AD-A167 790 CHENA RIVER LAKES PROJECT FAIRBANKS ALASKA OVERVIEW OF TANANA RIVER MONIT..(U) COLD REGIONS RESEARCH AND ENGINEERING LAB HANOVER NH C R NEILL ET AL. JAN 84 1/4

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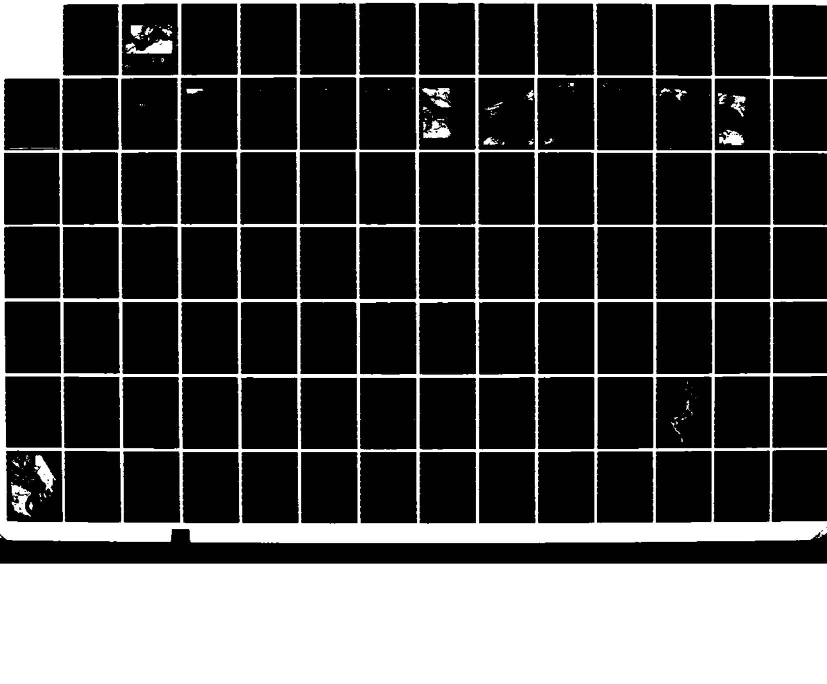

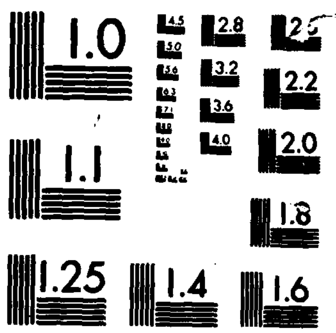

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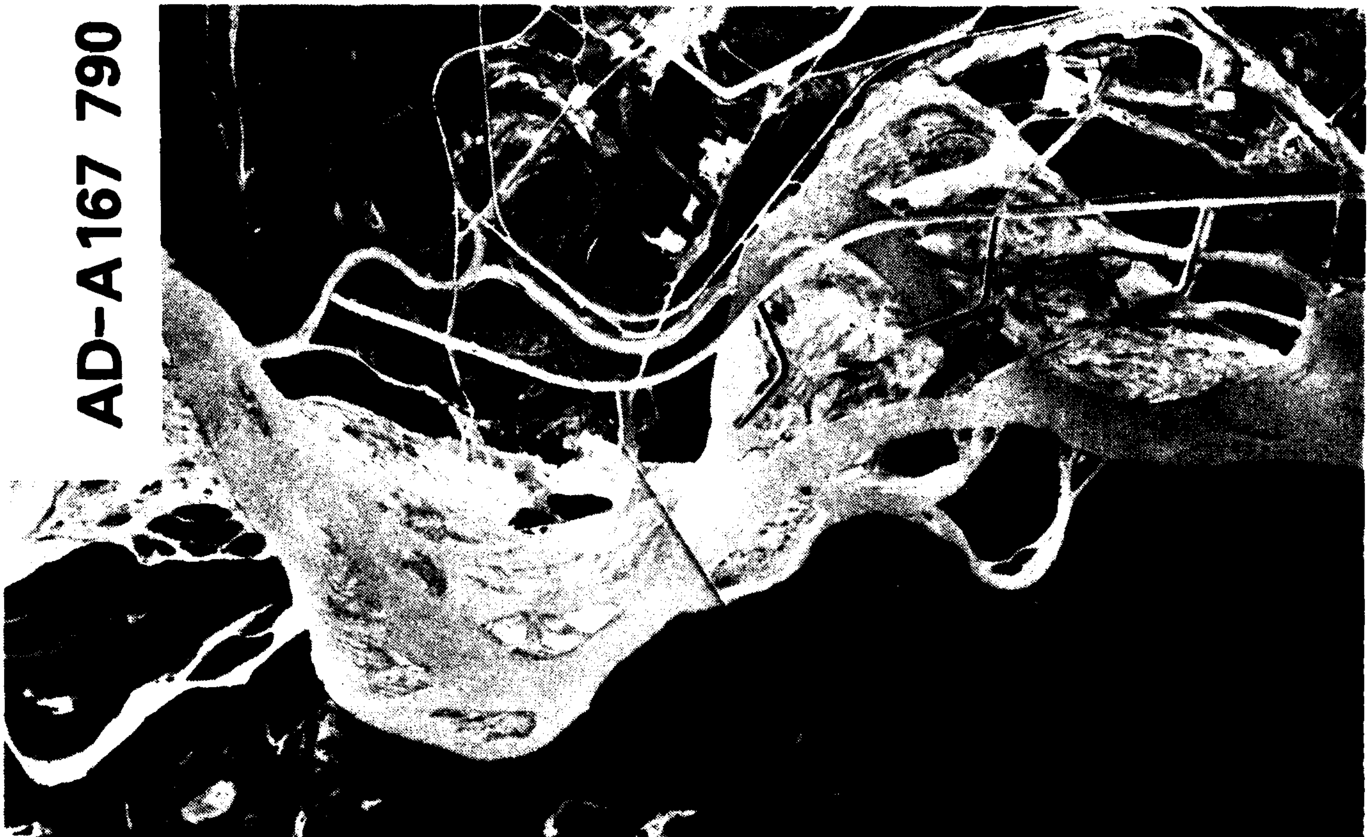
(1)

