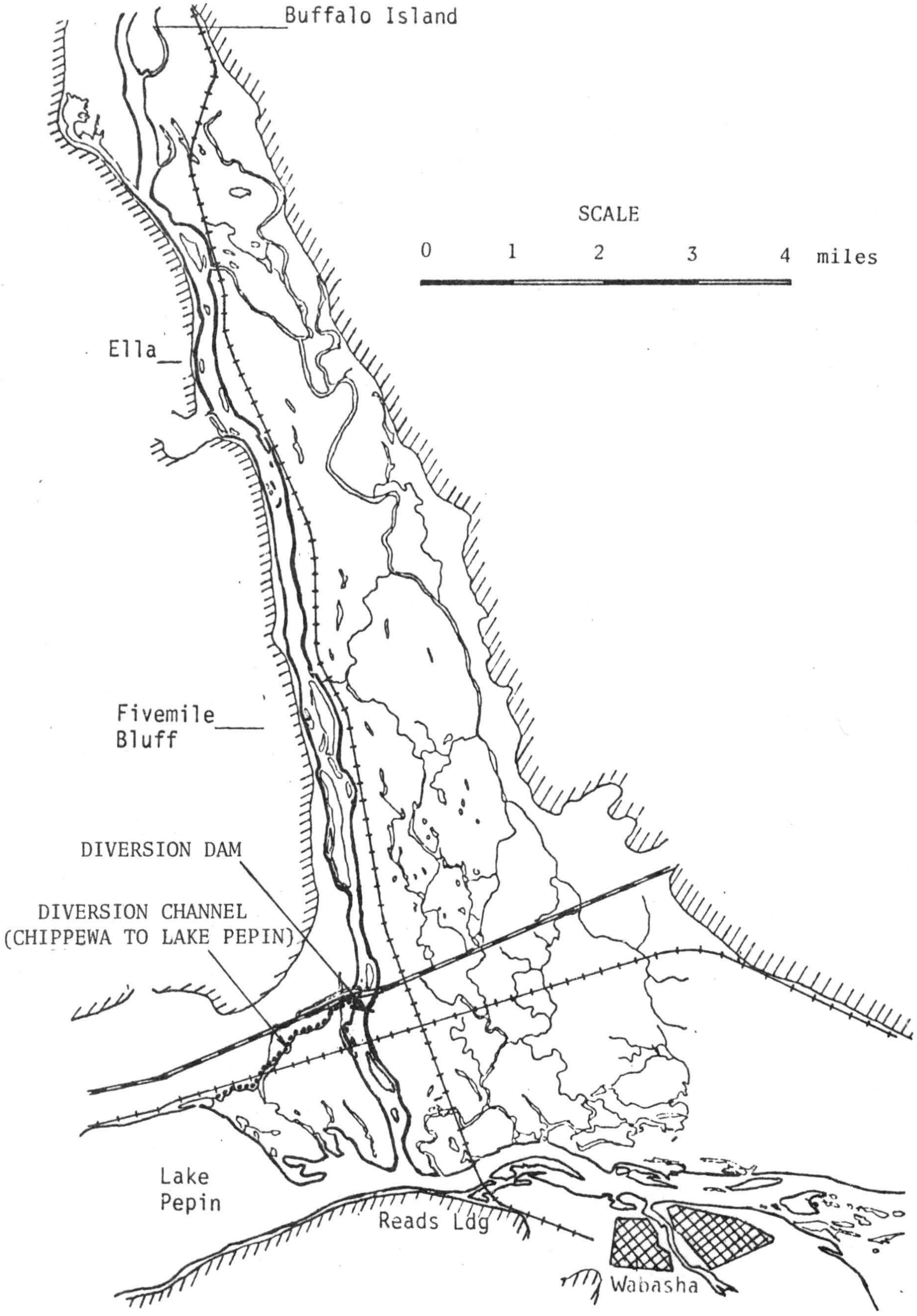
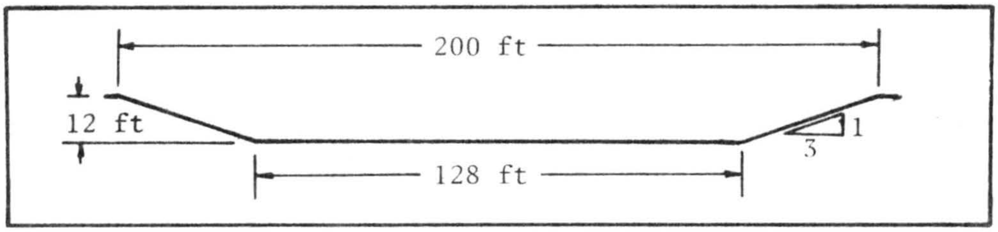
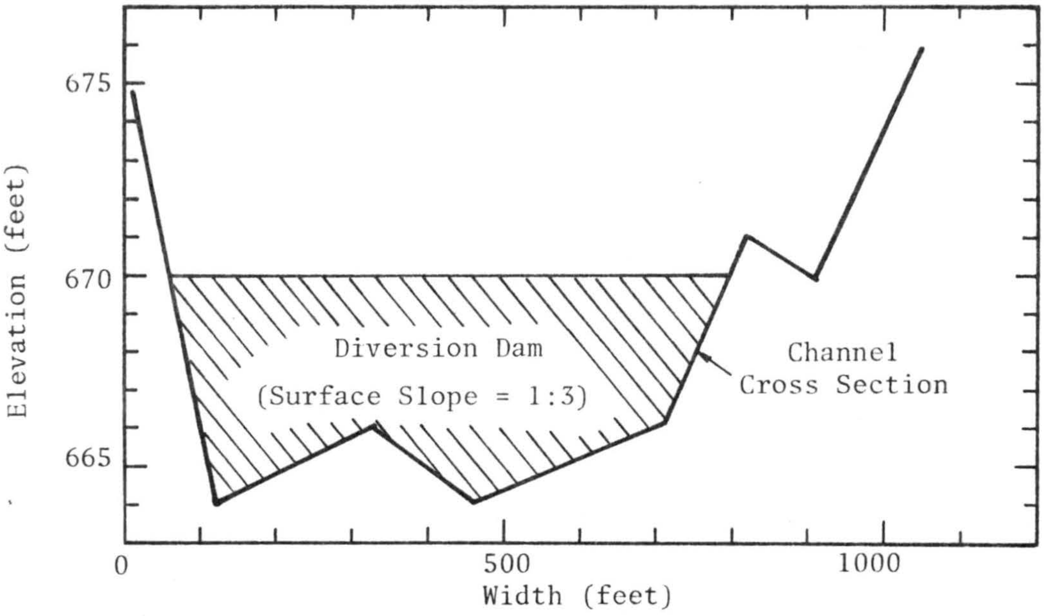


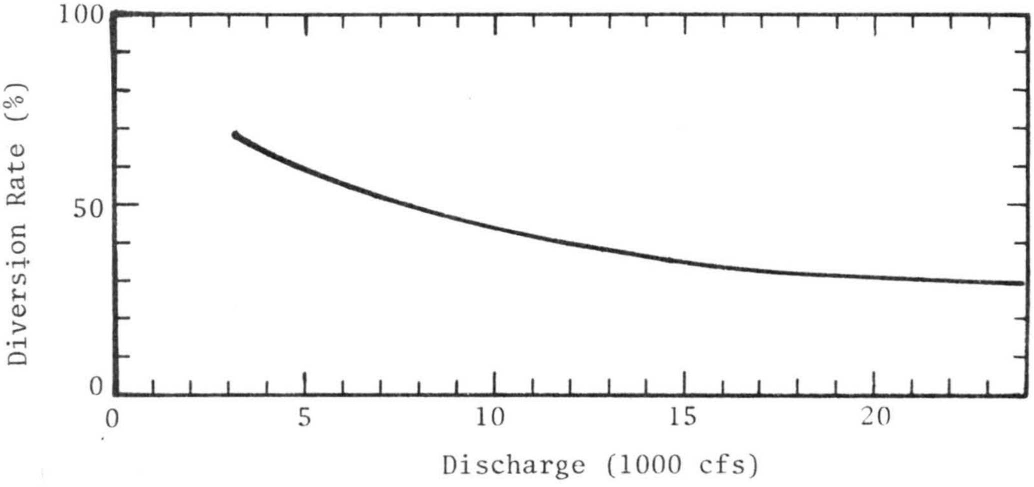
Figure 12. Location of Alternative 4: Divert a Portion of the Chippewa Flow into Lake Pepin



(a) Typical cross section of Diversion Channel



(b) Diversion Dam at River Mile 2.1



(c) Diversion Rate

Figure 13. Cross Section of Diversion Dam Connecting the Chippewa River and Lake Pepin and its Diversion Rate

would divert about 30 percent of the Chippewa flow at high stages (see Figure 13c). This would lower the average flood stage (Q = 35,000 cfs) by 2.5 ft in the river reach downstream of the diversion dam if the backwater effect from the Mississippi River is negligible. Due to this reduction of stage below dam, the stage immediately upstream of the dam would be lowered 1 ft than the normal flood stage. The hydraulic efficiency of this system was not evaluated. A better system could be developed later if this alternative is selected for detailed investigation.

The diversion structure would significantly affect water and sediment movement in the Lower Chippewa River and Pool 4. The sediment transported to the Mississippi would be reduced because of the diversion of sediment to Lake Pepin and because of deposition of sediment upstream of the diversion dam and the backwater effects from the Mississippi River. In the first year, the reduction in sediment supply to the Mississippi could be twice the diversion rate as shown in Figure 14. This figure was obtained by: (1) computing the annual sediment supply rates from the Chippewa River to the Mississippi River when routing the 1956 (2-year recurrence interval) and 1965 (5-year recurrence interval) hydrographs alternatively through the mathematical model for 6 years; during the routing, 30 percent of water and sediment was diverted from the Chippewa River between river mile 2.76 and 2.12; and (2) determining the sediment reduction rates achieved by the diversions by comparing the sediment supply rates computed for this alternative with the rates supplied by the existing system.

As the process continues, the river reach near and below the diversion structure would approach equilibrium. Aggradation and degradation would occur immediately upstream and downstream of the diversion dam, respectively at a rate of about 0.2 feet/year. This rate of change would decrease with

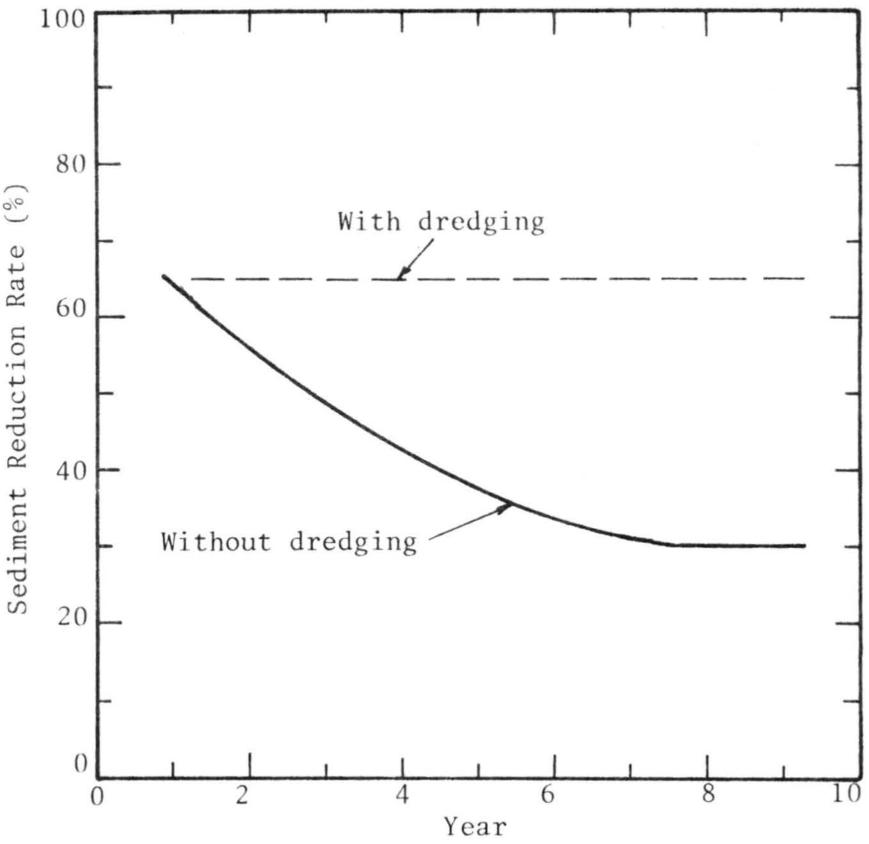


Figure 14. Reduction Rate of Sediment Supply from the Chippewa to the Mississippi River due to Diversion of 30 percent of Chippewa Flow to Buffalo Slough

time as the new system approached equilibrium. Some deposition would occur near the lower end of the Chippewa River. The sediment reduction rate would approach the diversion rate within about seven years after the construction if the deposited sediment was not dredged (see Figure 14). The effect due to this reduction of sediment supply on the Mississippi River would be similar to that casued by Alternatives 1 and 2 except that reduction of dredging requirements would vary. Again this alternative would not reduce bank erosion conditions in the Chippewa River.