Chena River Lakes Project
Fairbanks, Alaska

Overview of Tanana River monitoring and research studies near Fairbanks, Alaska



Prepared for:
U.S. ARMY ENGINEER DISTRICT, ALASKA
as part of the
TANANA RIVER MONITORING AND RESEARCH PROGRAM

Prepared by:
Cold Regions Research &
Engineering Laboratory

US Army Corps
of Engineers

January 1984

OVERVIEW OF TANANA RIVER MONITORING AND RESEARCH STUDIES NEAR FAIRBANKS, ALASKA

(with Appendices)

January 1984

Prepared by
U.S. Army Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire

for

U.S. Army Engineer District, Alaska
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The Tanana River changes character in the vicinity of Fairbanks, from the braided pattern upstream of North Pole to the anastomosing or irregular meander pattern upstream of the Chena River confluence. This transition in planform is accompanied by a marked decrease in gradient and a change in dominant bed material from gravel to sand. Within the past 50 years the river has been affected by a variety of human activities, including flood control works, access causeways and gravel extractions. The river's cross-section shows large variations in width and depth from one location to another, but total cross-sectional area and mean velocity are relatively constant at a discharge of about 60,000

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cfs, close to the mean annual flood. Annual flow hydrographs are quite similar from one year to another. Sediment transport in the river averages about 360,000 tons per year of bed load, approximately equally divided between sand and gravel sizes, and about 28,000,000 tons per year of suspended load, of which about 35% is sand and the rest silt and clay. Natural channel processes are dominated by within-bank shifts in channel and bar patterns and cross-sectional shapes, erosion of the main floodplain and island banks being fairly localized and generally proceeding at modest rates. No relationships have been discerned between rates of bank erosion and soil, permafrost or vegetation factors. Response to human intrusions is generally difficult to disstinguish from natural processes beyond the immediate vicinity of the intrusions and more than a short time after cessation of activity. Details are discussed regarding observation of inferred response to groin construction and gravel extraction. Generally structural intrusions and gravel extraction activities that have not constituted a major disturbance to the river system have achieved their desired results with no apparent adverse effects of any significance. Blockage of the north channel at Goose Island by causeways, reoccupation of gravel extraction areas from permanent bars and islands, and secondary channel closures are believed to have considerable effects on flow and erosional patterns for some distance downstream. The Phase III in-river levee and groin construction constituted a strong local disturbance of the river system where local river slope was steepened and large quantities of bed material were put into transport [illegible] pilot [illegible] enlargement as the river adjusted to the new alignment. As of the end [illegible] 982, the full and final effects of this disturbance were not clear. Recommendations are given regarding impacts from human activities, alleviation of impacts, levee protection, further interpretive analysis and future monitoring of river behavior.

FOREWORD

The Tanana River Monitoring and Research Program was set up in 1980 to monitor the effects of the Corps' construction of the levee and protective groin system of the Chena River Lakes Project on the Tanana River near Fairbanks, Alaska. The program established a systematic data collection and analysis effort to evaluate the effects of in-river construction on the natural processes of the Tanana River. The monitoring and research efforts were directed towards providing a better understanding of the interaction of the construction activities and the natural river processes.

This report and its appendices document the data acquisition, the analyses, and the conclusions and recommendations developed during the study effort. Consideration of the material herein should promote a better understanding of the impacts of in-river construction and gravel extraction activities.

The greater part of the overview report was prepared under contract by C.R. Neill of Northwest Hydraulic Consultants, other parts being contributed by J.S. Buska, E.F. Chacho, C.M. Collins and L.W. Gatto of CRREL and by personnel of the U.S. Army Engineer District, Alaska. Final editing by J.S. Buska incorporated review comments from a committee representing CRREL, the Alaska District, the North Pacific Division, the Office of the Chief of Engineers, the U.S. Geological Survey, and Northwest Hydraulic Consultants. The overview is based in part on documents attached hereto as appendices and in part on published and unpublished reports by the U.S. Geological Survey and other agencies.

CONTENTS
(cont'd)

FIGURES

TABLES

1. INTRODUCTION

1.1 Authority

The Chena River Lakes Project was authorized by the Flood Control Act of 13 August 1968, Public Law 90-483, Section 203, 90th Congress (S-3710), in accordance with the recommendations of the Chief of Engineers in Senate Document No. 89. One major feature of the project is the construction of the Tanana River levee and its protective groin system.

The Alaska District, Corps of Engineers, retained the services of Northwest Hydraulic Consultants, Ltd. on 9 November 1979 under Contract No. DACW-85-80-C-0002 to review in-river designs for Phase III of the project and make recommendations. This contract was modified on 23 February 1982 to provide for a key role in the preparation of this overview report.