Approximately 100,000 tons of sediment would be diverted in a year from the Chippewa River to Lake Pepin. Most of this sediment would be deposited near the mouth of the diversion channel, forming a delta in Lake Pepin. The delta would grow about 3 feet in height and propagate downstream with a speed of about 0.3 mile per year. This deposition would cause backwater effects in the diversion channel enhancing the deposition in the diversion channel. The deposition would continue, and eventually, if the diversion channel was not maintained, it would fill with sediment. If dredging was utilized to maintain the diversion channel, the placement of dredged material would be a problem and some of the diverted sediment would accelerate shoaling in Lake Pepin. Also, the diverted water would inundate about 100 acres of forest and wetland along the diversion channel.

In conclusion, this alternative would be an effective way to reduce the sediment inflow from the Chippewa to the Mississippi River. However, the initial construction cost as well as the subsequent maintenance expense would be high. The dredging required for construction and maintenance of the diversion channel could adversely affect the river environment. Bank erosion in the Chippewa River would not be reduced. The diversion dam would hinder boating. Also, the diverted sediment would accelerate shoaling in Lake Pepin which has already been identified as a problem.

3.2.5 Alternative 5: Divert a portion of the Chippewa Flow into a Sedimentation Basin through Buffalo Slough With and Without Dredging

According to the geomorphic study of Pool 4 (Simons, et al., 1976), the flow in the Chippewa was at one time divided with half in the present channel and half in Buffalo Slough. The Chippewa River below Durand shifted to a straighter, steeper course and gradually increased its capacity. This caused the deterioration of Buffalo Slough. Therefore, the idea here is to reverse this situation to create a dual channel system and divert a portion of the Chippewa sediment to a sedimentation basin formed by the backwater of Pool 4.

The diversion channel may be constructed by dredging the floodplain as shown in Figure 15 to divert the Chippewa River flow to Buffalo Slough. The impacts of this alternative on the Lower Chippewa basin would be enormous. By routing the 1956 and 1965 hydrographs alternatively for six years and diverting 30 percent of water and sediment from the mathematical model between river mile 10.6 and 9.9, it was found that deposition would occur in the Chippewa River above the diversion dam, degradation would occur immediately below the diversion dam, and deposition would occur some distance below the dam at a rate of about 0.2 feet/year.

The flood stage (for Q = 35,000 cfs before diversion) downstream of the diversion dam would be lowered by about 2 ft less than the normal flood stage, while the stage upstream of the diversion dam would remain approximately unchanged compared to the normal flood stage.

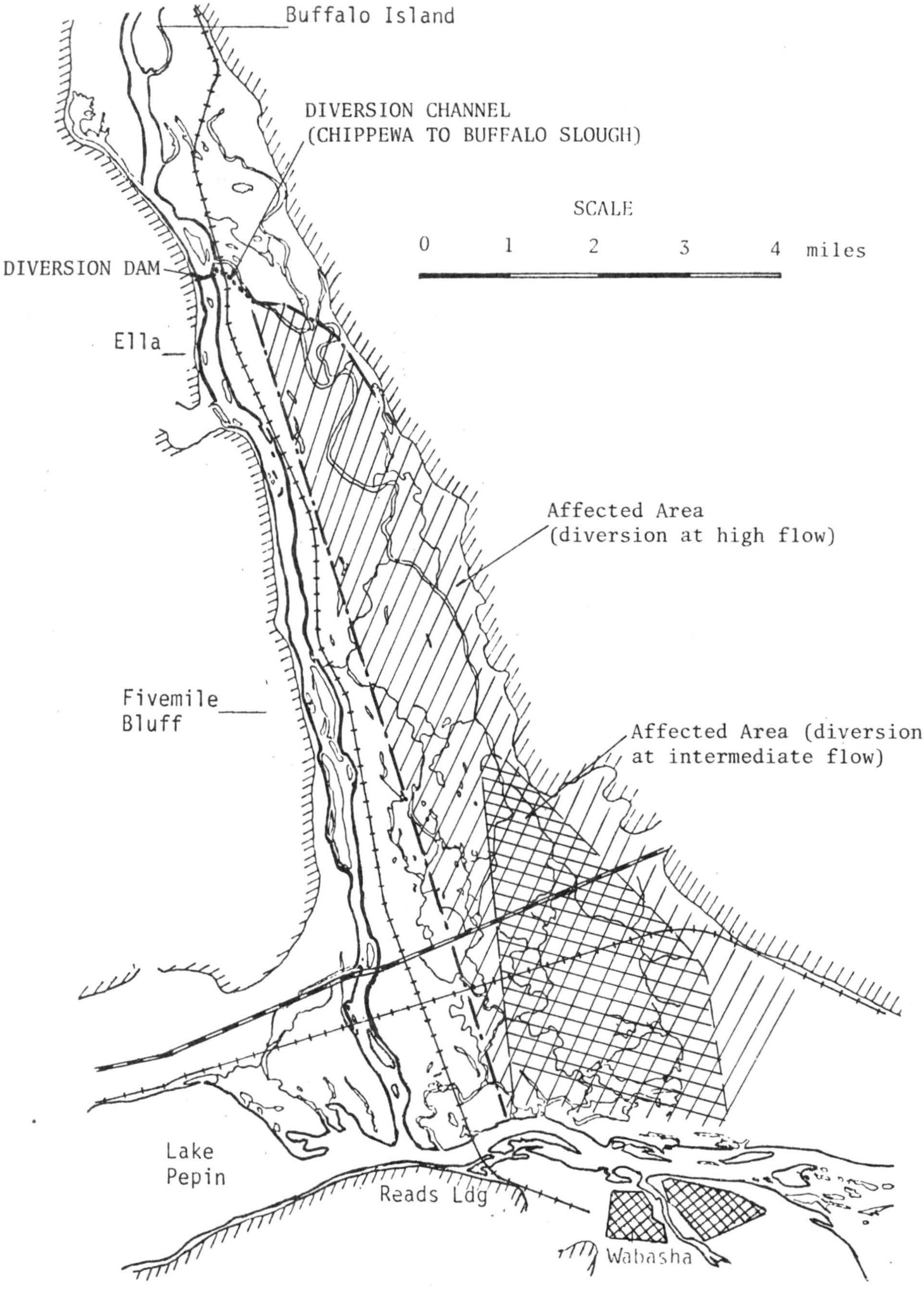
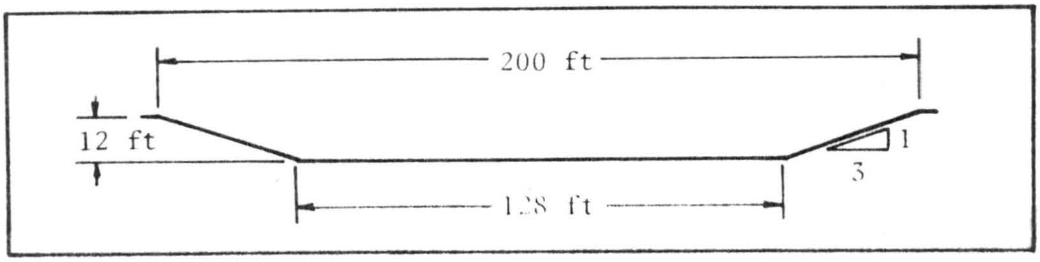
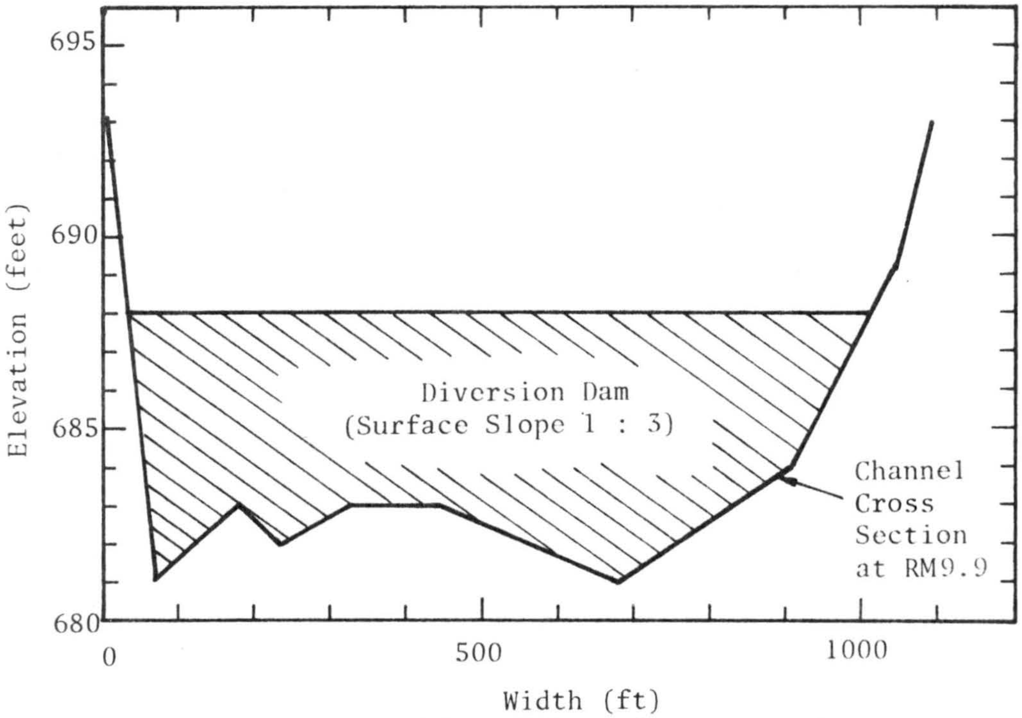


Figure 15. Locations of Alternative 4: Divert a Portion of the Chippewa Flow into a Sedimentation Basin through Buffalo Slough

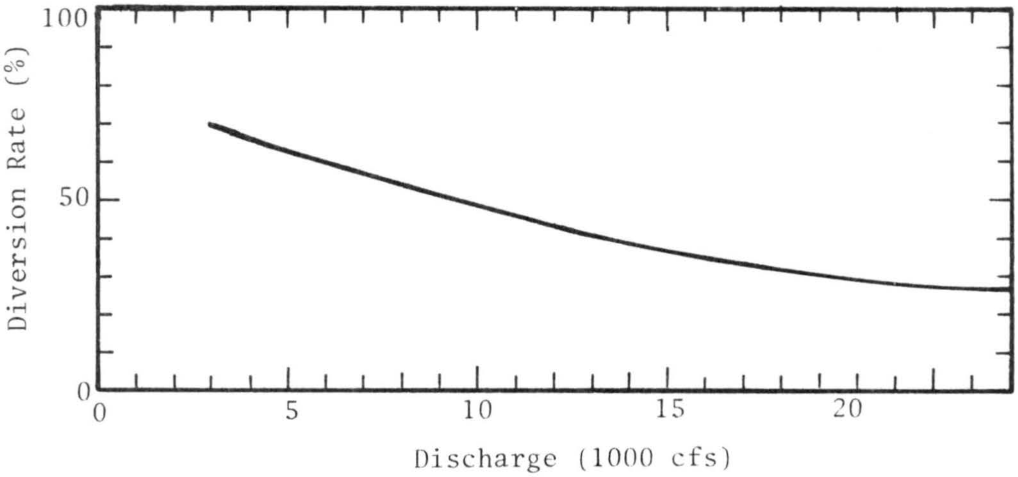
The extra water and sediment diverted through Buffalo Slough would cause significant impacts on the east floodplain along Buffalo Slough and on the backwater area of Pool 4. The dimensions of the diversion channel and diversion dam are shown in Figure 16. This system would be capable of diverting 30 percent of the Chippewa flow into the sedimentation basin at high flow. According to an estimation using the 1937 cross-sectional survey data of the Lower Chippewa River Basin below Durand (U.S. Army District, St. Paul, 1937), it was found that the existing Buffalo Slough network above river mile 4 could carry about 4,000 cfs without inundating the floodplain. However, the network below river mile 4 could only convey 1,000 cfs. Considering the diversion channel system in Figures 15 and 16, the floodplain along Buffalo Slough would be inundated at intermediate and high flows at the early stage of adjustment after diversion. Part of diverted sediment could return to the Chippewa or directly into the Mississippi River. The affected areas at intermediate flow would be about 3,000 acres of forest and wetland along Buffalo Slough below river mile 4 (Figure 15). At high flow, about 8,000 acres of floodplain would be inundated. Later on, as the system adjusted itself to the additional water, Buffalo Slough would enlarge increasing its capacity. Thereafter smaller areas of floodplain would be inundated. This extra water could improve the water quality and enhance fish and wildlife habitats. However, as the sediment continually flowed into the area, the newly created addition to the system would deteriorate unless proper maintenance was provided. Also, relocation or protection of the railroad on the floodplain could be necessary.



(a) Typical Cross Section of Diversion Channel



(b) Diversion Dam at River Mile 9.9



(c) Diversion Rate

Figure 16. Cross Sections of Diversion Channel and Diversion Dam Connecting the Chippewa River and Buffalo Slough and its Diversion Rate

Due to the sediment diversion and the deposition of sediment on the Chippewa bed, the reduction of Chippewa sediment to the Mississippi River could be twice the diversion rate. As the process continued the Chippewa River would approach a new equilibrium if the deposited sediment was not dredged, and the sediment reduction rate would approach the diversion rate (see Figure 17). The effects due to this reduction of sediment supply on the Mississippi River would be similar to those achieved by Alternatives 1 and 2.