In 1980 the Alaska District signed a Memorandum of Understanding with the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) that initiated the Tanana River Monitoring and Research Program (TRMRP) to evalute the effects of the Tanana River levee and protective groin construction and gravel extraction on the natural processes of the Tanana River. This program (TRMRP) honors a commitment by the Alaska District Engineer to the public to monitor the effects of the in-river levee and groin construction. TRMRP is administered by the Alaskan Projects Office of CRREL, and involves active collaboration in data collection and analysis by CRREL, the U.S. Geological Survey (USGS), and the Alaska District, Corps of Engineers.

1.2 Background and Objectives

The Tanana River levee, shown in Figure 1.1, was constructed in three phases between 1973 and 1981. The levee is designed to be protected by a series of groins, these to be constructed as and when necessitated by river encroachment on the floodplain set-back, specified as a minimum of 500 feet between the river bank and levee to provide a seepage reduction blanket. As of 1982, six groins have been constructed: one near the Floodway Sill, one near North Pole, and four along the in-river Phase III part of the levee, which was constructed mainly in the river because channel erosion had removed the originally-intended floodplain location. The in-river construction of the Phase III part was carried out in the early months of 1981.

The objectives of the Tanana River Monitoring and Research Program were stated in 1980 as follows: "The monitoring and research efforts will be directed towards providing an understanding of the interaction between in-river construction and natural river processes with the following project related objectives:

a. Monitor and evaluate the fluvial processes of the river to determine if any adverse impacts are occurring or may occur due to the Corps' construction of the levee and protective groin system of the Chena Flood Control Project and the permitted gravel extraction in the vicinity of Goose Island.

b. In the event adverse impacts are determined to be associated with Corps' construction or permitted gravel extraction, make recommendations to lessen or alleviate such impacts.

c. Provide data that relates to timing, location and design of the deferred construction concept for the protection of the Tanana levee system."

Participation of the U.S. Geological Survey in investigations of sediment transport and morphologic changes in the Tanana River on behalf of the Alaska District originates from 1977 and pre-dates formal establishment of the TRMRP. The USGS body of published and unpublished data on sediment transport constitutes a unique contribution to scientific information on alluvial gravel-bed rivers.

1.3 Prior COE Reports Pertinent to the Overview

a. Design Memorandum (DM) No. 1, "Hydrology," 1971, presented the basis for the standard project flood used in the design of the levee.

b. DM No. 5, "Chena River Lakes Project GDM," 1972, included preliminary studies of the levee and interior drainage facilities.

c. DM No. 3, "Tanana-Chena River Levee and Interior Drainage Facilities Phase I," 1972, included a discussion of Phase I of the levee from Station 70+00 at Moose Creek dike to Station 730+30, the west boundary of Fort Wainwright.

d. DM No. 3, Supplement 2, "Tanana River Bank Protection," 1974, covered the plan for the "North Pole" groin.

e. DM No. 5, Supplement 1, "Tanana Levee-Alternate Proposals," 1974, provided comparative data on all levee alternatives for the protection of Fairbanks from the Tanana River.

f. DM No. 9, "Tanana-Chena River Levee, Phase II-A," 1974, presented information pertinent to the design and construction of Phase II-A of the levee from Station 650+00 to Station 950+00.

g. DM No. 24, "Tanana River Levee, Phase II-B," 1978, presented the preliminary design of the Tanana levee from Station 788+00 to Station 1046+00. Deferred construction of the levee protection plan was discussed.

h. DM No. 27, "Effects of Levee Construction on the Tanana River," 1979, discussed potential effects of Phase III levee construction on the river regime.

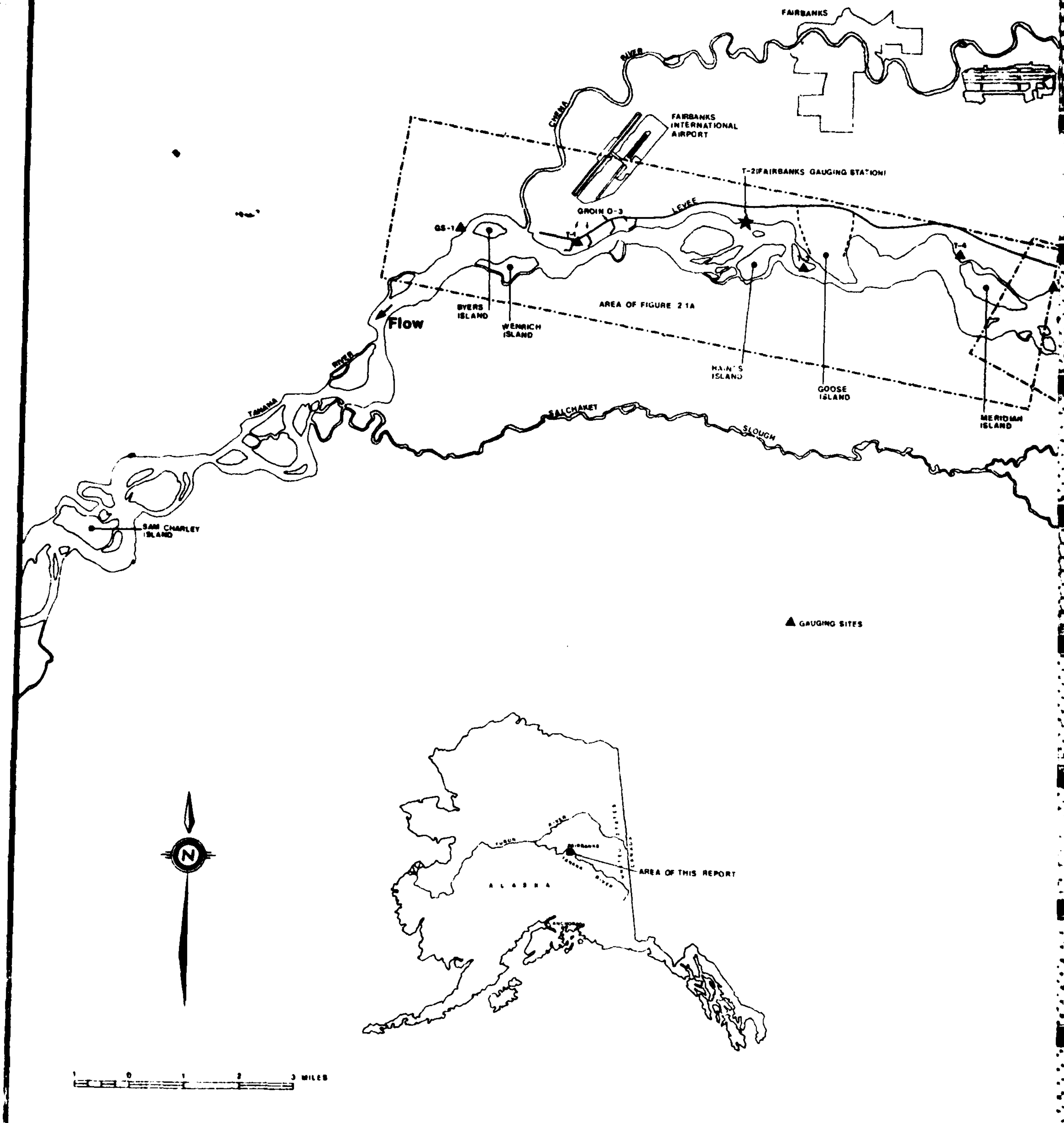
i. Letter Report No. 8, "Tanana River Levee, Emergency Construction," 1976, requested authorization to construct the Tanana River levee from Station 650+00 to Station 788+00.

j. Letter Report No. 10, "Bank Protection Diversion Dike, Pilot Channel, and Associated Features," 1978, discussed the protection of the floodway outlet and sill structure from erosion by the Tanana River.

k. Letter Report No. 14, "Stage Construction for Tanana Levee Settlement and Interior Drainage," 1979, recommended that repairs to the levee be accomplished by staged construction.

1.4 Organization of Overview Report and Appendices

This overview report is designed to review the hydraulic and morphologic characteristics of the Tanana River in the Fairbanks area, as inferred from previous studies and from results through October 1982 of the research and monitoring program, taking account of both natural processes and recent human activities. Efforts are made to discern relationships between various factors operating and to evaluate the effects of interference with natural processes.



FAIRBANKS
CHENA RIVER
FAIRBANKS INTERNATIONAL AIRPORT
T-2(FAIRBANKS GAUGING STATION)
GROIN D-3
LEVEE
GS-1
BYERS ISLAND
WENRICH ISLAND
Flow
AREA OF FIGURE 2.1A
GOOSE ISLAND
MERIDIAN ISLAND
TANANA RIVER
SALCHAKET SLOUGH
SAM CHARLEY ISLAND
GAUGING SITES
AREA OF THIS REPORT
N
3 MILES

1-2

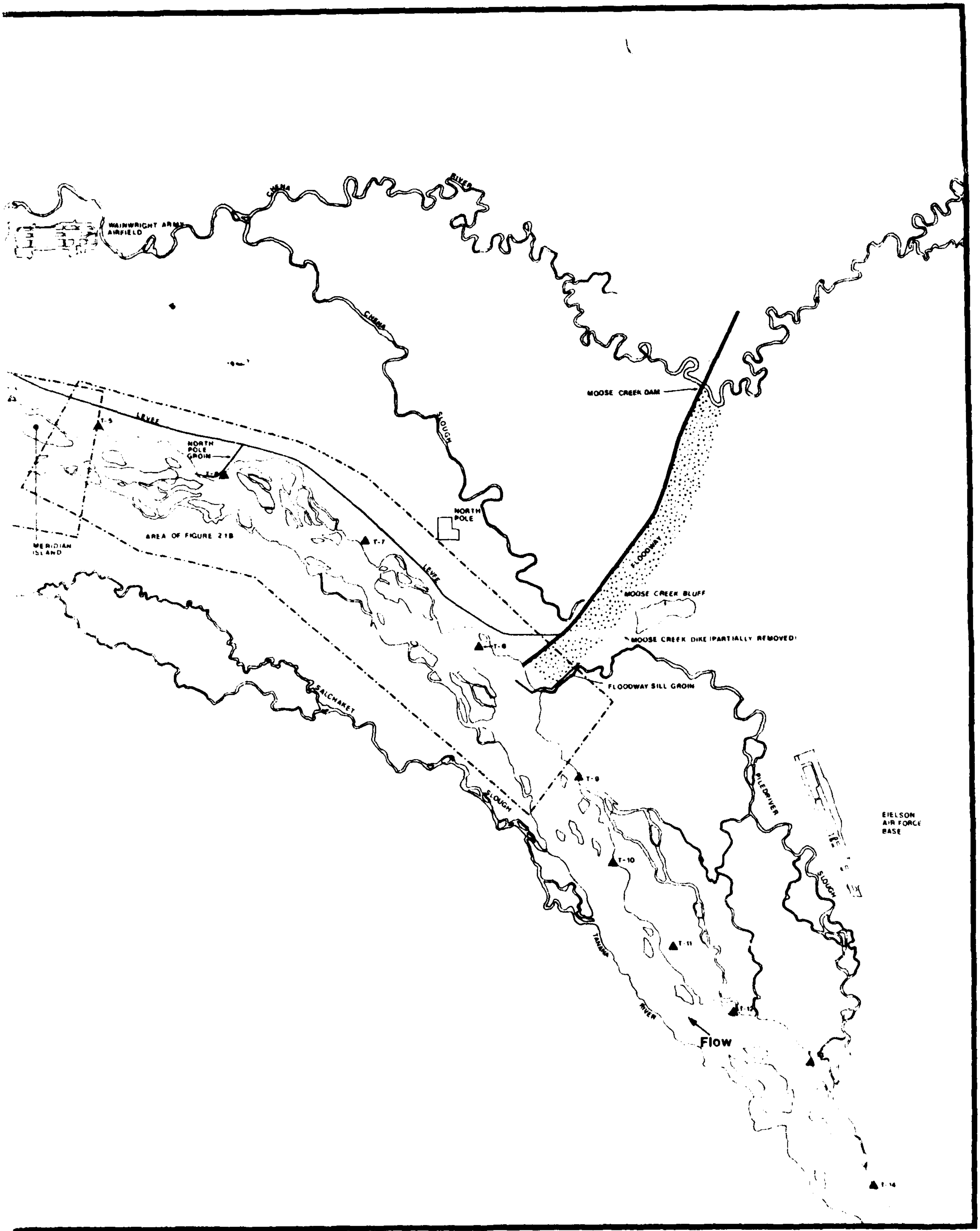


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FIGURE 1.1

The report is organized in seven main parts as shown in the Table of Contents. Key background reports are provided as Appendices. Other reports and publications from which data have been extracted are listed as references.