In conclusion, this alternative is quite similar to Alternative 4 except that the Chippewa River below the diversion dam would require a longer period of time to reach a new equilibrium. The flow would become shallower below the diversion dam. Also, the area affected by this alternative would be larger and the river response is less predictable.

3.2.6 Alternative 6; Construct a Low-Head Dam at the Lower End of the Chippewa River

Construction of a low-head dam at the lower end of the Chippewa River would raise the Chippewa outlet base level. This would enhance deposition above the dam and thereby reduce the sediment inflow from the Chippewa River to the Mississippi River. On the other hand, the flood level in the Chippewa basin near its mouth would be raised to a higher level and its flow would inundate a larger area. The magnitude of the effects of the low-head dam on the sediment supply and the flood stage depend mainly on the height of the dam.

The low-head dam would effectively reduce the sediment supply immediately after its closure. However, its effectiveness would decrease with time if the Chippewa banks were not protected to reduce current erosion rates and/or the deposited sediment behind the dam was not removed. For example, based on the results of the mathematical model considering a dam with a crest height of 664 feet above mean sea

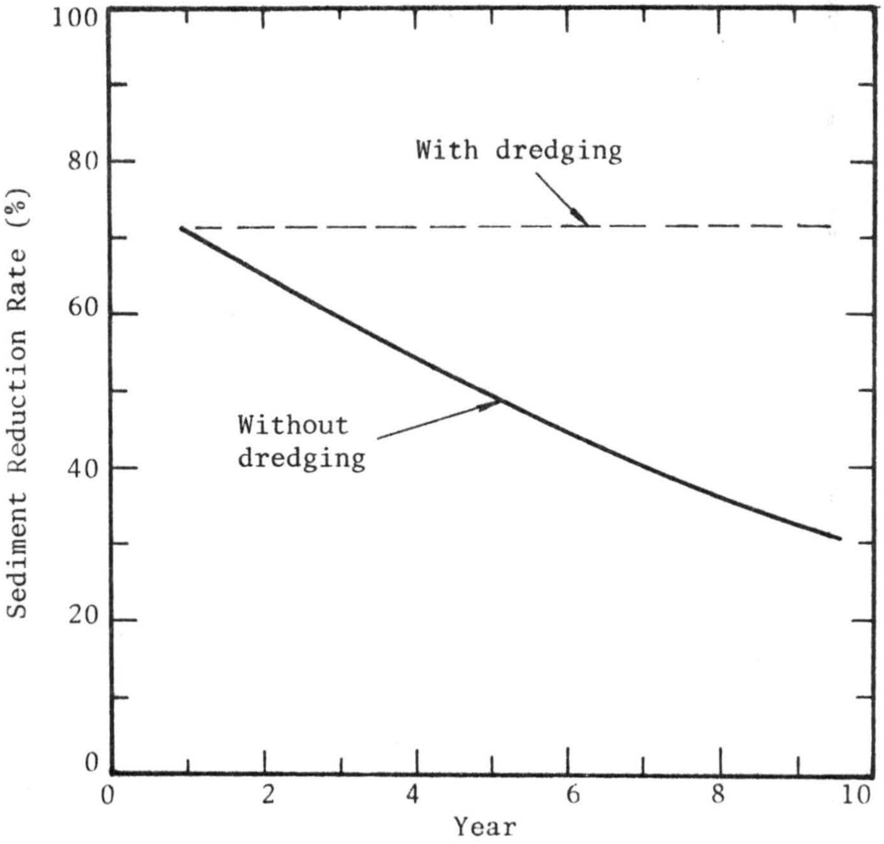


Figure 17. Reduction Rate of Sediment Supply from the Chippewa to the Mississippi River due to Diversion of 30 percent of the Chippewa Flow into Buffalo Slough

level (about 6 feet above the riverbed) as shown in Figure 18, the dam would reduce the sediment supply from the Chippewa to the Mississippi River by about 50 percent (about 190,000 tons of Chippewa sediment) immediately after its closure in an average year. However, the reduction rate would decrease to about 30 percent six years later as shown in Figure 19, unless the sediment deposited upstream of the dam was removed. Deposition behind the dam would reach the dam crest in about 10 years, reducing the channel bed slope below river mile 10 (see Figure 20). Similarly, a dam with crest height of 661 feet (about 3 feet above the riverbed) would reduce the sediment supply by about 30 percent immediately after its construction. The reduction rate would reduce to 20 percent six years later.

The 6-foot dam would raise the average flood stage by about 2 feet above the normal flood stage (without the dam) immediately upstream of the dam. Similarly, the 3-foot dam would raise the average flood stage by about 1.5 feet. Passing of a 100 year flood over the 6-foot dam would add about 3.5 feet to the normal 100-year flood stage. The effects of these increases in flood stage on the Chippewa floodplain would be limited to below river mile 6. These effects would not significantly increase the inundated area since the floodplain in this area is largely submerged by normal floods. However, it would be possible for the flood flow to bypass the dam, changing the channel alignment. Protection of river banks at the dam could be required. Additional information on bank stability near the dam site is needed to evaluate the probability of the Chippewa flow bypassing the dam.

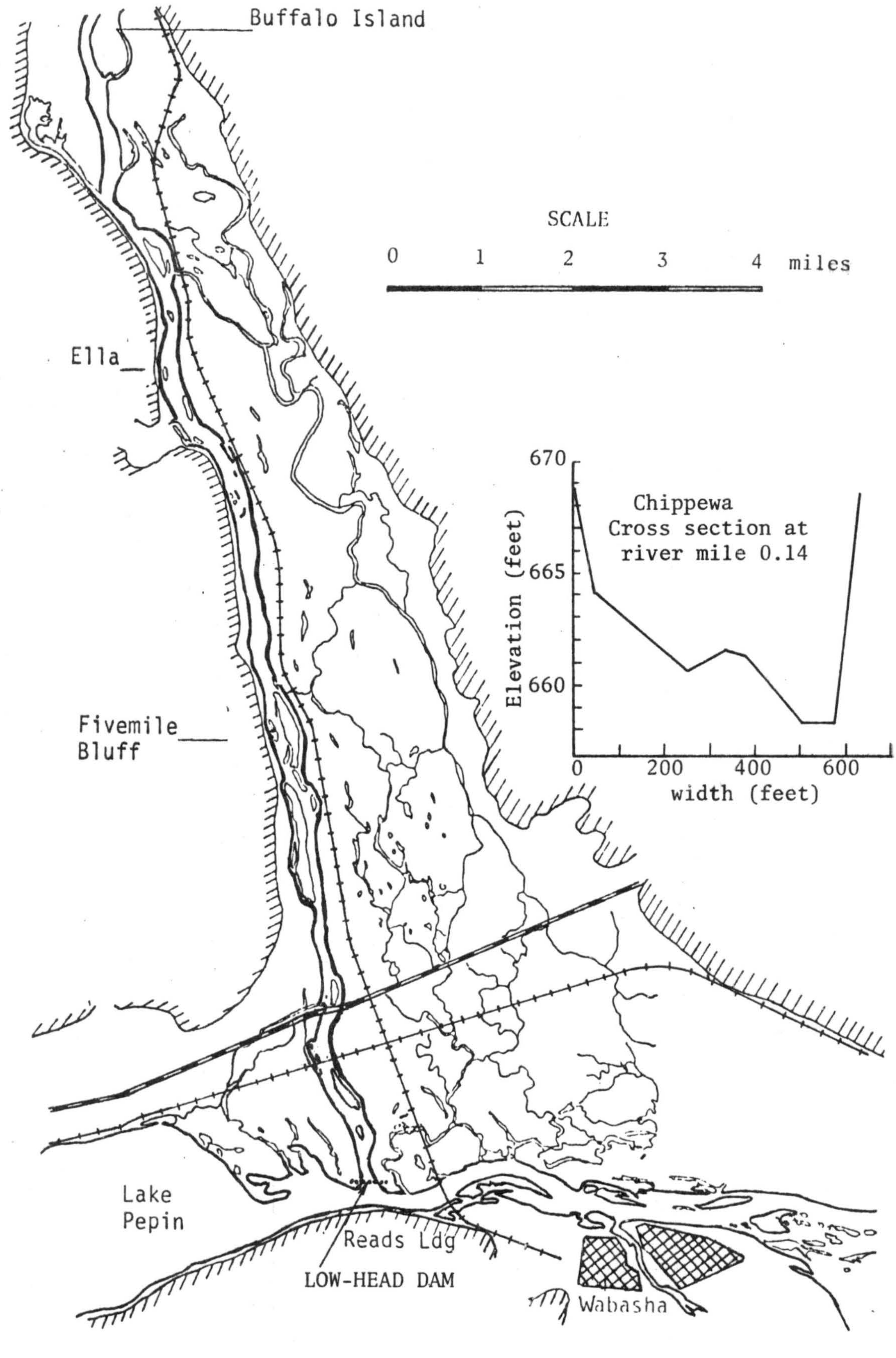


Figure 18. Location of Alternative 6: Construct a Low-Head Dam at the Lower End of Chippewa River

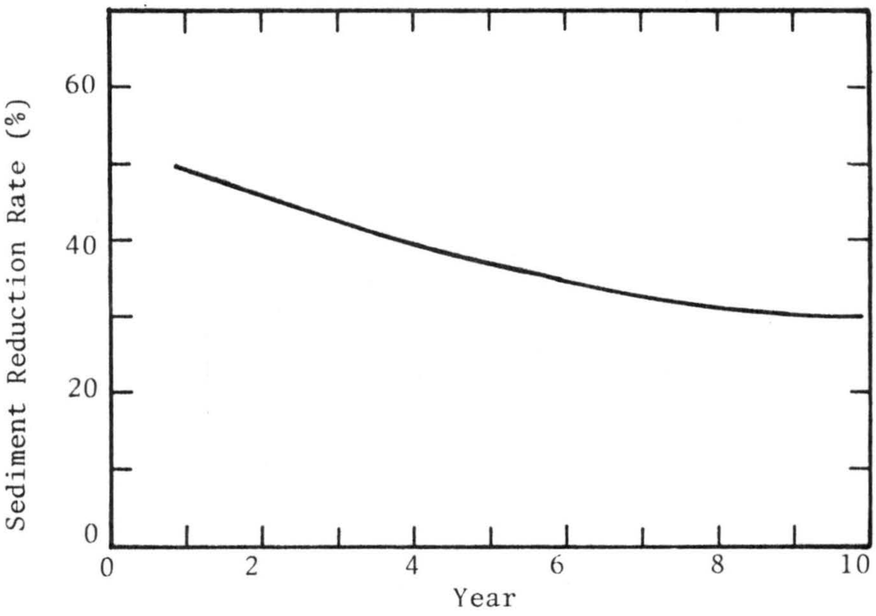


Figure 19. Sediment Reduction due to Construction of a 6 - Foot Dam near the Chippewa Mouth

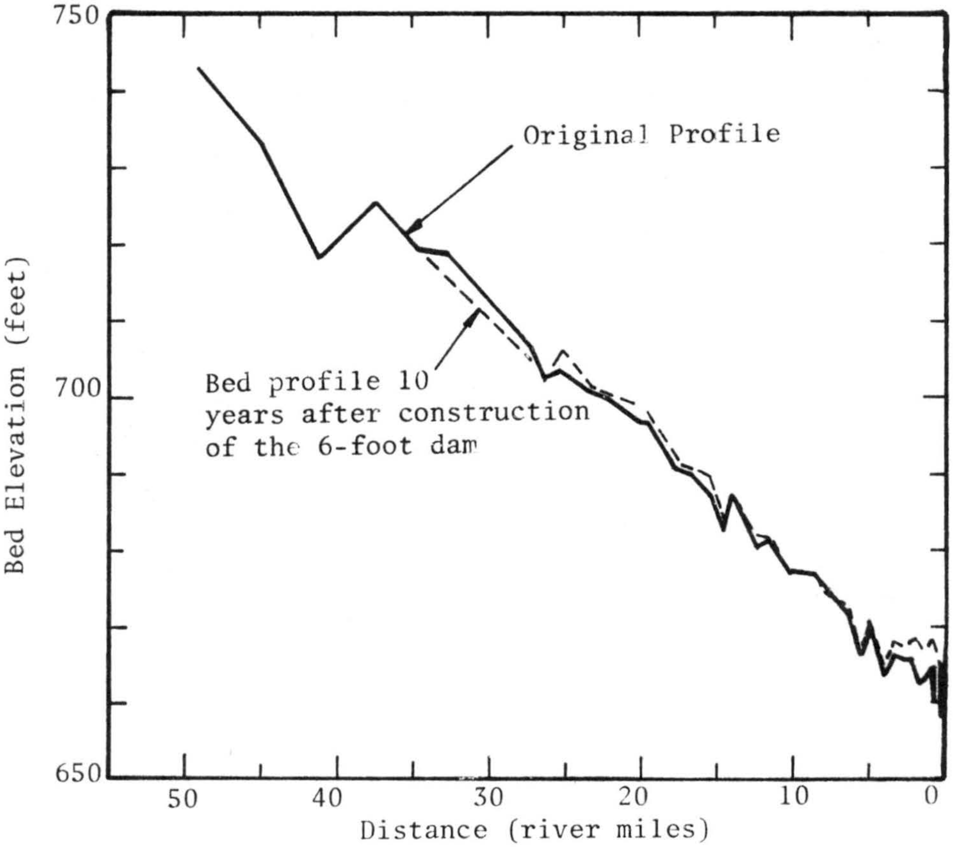


Figure 20. Bed Elevation Change in the Chippewa River due to Construction of a 6 - Foot Dam near the Chippewa Mouth

The reduction in sediment supply from the Chippewa to the Mississippi River due to the construction of the closing dam would be similar to that stated in Section 3.2.1. However, the effect would decrease with time because of the deposition behind the closing dam.