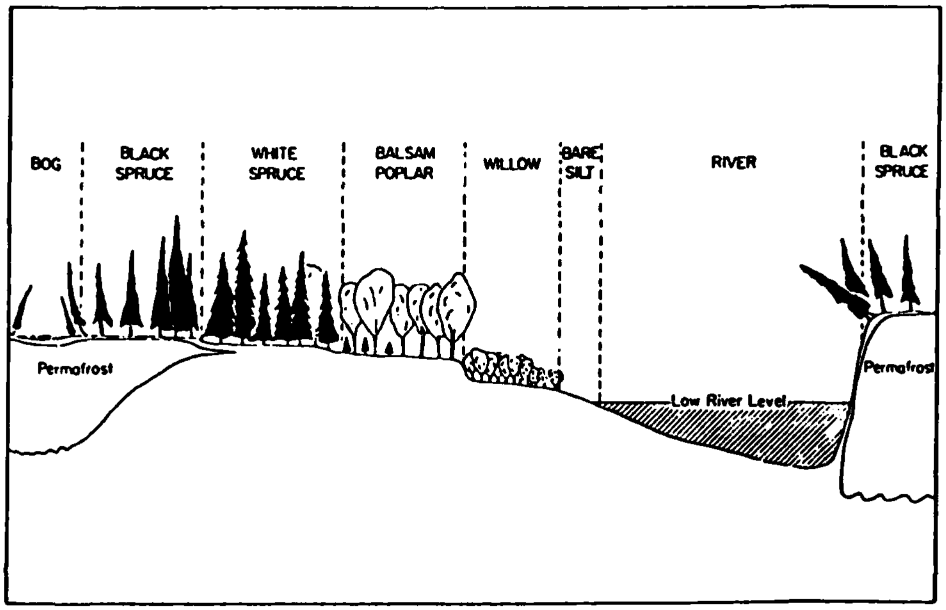
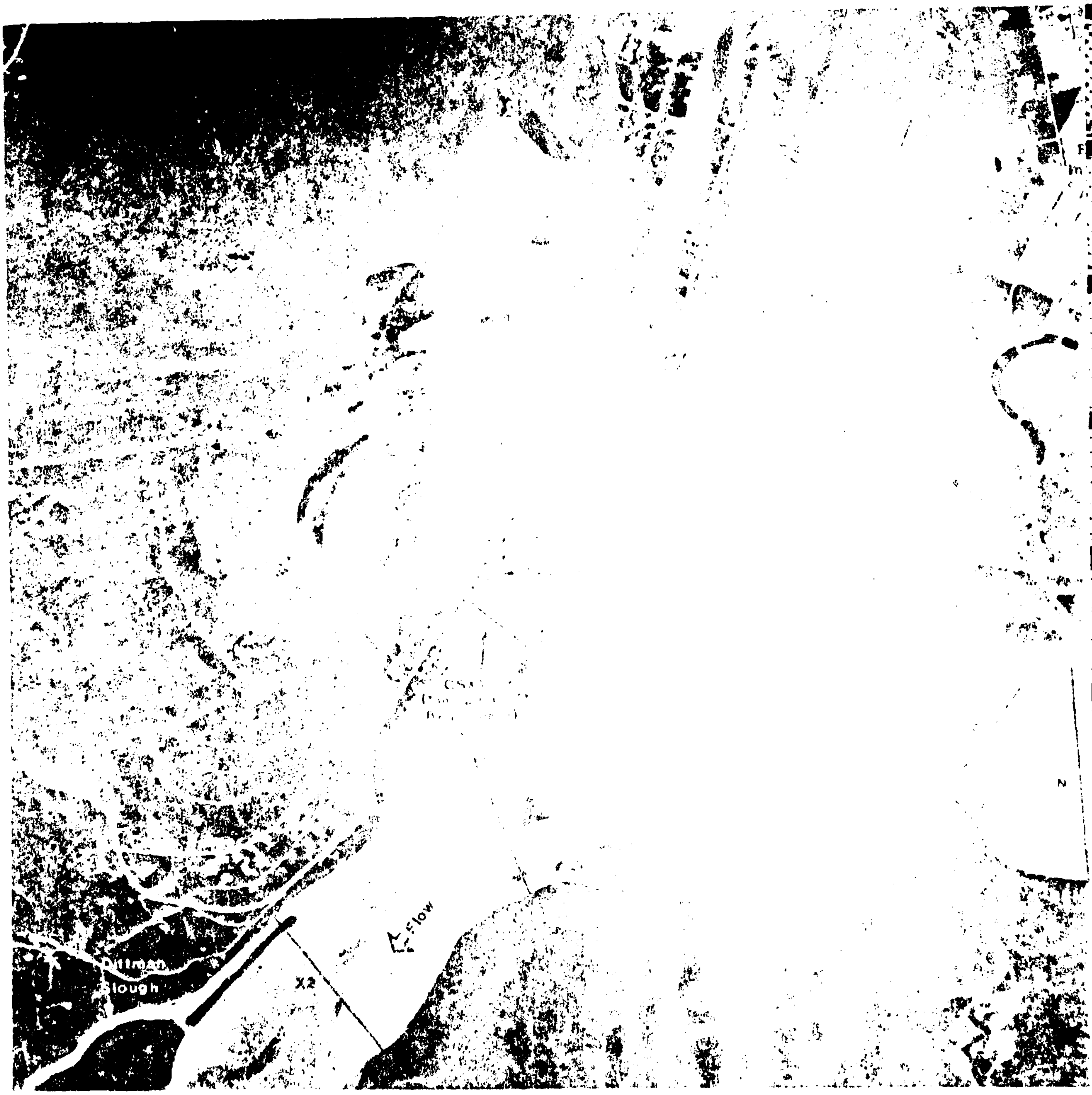
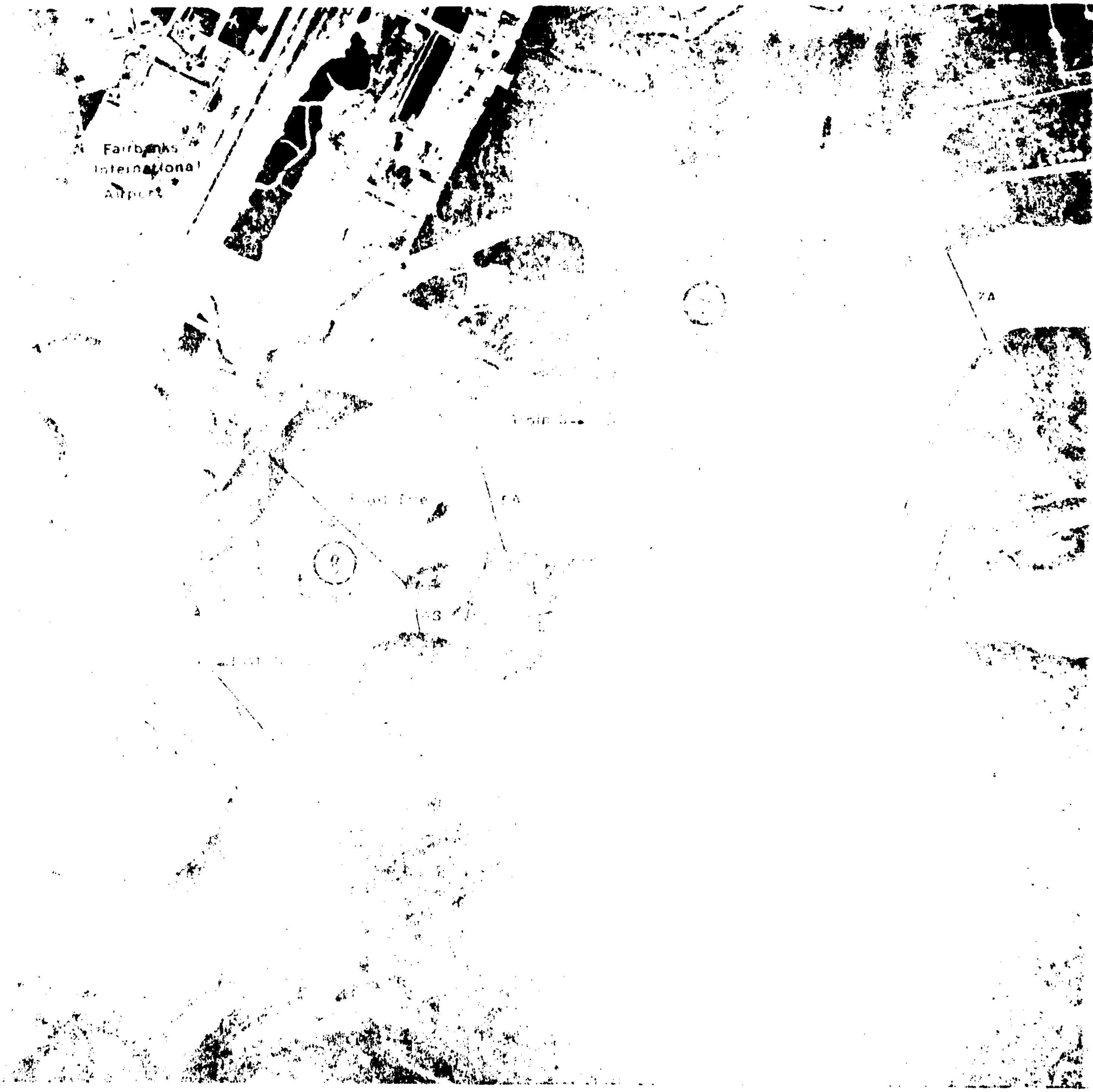


Figure 2.2. Typical permafrost and vegetation succession across river meander in interior Alaska (from Viereck, 1970).