In summary, the construction of the low-head dam at the lower end of the Chippewa River would reduce the sediment supply from the Chippewa to the Mississippi River and thereby reduce the maintenance requirement in the Mississippi and the sedimentation rate near the mouths of the backwater areas. However, the effectiveness of the dam would decrease with time if the deposited sediment behind the dam was not removed. Considering cost, there would be the initial construction expense as well as cost for continuous maintenance. In addition, the dam would raise flood stages and possibly increase flood damage in a 6-mile reach immediately above the dam.

3.2.7 Alternative 7: Construct a Series of Low-Head Dams on the Lower Chippewa River

A series of low-head dams could be constructed on the Chippewa River to reduce the channel gradient, the velocity and sediment transport. This would help reduce erosion of the Chippewa's banks and would reduce the sediment supply to the Mississippi River. The principle of this alternative is quite similar to that of Alternative 6. Based upon an examination of channel patterns, flow conditions and potential erosion sites in the Chippewa River below Eau Claire, four low-head dams are proposed as shown in Figure 21. Dams 1, 2 and 3 would raise the water surface behind the dams to reduce the ability of the Chippewa to erode its banks at the lower end of Elk Creek, along Happy Island and along Ninemile Island, respectively. Dam 4 would make this alternative effective right after their closures.

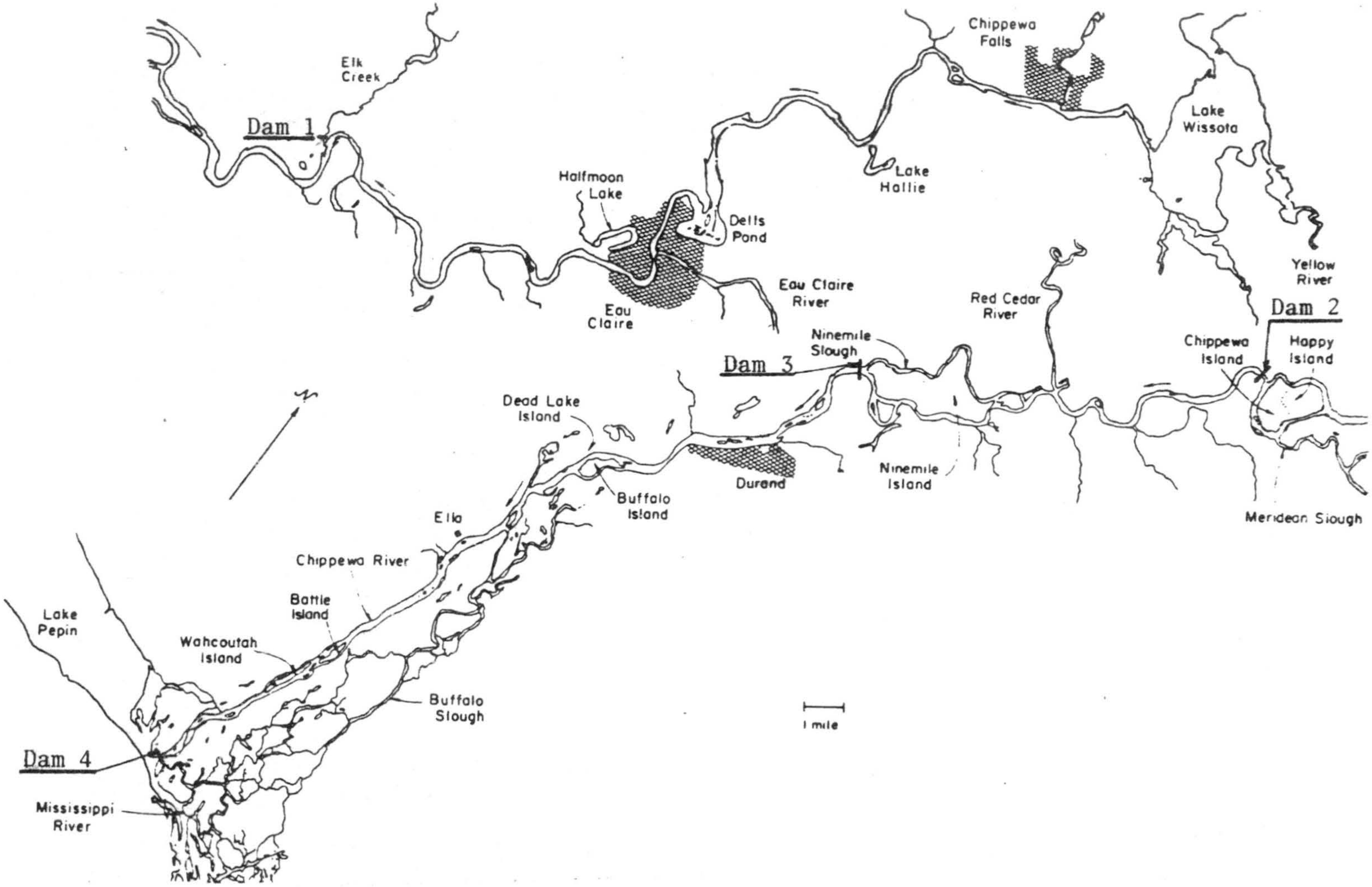


Figure 21. Location of Alternative 7: Construct a Series of Low-Head Dams

Dams 1, 2 and 3 would be about 3 feet high and 600 feet wide. Dam 4 would be about 4 feet high and 200 feet wide.

The riverbed of the Chippewa River would aggrade above the dams at a rate of about 0.2 feet/year based on the results of the mathematical model study, and there would be limited local degradation below the dams. The bed elevation would aggrade to the dam crests in about 8 years if deposited sediment were not removed. Each dam would increase the average flood stage immediately upstream of the dam by about 1.5 feet. This would reduce the flow velocity by 15 percent and would decrease channel erosion and sediment transport. Further study would be required to assess effect of this velocity reduction on channel stability. The increases in flood stages would inundate an additional 870 acres of the Lower Chippewa floodplain. The extra inundated areas would be within three miles of each dam on their upstream sides. Specifically, Dam 1 would cause inundation of 70 acres of farm land. An additional 300 acres of forest land adjacent to Ninemile Island would be inundated by Dam 3. Dam 2 would inundate an additional 300 acres of farm land and 200 acres of forest land near Happy Island and could affect the town of Meridean. Figure 22 shows the areas inundated by the average flood ($Q \approx 35,000$ cfs) and extra inundated areas caused by the backwater effects of the low-head dams. The figure was developed by plotting the computed flow lines on the 1972 U.S.G.S. quadrangle maps. Also, the low-head dams would block boat traffic unless special passages were incorporated into the design.

The low-head dams would reduce the sediment supply to the Mississippi River about 40 percent immediately after their closures. However, their effectiveness would decrease with time to 20 percent in 8 years if the deposited sediment was not removed. This reduction in

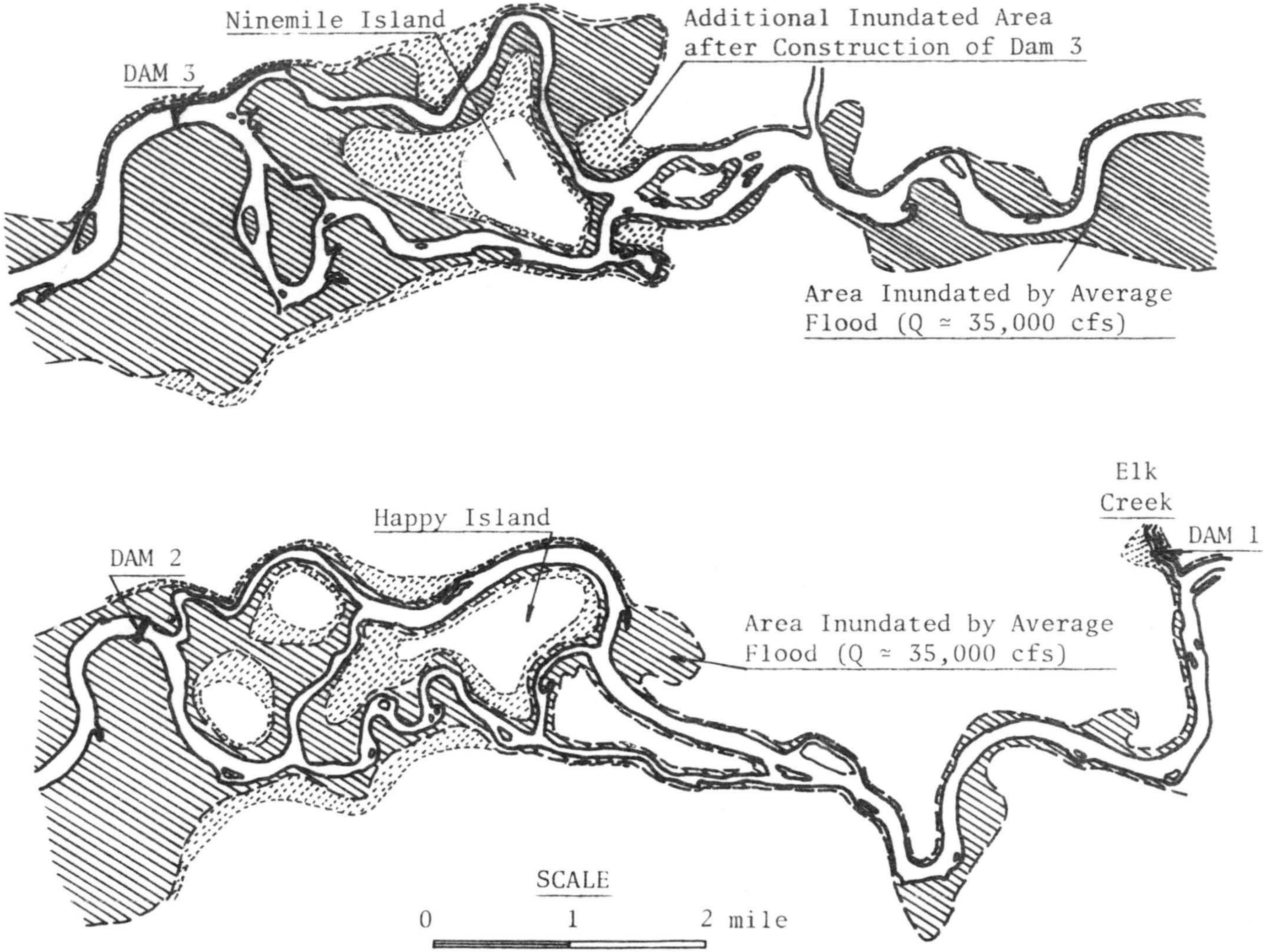


Figure 22. Floodplain in the Chippewa River Basin Inundated by an Average Flood with and without Low-Head Dams

sediment supply would decrease the dredging requirement in the Mississippi River accordingly.

3.2.8 Alternative 8: Establish Streambank Erosion Controls and Supplemental Sediment Controls

A geomorphic study of the Chippewa River indicates that the sediment transported from this river to the Mississippi River mainly originates from erosion of the channel and banks below Eau Claire. The most efficient way to reduce the sediment supply and to save the property from erosion is to stabilize the banks and/or to deflect the flow from these areas. Three high banks subjected to significant erosion were identified. They are (1) along the right bank of Ninemile Slough (Yellow Bank), (2) opposite Happy Island (Happy Bank) and (3) at Lower Elk Creek. These banks are more than 100 feet in height and are being undermined at the toe of the banks causing slides into the channel. Because of the decrease in flow rate along Happy Bank after a natural cutoff through Happy Island, erosion of Happy Bank would not be a severe problem.

Many low banks along the Chippewa River below Eau Claire are also being eroded. As stated in Section 2.1.1 and shown in Figure 2, areas of most severe erosion occur in the meandering reach of the Chippewa River between Eau Claire and Durand and the erosion is greatest along Ninemile Island between river mile 18 and 32. This erosion has lowered the flow line and could cause further cutting of the upstream riverbed and additional bank erosion. The same condition occurred along Happy Island after the natural cutoff occurred.

Various channel modifications and structures have been developed to control river flow alignment and to stabilize the banks. Most have been developed through a trial and error process aided, in some instances, by hydraulic model studies. Bank protection works may be broadly classified into two groups: direct protection and indirect protection. Direct protection includes works done directly on the bank itself including protection of the embankment, the upper bank and toe against erosion. As such works continuously cover the banks, they may be referred to as continuous bank protection. Indirect protection utilizes those works that are not constructed directly on the banks but in front of them or normal to them to reduce the erosive force of the current either by deflecting the current away from the banks and/or by inducing deposition in front of them.

Dikes, retards and jetties are the three types of devices most commonly used for river training and indirect bank protection. In general, dikes extend outward from the bank into the channel at some angle thereto, to deflect the current. Retards are permeable devices placed parallel to embankments and river banks to decrease the stream velocities and prevent erosion. A jetty field usually consists of steel or wooden jacks tied together with cables. Its purpose is to add roughness to a channel or overbank area to train the main stream along a selected path and to encourage advantageous deposition of sediment to improve channel and floodplain alignment and stability.

The most common direct bank protection is rock riprap. The banks are covered with large rocks underlain by an appropriate filter to prevent bank and toe erosion. When adequate riprap sizes are not available, rocks of cobble sizes may be placed in wire baskets made of galvanized wire placed along the bank forming a riprap mattress. Sometimes, rock-fill trenches are used to protect banks from excessive erosion. Also, precast concrete blocks held together by steel rods or cables can be used to form a flexible mat to protect banks. Other types of mattresses such as woven willow, brush, woven lumber, asphalt, and soil cement mattresses are occasionally utilized to protect banks from erosion.

The selected method used for river training and bank stabilization depends upon such factors as the size of river (width, depth and discharge); type of river (meandering, braided or straight); sediment transport considering concentration and size distribution; length of river to be protected; availability of materials; environmental considerations; aesthetics; legal aspects; navigation, surface waves, recreation, agriculture, municipal and industrial purposes; and perhaps other factors. The best method is established by studying each individual case.

Table 2 is offered as a guide to assist the engineer with regard to selection of channel improvement, bank protection and river training works. The rivers are first categorized as to size and type. The descriptors large, medium and small are relative terms but this should not cause interpretive problem. Straight rivers are those which have a sinuosity less than 1.5. Note that long reaches may occur between river bends. These reaches that are essentially straight are included in the straight river classification. In Table 2 the X in the box indicates that consideration could be given to this particular device. The absence of a check mark in the box indicates that the device is not often used, but they may be considered under special circumstances. Additional information on river training and stabilization can be obtained from the publications by the Corps of Engineers, the U.S. Bureau of Reclamation, and the U.S. Department of Transportation.

TABLE 2. Guide for Selection of Methods and Devices for River Channel Improvement and Bank Protection Works.

Size of River	Type of River	Channel Improvement	Dikes			Retards		Jetties		Bank Protection					
												Mattresses			
			Timber	Stone-fill	Earth	Timber	Steel Jacks	Timber	Steel Jacks	Riprap	Rock Trench	Rock and Wire	Concrete	Other	Cribs
Large	Meandering		X	X	*	*		X		X	X	*	X	X	
	Braided	X	X	X	*	*		X		X	X	*	X	X	
	Straight		X	X		*		X		X	X	*		X	
Medium	Meandering	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Braided	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Straight	X	X			X		X		X	X	†		X	X
Small	Meandering	X				X	X	X	X	X	X	†		X	X
	Braided	X				X	X	X	X	X	X	†		X	X
	Straight	X								X	X	†		X	X

* Floodplain embankment protection

† Where large rocks for riprap are not available

To protect the three high banks previously identified and to prevent headcutting upstream of Ninemile Island and Happy Island, the construction of three closing dams at the locations shown in Figure 23 is suggested. Dam 1 would be about 200 feet wide and 6 feet high. This dam would raise the channel gradient of Lower Elk Creek, reducing stream erodibility and trapping some of the sediment. The dam would increase the average flood stage ($Q \simeq 35,000$ cfs) immediately upstream of the dam by about 2.0 feet. This stage increase would inundate an additional 80 acres of farm land.

Dams 2 and 3 would be about 300 feet wide and 7 feet high. These two dams would reduce the flow passing through the divided channels along Happy Island and Ninemile Island by about 25 percent (from 8,900 to 6,600 cfs), and 35 percent (from 12,000 to 7,500 cfs) respectively at an average flood ($Q \simeq 35,000$ cfs). The flood stages immediately upstream of the dams would be raised by 1 foot. Dam 2 would inundate an additional 150 acres of farmland and 100 acres of forest land near Happy Island. Dam 3 would inundate an additional 100 acres of forest land near Ninemile Island. The divided channels receiving the flows diverted by Dams 2 and 3 would experience an increase in stages and reduced headcutting. A certain degree of protection of river banks would be required to maintain the desired river alignment.

If closing dams are not acceptable in these river reaches, other methods as described above for controlling the bank erosion could be used to protect these high banks. Other erodible banks requiring protection include the banks: (1) between river mile 3 and 4, (2) between river mile 8 and 9, (3) between river mile 11.5 and 14, (4) near river mile 14.5 and 18.5, (5) between river mile 20 and 30, and

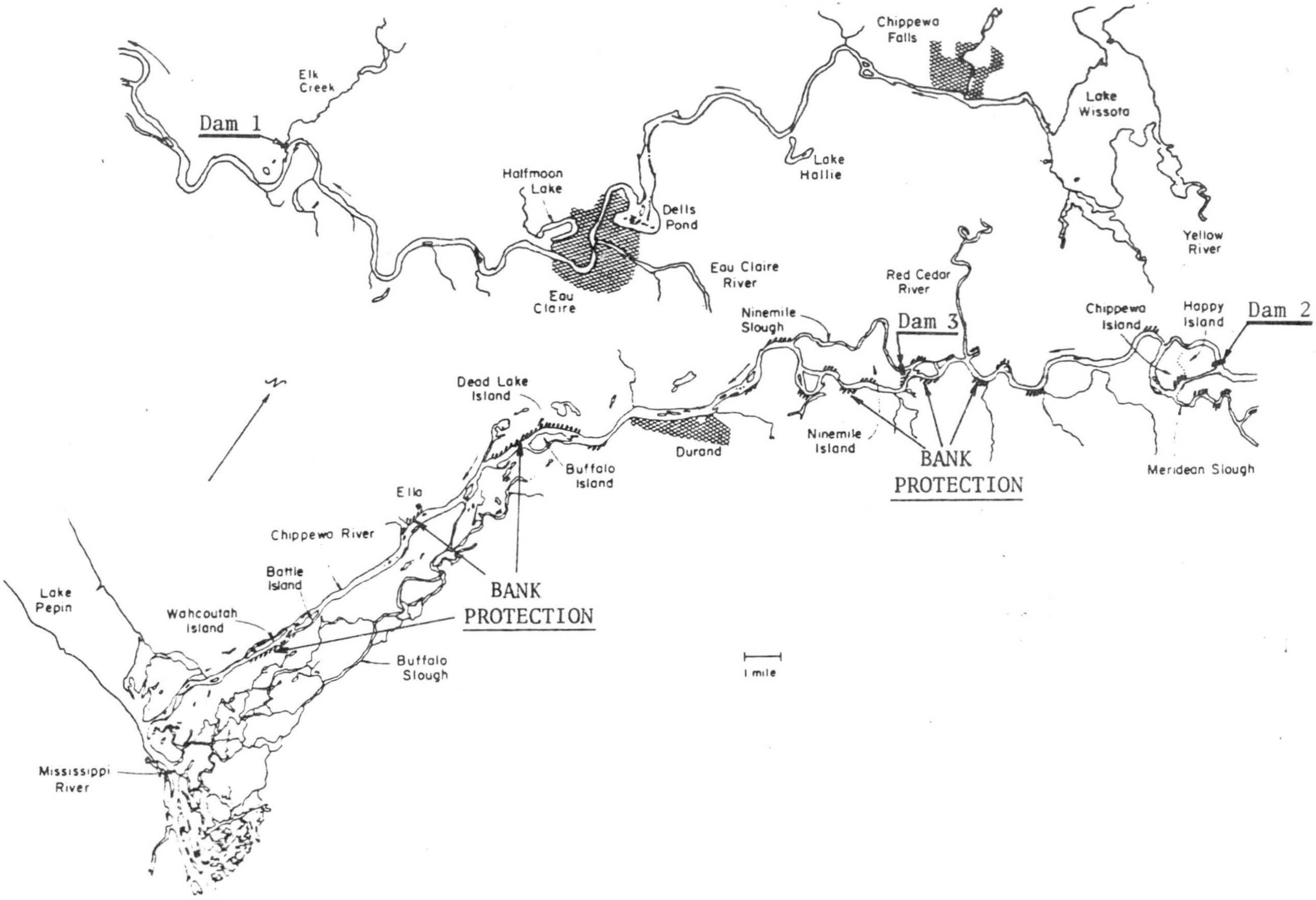


Figure 23. Some Locations of Alternative 8: Establish Streambank Erosion Controls and Supplemental Sediment Controls

(6) near river mile 36, 53, and 55 (see Section 2.1.1 and Figure 2.). Approximately 15 linear miles of river banks would require protection (see Figure 23). Detailed investigations would be required to identify suitable streambank erosion control measures and their impacts.

If the banks of the Chippewa were properly protected, the lands which are being eroded could be saved. The river basin could be further developed for recreation, navigation, agriculture, municipal and industrial purposes. However, the protection of banks would increase bed degradation due to the reduction in sediment supply from bank erosion. The degradation rate and magnitude would depend on the reduction of sediment supply and development of armoring of the bed. Based on a geomorphic analysis of the Chippewa River, it was found that the bank erosion contributed about 50 percent of bed-material load entering Pool 4. Assuming that the flow would erode the riverbed to obtain its full transport capacity and the bed degradation rate would be proportional to the historic rates of erosion, then a complete protection of river banks would result in the following riverbed degradation:

River Mile	Average Degradation Rate Over the River Reach (feet/year)
0 - 10	~ 0
10 - 14	0.06
14 - 18	~ 0
18 - 32	0.1

The development of an armor coat would cause the degradation rate to decrease with time and so would the sediment supply to the Mississippi River. It is then concluded that protection of the Chippewa banks would not immediately reduce the sediment supply to the Mississippi River. Some supplemental controls would be required if sediment supply was to be reduced immediately. The dredging of a sediment trap or construction of a low-head dam near the mouth of the Chippewa would provide good supplemental control. The effect of the sediment trap and low-head dam on sediment supply would be similar to that stated in Sections 3.2.2 and 3.2.6, respectively. Some low-head dams (check dams) could be constructed where degradation is expected to protect the bed from excessive erosion and to trap the sediment. These dams could be one to two feet high and about 650 feet wide. Potential construction sites are located downstream of Ninemile Island and at river mile 11. It appears that a combination of bank erosion control measures to protect the banks, the construction of check dams to control local degradation and the utilization of a sedimentation trap near the Chippewa mouth (or divert the Chippewa flow to Buffalo Slough) to immediately reduce the sediment supply, is a good alternative. When this system approaches equilibrium, the reduction in sediment supply from the Chippewa to the Mississippi River would be equal to the sediment load from the Chippewa banks. This new equilibrium condition would be approached in about 20 years (assuming the effects propagate at a rate of 1 mile/year as estimated from the mathematical model).

Chapter 4

SUMMARY AND RECOMMENDATION

4.1 Impacts of Alternative Measures on the Physical Environment

The impacts of the alternative measures studied in this project on the physical environment of the Mississippi and Chippewa Rivers are summarized in Table 3. The factors considered include: sediment reduction, time required to achieve the reduction, bank stability, geomorphic changes, hydrologic changes, affected areas and dredging requirements.

4.2 Identification of Feasible Alternative Measures

Considering the objectives of development in the Lower Chippewa Basin, the selected alternative measure should decrease bank erosion, decrease sediment supply to the Mississippi, and improve the river basin for recreation, navigation, fish and wildlife resources, agriculture, municipal and industrial purposes. Also, the alternative should have a favorable benefit-cost ratio. Among the eight alternative measures evaluated, two are considered to be impractical based on the discussions in Chapter 3 and the summary information in Tables 3 and 4. Table 4 gives the criteria for evaluation of each alternative. The two alternatives judged impractical are:

Alternative 3: Establish a meander pattern in the Chippewa River

Reasons:
- (a) Not an efficient method to reduce sediment supply
- (b) Large area affected
- (c) Relatively expensive
- (d) No reduction of bank erosion

Table 3 Summary of Impacts of the Alternative Measures on the Physical Environment

Alternative	Sediment Reduction	When Effective	Bank Stability	Hydrologic Changes	Affected Area in Chippewa	Geomorphic Changes and Dredging Requirements
1. Increase storage of existing flood control dam (Figure 4)	15-20% (additional 5-feet storage) 10-15% (additional 2.5-feet storage)	Immediately	Provides minor protection	Reduces the flood peak discharge by 6,000 cfs and flood stage by about 1.5-feet with additional 5-foot storage	Reduces the flood inundated area	1) Bank erosion and sediment supply would be reduced; 2) Effect of the reduction would propagate downstream in the Mississippi River at about one mile per year; 3) Dredging requirements and growth of natural levees in the Mississippi River would be reduced proportional to sediment reduction. The sediment reduction from the Chippewa River would become fully effective in the entire Lower Pool 4 reach below Lake Pepin in about 15 years and this would reduce the dredging requirement by about two-thirds of the sediment reduction rate from the Chippewa River; 4) Sedimentation in the backwater areas (mainly Robinson Lake and Big Lake) would not be significantly reduced except near offtakes from the Mississippi.
2. Dredge a sedimentation trap at the lower end of the Chippewa River (Figure 7)	Depends on ratio of the size of the trap to the annual sediment load. For example, a sedimentation trap of 400 feet deep, 600 feet wide and 1,600 feet long would reduce sediment supply by 50 percent.	Immediately	No improvement	Not significant	Mainly the disposal site	1) The dredged trap would fill periodically, often within a year; 2) The efficiency of this alternative would decrease with time unless the dredged trap is maintained annually; 3) Changes in geomorphology and dredging requirement in the Mississippi River would be similar to Alt. 1 if the trap is maintained.