Dittman
Slough
X2
Flow


Fairbanks
International
Airport


Goose Isl
East Cau
X9
5

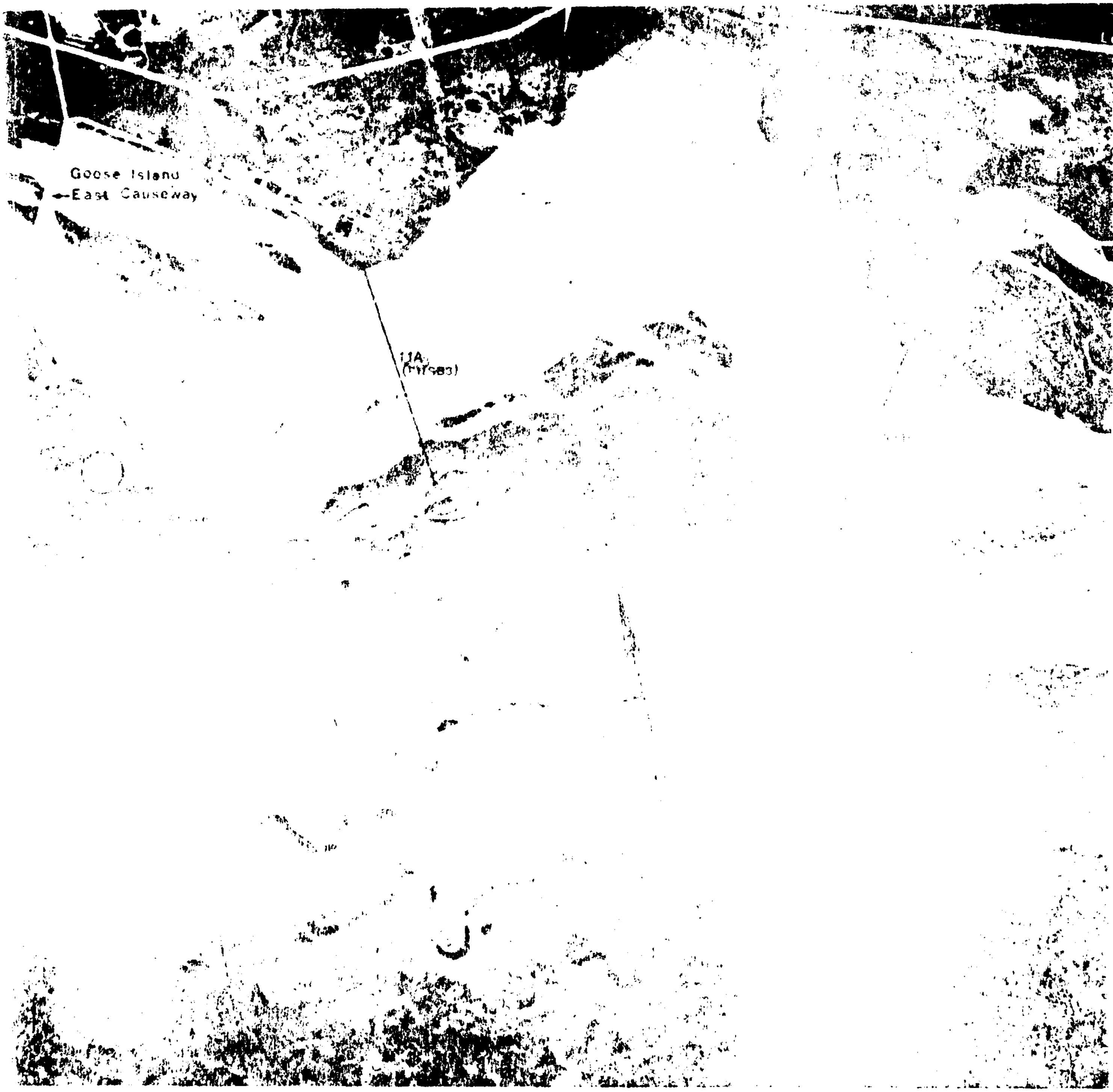

Goose Island
East Causeway
11A

FIGURE 2.1 (a)


4
14A
5A
13A
14B


Richardson
Highway
North Pole
Groin (#13)
4
16A
17B
17D


19B
18A

20A
21X
Floodway
22A
20B
GSX5
(Tanana River Near North Pole)
(21A and 21C)
23B

FIGURE 2.1 (b)