Table 3. Summary of Impacts of the Alternative Measures on the Physical Environment (continued)

Alternative	Sediment Reduction	When Effective	Bank Stability	Hydrologic Changes	Affected Area in Chippewa	Geomorphic Changes and Dredging Requirements
3. Establish a meander pattern in the Chippewa River below Durand (Figure 10)	10% reduction	Slowly develop	Minor protection below Durand	Minor	Affect the floodplain area along the new channel.	1) Sinuosity of the new river reach would increase from 1.06 to 1.2 and the slope would decrease from 1.76 to 1.55 feet/mile; 2) Impact on the Mississippi River would be minor.
4. Divert a portion of the Chippewa River flow into Lake Pepin (Figure 11)	Twice the sediment diversion rate in 1st year but reduce to the diversion rate in about the 7th year. The diversion system in Figure 12 would divert about 30% of Chippewa water and sediment.	Immediately	Minor protection below the diversion dam	Reduce flow downstream of diversion and increase flow in Lower Lake Pepin	Affect about 100 acres of forest and wetland along the diversion channel	1) The floodplain along the diversion channel would be affected; 2) Aggradation would occur upstream of dam and near the lower end of the Chippewa at a rate of about 0.2 feet/year; 3) Degradation would occur immediately below the dam. 4) Deposition would occur in the diversion channel and in Lake Pepin near the channel mouth; 5) Changes in the Mississippi River would be similar to Alt. 1.
5. Divert a portion of the Chippewa River flow into a sedimentation basin (Figure 14)	Do	Immediately	Minor protection below the diversion dam	Reduce flow downstream of diversion and increase flow in Buffalo Slough	Inundate about 3,000 acres of forest land along Buffalo Slough below river mile 4 at intermediate flow if 30% was diverted. At high flow about 8,000 acres along Buffalo Slough would be inundated.	1) Buffalo Slough would become active; 2) Excess water could refresh the affected area initially but the area could deteriorate as the sediment inflow continued; 3) Other changes would be similar to Alt. 1, and 1 and 2 of Alternative 4.

Table 3. Summary of Impacts of the Alternative Measures on the Physical Environment (continued)

Alternative	Sediment Reduction	When Effective	Bank Stability	Hydrologic Changes	Affected Area in Chippewa	Geomorphic Changes and Dredging Requirements
6. Construct a low-head dam at the lower end of Chippewa River (Figure 17)	50%-30%(6-foot dam after 6 years) 30%- 20% (3-foot dam after 5 years)	Immediately	Minor protection near the dam	Raise the flood peak 2.5 feet at an average flood and 5 feet at a 100-year flood (6-foot channel)	The rise of flood stage would extend to river mile 6 upstream of the dam	1) Deposition would occur behind the 6-foot dam and would reach the dam crest in about 10 years, reducing the channel bed slope below river mile 10; 2) Changes in the geomorphology and dredging requirement in the Mississippi River would be similar to Alt. 1.
7. Construct a series of low-head dams on the Chippewa River (Figure 20)	40%-20% (4 of 3-foot dams after 8 years)	Immediately	Provides additional protection to the three erodible high banks and the low banks within 4 miles upstream of the dams	Raise the water surface within 3 miles upstream of the dams	Inundate an additional 1,300 acres during average flood	1) The riverbed would aggrade above the dams and degrade below the dams at a rate of about 0.2 ft/year; 2) Changes in the geomorphology and dredging requirement in the Mississippi River would be similar to Alt. 1.
8. Establish streambank erosion controls and supplemental controls (Figure 22).	Depends on the extent of bank protection. Would reduce sediment supply by 50%.	Slowly if only control bank erosion but would become effective immediately after implementing supplemental controls	Major protection	Depends on the types of control structures. Revetment causes min. effect. Closing dam causes max. effect with dikes and jetties in between		1) Geomorphic changes in the Chippewa basin would depend on the types of control structures; 2) The Chippewa River would degrade with an overall rate of about 0.05 feet/year if the banks were completely protected. Degradation rate would be proportional to the historical rate of erosion; 3) Effects on the Mississippi River would be similar to Alt. 1.

Table 4. Criteria for Evaluation of Alternative Measures

		ALTERNATIVE *							
		1	2	3	4	5	6	7	8
Efficiency on Reduction in Sediment Supply and Dredging Requirement	Good		√		√	√	√	√	√
	Fair	√							
	Poor			√					
When Effective	Immed.	√	√		√	√	√	√	√
	Slowly			√					
Bank Erosion Improvement	Major								√
	Fair	√						√	
	Minor			√	√	√	√		
	No		√						
Flood Stage Changes	Incr.			√			√	√	√
	No		√						
	Decr.	√							
Affected Area	Large			√		√		√	√
	Small	√	√		√		√		
Recommendations on Future Study	Yes		√			√		√	√
	No	√		√	√		√		

* Alternative 1. Increase storage of existing flood control dam.

2. Dredge a sedimentation trap at the Chippewa mouth.
3. Establish a meander pattern below Durand
4. Divert a portion of Chippewa flow into Lake Pepin
5. Divert a portion of Chippewa flow into a sedimentation basin.
6. Construct a low-head dam at the Chippewa mouth.
7. Construct a series of low-head dams on the Chippewa River.
8. Establish streambank erosion controls and supplemental controls.

Alternative 4: Divert a portion of the Chippewa River flow into Lake Pepin

Reasons:
- (a) Relatively expensive to construct and maintain
- (b) Prohibit boating across the diversion dam
- (c) Cause shoaling in Lake Pepin
- (d) No reduction of bank erosion
- (e) Possibility of the diverted sediment reaching the navigation channel

Alternative 1 (increase storage capacity of existing flood control dams) provides an economical way to reduce sediment supply. However, its efficiency is limited by the available storage of existing dams. This alternative is recommended if minimum action is adequate.

Alternative 2 (dredge a sedimentation trap) effectively reduces sediment discharge to the Mississippi but the solution is temporary unless the basin is periodically re-dredged. This alternative is recommended if the cost is not prohibitive and if the dredged material has commercial values or can be placed in the riverine area without causing significant adverse impacts. Further study is needed to identify the beneficial uses of dredged material and to identify feasible disposal sites.

Alternative 5 (divert a portion of the Chippewa River flow into a sedimentation basin) would effectively reduce sediment supply. However, this alternative would be relatively expensive. Also, it would limit boating and the diverted sediment could subsequently reach the Mississippi navigation channel. This alternative is feasible only if the beneficial impacts on the river environment can offset the costs and other adverse effects. If the floodplain along Buffalo Slough is of major concern, this alternative should be investigated further.

Alternatives 6 and 7 (construct a low-head dam at the lower end of the Chippewa River or a series of low dams) would effectively reduce the sediment supply and would help minimize erosion problems. The dams would continue to be effective if properly maintained. However, construction and maintenance of these dams are expensive. Also, they would partially block boat traffic and possibly increase flood damage by raising the flood stage. These alternatives should be further investigated to evaluate their benefits and costs.

Alternative 8 (establish streambank erosion controls and supplemental controls) would effectively reduce the sediment supply to the Mississippi and would greatly reduce the erosion problems in the Chippewa River. Since there are many different erosion control methods, the efficiencies and costs of applying these methods to train and stabilize the Chippewa River should be carefully evaluated. Considering possible benefits obtained from improvement of the river environment, reduction in maintenance requirements and other uses, this alternative appears to be highly feasible and definitely deserves further study.

Chapter 5

SUGGESTED PROGRAM FOR PHASE II STUDY

5.1 Introduction

Phase I evaluated the feasibility of alternatives, considering the percentage reduction of sediments reaching the Mississippi River from the Chippewa River and the time required for each alternative to become effective. However, according to the "Principles and Standards for Planning Water and Related Land Resources" (Water Resources Council, 1974), the beneficial and adverse effects of these alternative plans should be examined considering: national economic development, environmental quality, regional development, and social well-being; and the final recommended plan should, to the best of current understanding and knowledge, reflect the preferences and economic-environmental emphasis desired by the public involved. Since this Phase I study only identifies the most feasible alternatives by investigating their general impacts on the physical environment of the rivers, it is necessary to conduct a Phase II study to evaluate the detailed impacts on the physical as well as biological and social environments induced by the selected alternatives.

5.2 Alternatives Recommended for Phase II Study

As summarized in Chapter 4, Alternatives 2, 5, 6, 7 and 8 can effectively reduce the sediment supply from the Chippewa River. However, there are problems associated with each alternative. Among these, two alternatives appear to be highly feasible. They are:

Alternative 7: Construct a series of low-head dams.

Alternative 8: Establish streambank erosion controls and supplemental controls.

These two alternatives or a combination of them deserve detailed investigation in the Phase II study. A study program for Phase II is presented in the following sections. Such investigations will essentially include a study of Alternative 6: construct a low-head dam at the lower end of the Chippewa River. Alternative 2(dredge a sedimentation trap) is only a temporary solution to sediment related problems in the river system. The associated environmental problems are mainly caused by the disposal of dredged material, which is a localized problem. Investigation of this alternative can concentrate on identifying the beneficial use of dredged materials, feasible disposal sites, and the associated costs and benefits. This alternative may be included as a supplemental part of the Phase II study. Also, during the Phase II study, the river environment along Buffalo Slough can be assessed. If it is found that diversion of a portion of the Chippewa River flow into a sedimentation basin along Buffalo Slough can be beneficial to the river environment, Alternative 5 will be investigated further.

5.3 Detailed Evaluation of Alternatives

The Phase II study program is an environmental assessment study to establish the costs and benefits of the two selected alternative measures and to predict their environmental impacts.

An inventory study is required to assess the present environmental setting, including the physical environment (river morphology, surface water hydrology, soil, ground water, and atmospheric setting), the biological environment (terrestrial biology and aquatic biology) and the social environment (quality of life, regional economy, recreation, soil and land use). Useful information can be obtained from the following reports:

1. Report on Investigation of Sediment Carried by Rivers of St. Paul U.S. Engineer District, 1937 and 1938. By E. W. Lane, Iowa Institute of Hydraulic Research, September, 1938.

2. The Physical Geography of Wisconsin. By L. Martin, The University of Wisconsin Press, 1965.

3. Wisconsin Soil and Water Conservation Needs Inventory. Wisconsin Conservation Needs Committee, September, 1970.

4. Minnesota Soil and Water Conservation Needs Inventory. Minnesota Conservation Needs Committee, August, 1971.

5. Water Resources of Wisconsin, Chippewa River Basin. By H. L. Young and S. M. Hindall, U.S. Geological Survey Hydrologic Investigators ATLAS HA-386, 1972.

6. Upper Mississippi River Comprehensive Basin Study. By UMRCBS Coordinating Committee, 1972.

7. Final Environmental Impact Statement, Operation and Maintenance, 9-Foot Navigation Channel, Upper Mississippi River. U.S. Army Engineer District, St. Paul, August, 1974.

8. Upper Mississippi River Resource Management Study. Plan of Study. U.S. Army Engineer District, St. Paul, October, 1974.

9. Interim Survey (Feasibility) Report for Flood Control of the Chippewa River at Eau Claire, Wisconsin, U.S. Army Engineer District, St. Paul, March, 1975.

10. Measurement and Prediction of Sediment Yield in Wisconsin Streams. By S. M. Hindall, U.S. Geological Survey Water-Resources Investigation 54-75, January, 1976.

11. A Geomorphic Study of Pool 4 and Tributaries of the Upper Mississippi River. Prepared for the U.S. Fish and Wildlife Service, Twin Cities, Minnesota, by D. B. Simons, S. A. Schumm, Y. H. Chen, and R. M. Beathard, Colorado State University, October, 1976.

This information and other river basin data presently available are not adequate to perform a detailed study. Additional information is required to assess the present river environmental settings, especially those related to erosion and sedimentation. A data collection program should be implemented to identify and collect the necessary data for a detailed analysis. The data will be analyzed during the inventory study to assess the following environmental parameters:

1. Physical Environment

   River morphology: basin topography, river pattern, channel geometry

   Surface water hydrology: stage, discharge, sediment load

   Soil and groundwater: soil moisture and property, groundwater level

   Atmospheric setting: microclimate (solar radiation, wind, temperature, humidity, precipitation, evapotranspiration)

2. Biological Environment

   Terrestrial biology: vegetation, terrestrial invertebrates, vertebrates

   Aquatic biology: water quality, primary producers, aquatic invertebrates, fish

3. Social Environment

   Quality of life: population, housing, government, health services, attitude

   Regional economy: employment, income, output

   Recreation: outdoor recreation, game production

   Soil and land use: land cover, land use, productivity of soils, natural resources, flood protection

From the inventory study, also the sediment sources and soil conditions at all sites along the lower Chippewa River can be determined. The priority of protection works for the Chippewa River can be evaluated.

The specific impacts of the selected alternatives on the river environment can be evaluated by predicting changes in environmental parameters as listed above. The cost of construction and maintenance of each selected alternative measure can be assessed. Then, an analysis of costs and benefits can be performed to evaluate selected alternative measures.

After considering overall environmental impacts and coordinating these with public input, a final plan based on the best available analysis and understanding of the problem would be recommended. The information obtained from this study would be used to prepare the environmental impact statement.

5.4 Time Schedule for Phase II Study

The proposed time schedule required to perform the work outlined in the Phase II study program is approximately two years. The work is scheduled on a yearly basis. In each year, a report describing progress and presenting the results of the study will be prepared. The approximate time required to perform each major step in the study program is given.

I. First Year

1. The data required for the Phase II study would be assembled in 2 months. Much of the data related to the physical environment of the river system is available at Colorado State University. The major effort would concentrate on assembling data on the biological and social environments.

2. A data collection program would be developed to identify and collect the additional data required. The development of the data collection program and collection of additional data would take about four months.

3. The existing data and newly collected data would result in a large volume of valuable information suitable for analysis of a variety of river actions. These data would be classified by category and processed in a data storage and retrieval system stored in magnetic tapes to a computer sort and merge routine, which would permit ready access. The data storage and retrieval system would be treated as an integral part of the whole study. The system would be developed first. Then

data would be stored in the system as they become available. This system could be expanded to establish the data base for the entire Upper Mississippi River Basin within the St. Paul District. The data storage and retrieval system would be developed in about three months.

4. An inventory study would be conducted to assess the present environmental setting, identify the sediment sources and soil conditions, assess the feasibility of field construction, and determine the priority in terms of protecting the Chippewa River environment. This would require five months.

5. A report presenting the progress and study results would be prepared. This would require one month.

II. Second Year

1. The design of selected alternatives, and cost of construction and maintenance would be assessed. Three months would be required.

2. Possible environment impacts caused by the selected alternatives would be assessed in five months.

3. An analysis of costs and benefits for each selected alternative would be conducted and would require two months.

4. A report which documents the study results and recommends the final development plan, based on the best available understanding of the problem, would be prepared. This would require three months.

5.5 Monitoring Program

The Chippewa River Basin is an ecosystem involving the complex interaction of social, biological and physical systems. Any natural or man-induced activity will affect this system as well as the Mississippi River downstream from the confluence with the Chippewa River. The severe erosion problems occurring on the lower Chippewa River affect not only the immediate area but are also linked to recognized environmental deterioration and maintenance problems along the Mississippi River. Development programs such as the construction of low-head dams or streambank erosion controls have been proposed to improve the river system. A detailed evaluation of these alternatives and their possible impacts on the river environment has been suggested as part of the Phase II study. However, the efficiencies of the imposed structures and their actual impacts have not been finalized.

Monitoring is a process which measures the change in selected environmental parameters over time. The monitoring program will develop methodologies to identify and analyze changes and identify the cause of impacts. Monitoring is a scientific endeavor to improve our ability to predict environmental impacts. The assumption which underlies this objective is that improved prediction will ultimately lead to better decision making. The monitoring program should study the Chippewa River Basin and determine major social, biological, and physical consequences. A major objective should involve improvement of the existing methodologies and/or the construction testing of new methods for assessing the environmental impacts.

The technical knowledge gained from this work would be extremely useful for resolving problems associated with the Chippewa River and other streambank erosion prone tributaries entering the Upper Mississippi River corridor and other similar systems. The U.S. Army Engineer District, St. Paul (1976) has proposed an erosion control demonstration program on the Lower Chippewa River Basin. The program is fully supported by the Great River Environmental Action Team (GREAT I), other government agencies and public organizations. Also, since the streambank erosion control measure is a highly feasible alternative to achieve desired benefits as proven by this study, Colorado State University also supports the demonstration program. However, in addition to monitoring selected parameters relating to the physical environment, the monitoring of impacts on biological and social environments should be considered.

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APPENDIX

GLOSSARY

Abrasion. Act or process of wearing down by friction, or the resulting effects. Moving debris, whether it be in a stream, sea, ice and wind.

Acre-Foot. A unit for measuring the volume of water, is equal to the quantity of water required to cover 1 acre to a depth of 1 foot and is equal to 43,560 cubic feet or 325,851 gallons. The term is commonly used in measuring volumes of water used or stored.

Aggradation. Process of raising a land surface by the deposition of sediment.

Alluvial Channel. A channel whose bed is composed of noncohesive sediment that has been or can be transported by the flow.

Alluvial Fan. Alluvial deposit of a stream where it issues from a gorge upon an open plain.

Alluvial Plain. Plain formed by the deposition of alluvial material eroded from area of higher elevation.

Alluvium (Alluvial Deposit). Clay, silt, sand, gravel, pebble or other detrital material deposited by water.

Anabranch. A diverging branch of a river which reenters the main stream.

Antidunes. Bed forms of curved symmetrically shaped sand waves that may move upstream, remain stationary, or move downstream. They occur in trains that are inphase with and strongly interact with gravity water-surface waves. The water-surface waves have larger amplitudes than the coupled sand waves. At large Froude number, the waves generally move upstream and grow until they become unstable and break like surf (breaking antidunes). The agitation accompanying the breaking obliterates the antidunes, and the process of antidune initiation and growth is repeated. At small Froude numbers the antidunes generally remain stationary and increase and then decrease in amplitude without breaking (standing waves).

Apron. An adjunct to a dam or other structure, consisting of a surface protection against erosion.

Backwater. Water backed up or retarded in its course as compared with its normal or natural condition of flow. In stream gaging, a rise in stage produced by a temporary obstruction such as ice or weeds, or by the flooding of the stream below.

Backwater Curve. Longitudinal profile of the water surface in a stream where the water surface is raised above its normal level by a natural or artificial obstruction.

Bank. The margins of a channel. Banks are called right or left as viewed facing in the direction of the flow.

Bankfull Stage. Stage at which a stream first overflows its natural bank.

Barrage. A dam.

Bars. Bed forms having lengths of the same order as the channel width or greater, and heights comparable to the mean depth of the generating flow.

Bars, Alternate. Bars occured in straighter reaches of channels and tend to be distributed periodically along the reach, with consecutive bars on opposite sides of the channel. Their lateral extent is significantly less than the channel width.

Bars, Middle (or Transverse). Bars occurred in straight channels and occupied the full channel width.

Bars, Point. Bars occurred adjacent to the convex bank of channel bends.

Bars, Tributary. Bars occurred immediately downstream from points of lateral inflow into a channel.

Bed (Streambed). The bottom of a water course.

Bed Configuration. A complex of bed forms covering the bed of an alluvial stream.

Bed Form. A generic term used to denote any irregularity produced on the bed of an alluvial channel by flowing water and sediment.

Bed Layer. A flow layer, several grain diameter thick (usually taken as two grain diameter thick) immediately above the bed.

Bed Load. That part of the total sediment load that moves by rolling or sliding along the bed. The term "bed load" may be used to designate either coarse material moving on or near the bed, or material collected in or computed from samples collected in a bed load sampler or trap. In other words, load which is not sampled by a suspension load sampler.

Bed-Load Discharge. The quantity of bed load passing any cross section of a stream in a unit of time.

Bed-Load Discharge Sampler. A device to measure the discharge of bed load over part or all of the stream width.

Bed Material. The material of which a streambed is composed.

Bed-Material Discharge. Sediment discharge that consists of particles large enough to be found in appreciable quantities in the streambed.

Bed-Material Load. That part of the total sediment load which is composed of grain sizes represented in the bed--equal to the transport capacity of the flow.

Benthic Community. A group of plants or animals living in or on the streambed.

Braiding of River Channels. Successive division and rejoining (of riverflow) with accompanying islands is the important characteristic denoted by the synonymous terms, braided or anastomosing stream. (Leopold and Wolman, 1957, p. 40.) A braided stream is composed of anabranches.

Breaking Antidune. Curved symmetrically shaped waves on the water surface and on the channel bottom that build up with time and then break like surf.

Canal. An open conduit for the conveyance of water; distinguished from a ditch or lateral by its larger size; usually excavated in natural ground.

Capacity. The ability of a stream current to transport in terms of quantity.

Capture. Diversion of the flow of water in the upper part of a stream by the headward growth of another stream.

Channel. (1) Deepest portion of a river bed, in which the main current flows. (2) Natural or artificial, clearly distinguished, waterway which periodically or continuously contains moving water, or which forms a connecting link between two bodies of water.

Channel, Backwater. Side channels which do not carry appreciable flows even at high stage.

Channel, Side. The smaller channels in a reach of river where islands divide the reach into two or more channels. The larger is referred to as the main or thalweg channel.

Channel, Stable. Channel in which accretion balances scour on the average.

Channel, Straight. A channel having its sinuosity less than 1.5.

Chute. Natural or artificial steep-sloped reach of an open channel.

Chute and Pools. The flow phenomenon and bed configuration accompanying flows that occur at steep slopes and large bed-material discharges. The flow occurs at slopes steeper than for antidunes and consists of a series of pools in which the flow is tranquil, connected by steep chutes where the flow is rapid. A hydraulic jump forms at the downstream end of each chute where it enters the pool. The bed configuration consists of triangle-shaped elements with a steep upstream slope, a flat, almost horizontal back, and a gently downstream slope. The chutes and pools move slowly upstream.

Clay. Sediment finer than 0.004 mm (millimeters) regardless of mineralogical composition.

Competency. The ability of currents to transport, in terms of dimensions of particles.

Confluence. Joining, or the place of junction, of two or more streams.

Contact Load. Sediment particles that roll or slide along in almost continuous contact with the streambed (often used synonomously with bed load).

Control. A natural constriction of the channel, a long reach of the channel, a stretch of rapids, or an artificial structure downstream from a gaging station that determines the stage-discharge relation at the gage.

Critical Flow. Flow conditions at which the discharge is a maximum for a given specific energy, or at which the specific energy is minimum for a given discharge.

Crossing and Pool. A series of shoals (crossings or bars) and deep (pools) sequence exhibited in rivers.

Crossover. Relatively short and shallow length of a river between bends.

Cross Section (of a Stream). Section of the stream at right angle to the main (average) direction of flow.

Cubic Feet per Second. A unit expressing rates of discharge. One cubic foot per second is equal to the discharge of a stream of rectangular cross section, 1 ft wide and 1 ft deep, flowing water an average velocity of 1 ft per second.

Cusec. This abbreviation for cubic foot per second, common in the British Commonwealth countries (except Canada), is not used by the U.S. Geological Survey; instead, cfs is used.

Cut-off (Cutoff). Direct channel, either natural or artificial, connecting two points on a stream, thus shortening the length of the channel and increasing its slope.

Degradation. Disintegration and wearing down of the surface of rocks, cliffs, strata, streambeds, etc. by atmospheric and aqueous action.

Delta. Alluvial deposit at the mouth of a river and the geographical and geomorphological unit which results from it.

Density, Water-Sediment Mixture. The bulk density which is the mass per unit volume including both water and sediment.

Depth-Integrated Sample. A water-sediment mixture that is accumulated continuously in a sampler that moves vertically at an approximately constant transit rate between the surface and a point a few inches above the bed of a stream, and that admits the mixture at a velocity about equal to the instantaneous stream velocity at each point in the vertical. Because the sampler intake is a few inches above the sampler bottom, there is an unsampled zone a few inches deep just above the bed of the stream.

Detritus. Any loose material that results directly from rock disintegration, especially when composed of rock fragments--contrasted with soil. In the sediment field detritus has generally been used to designate the coarser material moved or deposited.

Discharge. In its simplest concept discharge means outflow; therefore, the use of this term is not restricted as to course or location and it can be applied to describe the flow of water from a pipe or from a drainage basin. If the discharge occurs in some course or channel, it is correct to speak of the discharge of a canal or of a river. It is also correct to speak of the discharge of a canal or stream into a lake, a stream, or an ocean.

Discharge-Weighted Concentration. The dry weight of sediment in a unit volume of stream discharge, or the ratio of the discharge of dry weight of sediment to the discharge by weight of water sediment mixture.

Disposal, On Land. Disposal of dredged material on land at locations where the materials are not subjected to the influence of water stage fluctuation.

Disposal, Open Water. Disposal of dredged material on islands, marshes, and along riverbanks at locations where these materials are subject to the influence of river stage fluctuations, or are readily washed back into the river by rainfall.

Disposal, Thalweg. Disposal of dredged material in the main channel.

Diversion. The taking of water from a stream or other body of water into a canal, pipe, or other conduit.

Diversion Dam. A dam built for the purpose of diverting part or all the water from a stream into a different course.

Drainage Basin. A part of the surface of the earth that is occupied by a drainage system, which consists of a surface stream or a body of impounded surface water together with all tributary surface streams and bodies of impounded surface water.

Drainage Divide. The rim of a drainage basin.

Dredging. A process by which sediments are removed from the bottom of streams, lakes, and coastal waters, transported by ship, barge, or pipeline, and discharged in open water or on land.

Drift. Deposit of detritus

Dunes. Large bed forms having triangular profiles, a gentle upstream slope, and a steep downstream slope. They form in tranquil flow and, thus, are out of phase with any water-surface disturbance that they may produce. They travel slowly downstream as sand is moved across their comparatively gentle, upstream slopes and deposited on their steeper, downstream slopes. The downstream slopes are approximately equal to the angle of repose of the bed material. Dunes are smaller than sand bars but larger than ripples. They generally form at higher velocities and larger sediment discharges than do ripples, but at lower velocities and smaller sediment discharges than do antidunes. However, ripples form on the upstream slopes of dunes at lower velocities.

Eutrophication. Process by which waters become more eutrophic (richer in dissolved nutrients required for the growth of aquatic plants such as algae) either as a natural phase in the maturation of a body of water or artificially (as by fertilization and pollution).

Evapotranspiration. Water withdrawn from a land area by evaporation from water surfaces and moist soil and plant transpiration.

Fall Diameter or Standard Fall Diameter. The diameter of a sphere that has a specific gravity of 2.65 and the same terminal uniform settling velocity as the particle (any specific gravity) when each is allowed to settle alone in quiescent distilled water of infinite extent and at a temperature of 24°C.

Fall Velocity. Average terminal settling velocity of a particle falling alone in quiescent, distilled water of infinite extent.

Fine Sediment. That part of the sediment discharge that consists of sediment so fine that it is about uniformly distributed in the vertical and is only an inappreciable fraction of the sediment in the streambed (referred to by some writers as washload). Its upper size limit at a particular time and cross section is a function of the flow as well as of the sediment particles.

Flood. An overflow or inundation that comes from a river or other body of water (Barros, 1948) and causes or threatens damage. Any relatively high streamflow overtopping the natural or artificial banks in any reach of a stream (Leopold and Maddock, 1954, pp. 249-251).

Flood-Frequency Curve. 1. A graph showing the number of times per year on the average, plotted as abscissa, that floods of magnitude, indicated by the ordinate, are equaled or exceeded. 2. A similar graph but with recurrence intervals of floods plotted as abscissa.

Flood Peak. The highest value of the stage or discharge attained by a flood; thus, peak stage or peak discharge. Flood crest has nearly the same meaning, but since it connotes the top of the flood wave, it is properly used only in referring to stage--thus, crest stage, but not crest discharge.

Flood Plain. A strip of relatively smooth land bordering a stream, built of sediment carried by the stream and dropped in the slack water beyond the influence of the swiftest current. It is called a living flood plain if it is overflowed in times of highwater; but a fossil flood plain if it is beyond the reach of the highest flood.

Flood Routing. The process of determining progressively the timing and shape of a flood wave at successive points along a river.

Flood Stage. The stage at which overflow of the natural banks of a stream begins to cause damage in the reach in which the elevation is measured.

Flood Wave. A distinct rise in stage culminating in a crest and followed by recession to lower stages.

Floodway. A part of the flood plain, otherwise leveed, reserved for emergency diversion of water during floods. A part of the flood plain which, to facilitate the passage of floodwater, is kept clear of encumbrances.

Flow-Duration Curve. A cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded.

Flow, Free Surface. Flow of water in which an interface exists between air and water.

Flow, Gradually Varied. Varied flow in which the velocity or depth changes gradually over a long distance.

Flow, Laminar. Flow of a fluid in which the viscous forces are predominant. In channel flow the fluid particles move approximately in definite, relatively smooth paths with no significant transverse mixing. In channel flow it occurs at Reynolds number smaller than 500-2000 and in flow through porous media at Reynolds number smaller than 1-10.

Flow, Nonuniform. Flow in which the velocity vector is not constant along every streamline.

Flow, Open Channel. Flowing water having its surface exposed to the atmosphere.

Flow, Rapidly Varied. Varied flow in which the velocity or depth changes abruptly over a comparatively short distance.

Flow Regime. A range of flows producing similar bed forms, resistance to flow, and mode of sediment transport.

Flow, Sheet. Flow in a relatively thin sheet, of nearly uniform thickness over the soil surface.

Flow, Steady. Flow in which the velocity is constant in magnitude or direction with respect to time.

Flow, Turbulent. Flow with turbulence. In channel flow, it occurs at Reynolds number larger than approximately 5000.

Flow, Uniform. Flow in which the velocity vector is constant along every streamline.

Flow, Unsteady. Flow in which the velocity changes in magnitude or direction with respect to time.

Flow, Varied. Flow in which velocity or depth changes along the length of the channel.

Fluvial Sediment. Fragmentary material that originates from weathering of rocks and is transported by, suspended in, or deposited from water.

Freshet. Flooding or overflowing of a stream caused by heavy rains or snowmelt.

Gage Height. The water-surface elevation referred to some arbitrary gage datum. Gage height is often used interchangeably with the more general term stage although gage height is more appropriate when used with a reading on gage.

Gaging Station. A particular site on stream, canal, lake, or reservoir where systematic observations of gage height or discharge are obtained.

Geology. The science which treats of the earth, the rocks of which it is composed, and the changes which it has undergone or is undergoing.

Geomorphology. The study of the characteristics, origin, and development of land forms.

Habitat. The region where animals or plants naturally or usually live or are found.

Hydraulic Jump. Sudden passage of water in an open channel from supercritical depth to sub-critical depth, accompanied by energy dissipation.

Hydraulic Radius. The cross-sectional flow area of a conduit divided by its wetted perimeter.

Hydrograph. A graph showing stage, flow, velocity, or other properties of water with respect to time.

Hydrostatics. The statics of fluids, usually confined to the equilibrium and pressure of liquids.

Islands. The vegetated areas within the channel banks separated from the mainland by the main channel and side channel.

Levee. Water-retaining earthwork used to confine streamflow within a specified area along the stream or to prevent flooding due to waves or tides.

Levee, Natural. Low alluvial ridge adjoining the channel of a stream, composed of sediment deposited by flood water which has overflowed the banks of the channel.

Load (Sediment Load). The sediment that is being moved by a stream. (Load refers to the material itself and not to the quantity being moved.)

Load, Bed. That part of the total sediment load that moves by rolling or sliding along the bed.

Load, Bed-Material. That part of the total sediment load which is composed of grain sizes represented in the bed--equal to the transport capacity of the flow.

Load, Suspended. That part of the total sediment load that is supported by the upward components of turbulence and that stays in suspension for an appreciable length of time.

Load, Total Sediment. The sum of the bed-material load and the wash load, or bed load and suspended load, or measured and unmeasured load.

Load, Wash (Fine Material). That part of the total sediment load which is composed of particle sizes finer than those represented in the bed--determined by available bank and drainage area supply rate.

Lower Flow Regime. A category for flows producing bed forms of ripples, ripples on dunes, or dunes. In this flow regime, flow is tranquil, water-surface undulations are out of phase with bed undulations, and resistance to flow is large.

Mantle. A layer of disintegrated and decomposed rock fragments, including soil, just above the solid rock of the earth's crust.

Meander. One curved portion of a sinuous or winding stream channel, consisting of two consecutive loops, one turning clockwise and the other counterclockwise.

Meander Length. Distance along the river between two corresponding points at the extreme limits of two successive, fully developed meanders.

Meander Width. Amplitude of swing of a fully developed meander, measured from midstream to midstream.

Measured (Sampled) Zone. Due to the design of the various depth integrating sediment samplers, there is a physical constraint on the depth to which a sample can be taken. Most sediment samplers can measure to within 0.3 ft of the bed. Above this point is termed the sampled or measured and below unmeasured zone.

Median Diameter. The midpoint in the size distribution of sediment such that half the weight of the material is composed of particles larger than the median diameter and half is composed of particles smaller than the median diameter.

Moraine. A ridge, mound, or irregular mass of boulders, gravel, sand and clay, transported in or on a glacier.

Morphology, Fluvial. Science of formation of beds and flood plains and of forms of streams by the action of water.

Outwash. Detritus chiefly consisting of gravel and sand and carried by running water from the melting ice of a glacier and laid down in stratified deposits.

Ox-Bow. Abandoned part of a former meander, left when the stream cut a new, shorter channel.

Plane Bed. A bed form in which there are no irregularities larger in amplitude than a few grain diameters.

Point-Integrated Sample. A water-sediment mixture that is accumulated continuously in a sampler that is held at a relatively fixed point in a stream and that admits the mixture at a velocity about equal to the instantaneous stream velocity at the point.

Pool. A deep reach of a stream. The reach of a stream between two crossings. Natural streams often consist of a succession of pools and crossings.

Reach. 1. The length of a channel for which a single gage affords a satisfactory measure of the stage and discharge. 2. The length of a river between two gaging stations. 3. More generally, any length of river.

Recurrence Interval (Return Period). The average interval of time within which the given flood will be equaled or exceeded once.

Regime. "Regime theory" is a theory of the forming of channels in material carried by the streams. As used in this sense, the word "regime" applies only to streams that make at least part of their boundaries from their transported load and part of their transported load from their boundaries, carrying out the process at different places and times in any one stream in a balanced or alternating manner that prevents unlimited growth or removal of boundaries. A stream, river, or canal of this type is called a "regime stream, river, or canal." A regime channel is said to be "in regime" when it has achieved average equilibrium; that is, the average values of the quantities that constitute regime do not show a definite trend over a considerable period--generally of the order of a decade. In unspecialized use "regime" and "regimen" are synonyms.

Riffles. Shallow rapids in an open stream, where the water surface is broken into waves by obstructions totally or partly submerged.

Ripples. Small triangular-shaped bed forms that are similar to dunes but have much smaller and more uniform amplitudes and lengths. Wave lengths are less than about 2 ft, and heights are less than about 0.2 ft.

River Bed. Lowest part of a river valley shaped by the flow of water and along which most of the sediment and runoff moves in interflood periods.

River Mile. River mile of a section is the mileage between the section and a reference point along the river thalweg or main-flow path.

River Training. Engineering river works built in order to direct the flow, or to lead it into a prescribed channel, or to increase the water depth for navigation and other uses.

River Width. The distance between vegetated banks taken normal to the general direction of flow in the river.

Sand. Sediment particles that have diameters between 0.062 and 2.0 mm.

Sandbar. A dune-shaped bed form whose upstream surface is extremely long in relation to the geometry of the channel (length, 2-3 times the width of the channel). The bar may often protrude above the flow.

Sand Waves. Crests and troughs (such as ripples, dunes, sandbars, antidunes, or standing waves) on the bed of an alluvial channel that are formed by the movement of the bed material.

Scour. Erosive action--particularly, pronounced local erosion--of water in streams, in excavating and carrying away materials from the bed and banks.

Sediment. Fragmental material that originates from weathering of rock and is transported by, suspended in, or deposited by water or air.

Sediment Concentration. The ratio of dry weight of sediment to total weight of the water-sediment mixture, expressed in parts per million.

Sediment Discharge. The amount of sediment that is moved by water past a section in a unit of time.

Sediment Yield. The total sediment outflow from a watershed or a drainage area at a point of reference and in a specified period of time. This is equal to the sediment discharge from the drainage area.

Shear Stress. The internal fluid stress which resists deformation.

Shingle. Gravel and cobblestones deposited by water to resemble lapped roofing pieces. The origin is "shingl"--a Norwegian term for a small round stone.

Sieve Diameter. The size of sieve opening through which the given particle will just pass.

Silt. Sediment particles whose diameters are between 0.004 and 0.062 mm.

Sinuosity. The ratio between thalweg length to down valley distance.

Stage. The height of a water surface above an established datum plane, also gage height.

Standing Waves. Curved symmetrically shaped waves on the water surface and on the channel bottom that are virtually stationary. When standing waves form, the water and bed surfaces are roughly parallel and inphase.

Stream. A general term for a body of flowing water. In hydrology the term is generally applied to the water flowing in a natural channel as distinct from a canal. More generally as in the term stream gaging, it is applied to the water flowing in any channel, natural or artificial. Streams in natural channels may be classified as follows:

Perennial. One which flows continuously.

Intermittent or Seasonal. One which flows only at certain times of the year when it receives water from springs or from some surface source such as melting snow in mountainous areas.

Ephemeral. One that flows only in direct response to precipitation, and whose channel is at all times above the water table.

Stream Discharge (Water Discharge). The quantity of natural water passing through a cross section of a stream in a unit of time. (The natural water contains both dissolved solids and sediment.)

Streamline. Line envelope in space of the tangents to the instantaneous flow direction at a given time.

Stream Order. Number expressing the degree of branching in a stream system.

Stream Tube. Surface formed by streamlines passing through a closed curve (which is not a streamline).

Surface Areas, River. The area between the vegetated riverbanks.

Surface Areas, Riverbed. The river surface area less the area of the islands.

Tailwater. Water located just downstream from a hydraulic structure on a stream.

Terrace. A berm or discontinuous segments of a berm, in a valley at some height above the flood plain, representing a former abandoned flood plain of the stream.

Thalweg. Line following the deepest part of a streambed or channel or of a valley.

Transition. A category for flows that occur between the lower and upper flow regimes and produce bed forms ranging from those typical of the lower flow regime to those typical of the upper flow regime.

Trap Efficiency. Ability of a reservoir to trap and retain sediment. Expressed as a percent of sediment yield (incoming sediment) which is retained in the reservoir.

Trend. Unidirectional, monotonous (diminishing or increasing) change in the average value of a hydrological variable.

Turbidity. Condition of a liquid due to fine, visible material in suspension which impedes the passage of light through the liquid.

Unmeasured (Unsampled) Zone. Most suspended-sediment samplers cannot sample within three or four inches of the streambed, and this three or four inches at the bottom of the sampling vertical is called the unmeasured zone in contrast to the measured zone above it.

Upper Flow Regime. A category for flows producing bed forms of plane bed with sediment moving, standing waves, antidunes, or chutes and pools. In the upper flow regime, water-surface undulations are inphase with bed undulations, except in breaking antidune or chute and pool flow.

Watershed. The divide separating one drainage basin from another and in the past has been generally used to convey this meaning. However, over the years, use of the term to signify drainage basin or catchment area has come to predominate, although drainage basin is preferred. Drainage divide, or just divide, is used to denote the boundary between one drainage area and another. Used alone, the term "watershed" is ambiguous and should not be used unless the intended meaning is made clear.

Water Year. In Geological Survey reports dealing with surface-water supply, the 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends and which include nine of the 12 months. Thus, the year ended September 30, 1959, is called the "1959 water year."