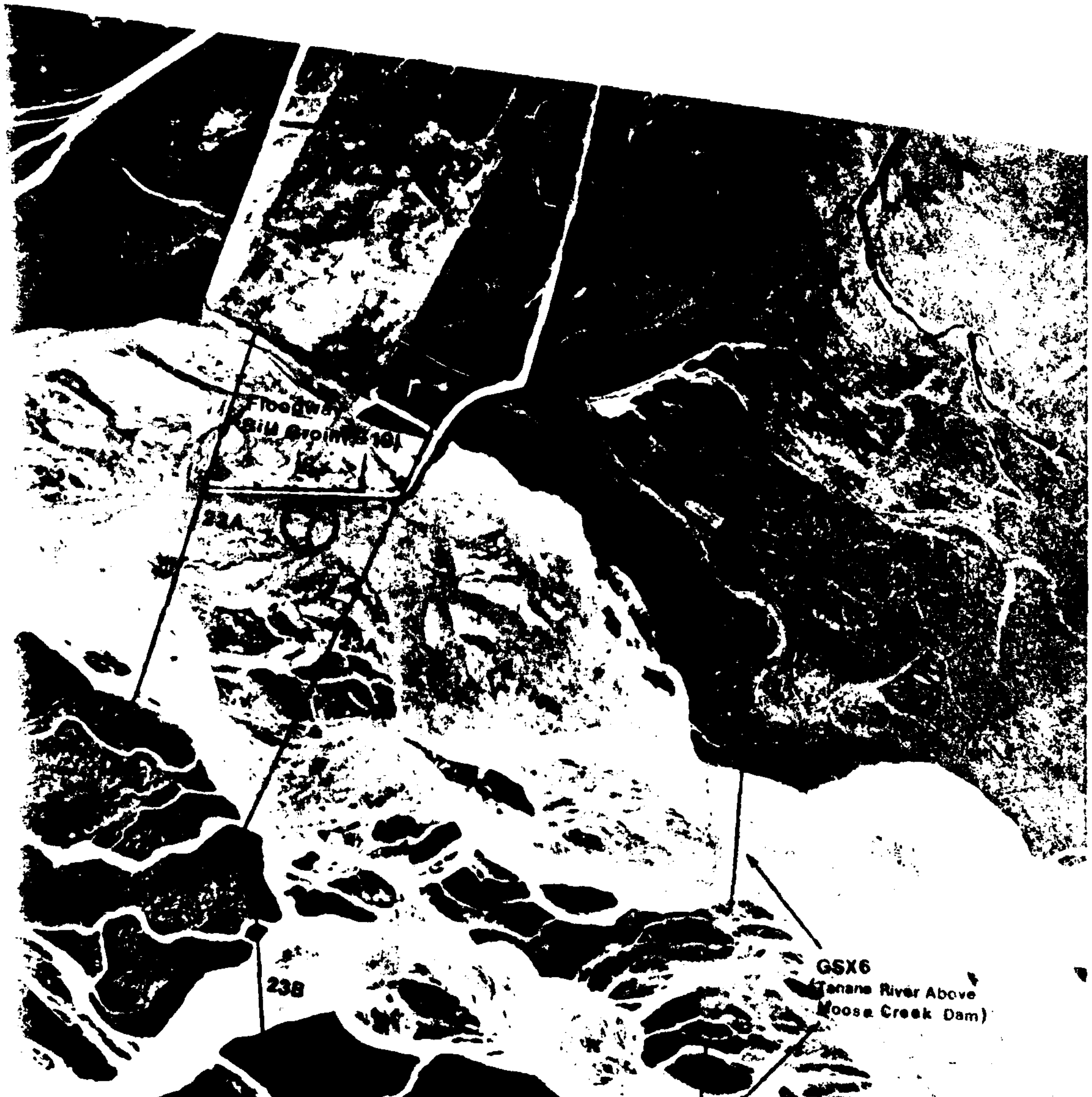

23B
GSX6
(Tanana River Above
Moose Creek Dam)
4000 FEET
DATE OF PHOTOMOSAIC 4 JUNE 1982

TABLE 2.1

CHRONOLOGICAL SEQUENCE OF PRINCIPAL RIVER WORKS AND ACTIVITIES

DATE	SITE No. (Fig 2.1)	EVENT
1945		Completion of Moose Creek Dike, stopping flow of Tanana River floodwater into Chena Slough.
1968		Authorization of the Chena Lakes Flood Control Project consisting of Moose Creek Dam on the Chena River, Floodway leading to the Tanana River, and Tanana River Levee.
1968-69		Rock revetment constructed just upstream of Chena Campground on north bank of Tanana River.
1969-76	1	Gravel extraction activities southwest of airport.
1969	2	Secondary channels closed upstream of Airport Erosion Area (Bend A).
1970-73	3	Gravel extraction activities north of Goose Island.
Oct 1972		DOT groin built southwest of International Airport (Bend B).
Oct 1974		Tanana River Levee Phase I completed.
1974-75	4	North Pole Groin constructed.
Nov 1975		Goose Island East Causeway constructed, connecting Goose Island with the north bank.
Aug 1976		Tanana Levee Phase II completed.
1977-82	5	Gravel extraction activities southeast of Goose Island.
1977-78		West Causeway to Goose Island completed.
1978-80		Piledriver slough blockages constructed at upstream entrances.
Spring 1979	6	West Goose Island Causeway extended to small island southwest of Goose Island, and large scale gravel removal initiated.
1979	7	Floodway Sill Groin constructed.
Jul - Aug 1979		1310 lineal feet of riprap revetment constructed in the Airport Erosion Area (Bend A).
Fall 1979		Tanana River Levee Phase IIB completed.
Jun 1980		170 lineal feet added to revetment in Airport Erosion Area.
Apr 1981	8	Tanana River Levee Phase II completed, including four groins; diversion into pilot channel 6 March 1981.
Aug 1981		Channel between Goose Island and small island to the southwest re-opened by river breaking through dike and causeway extension.

vial fans originating from the Alaska Range. To the north it is bordered by bedrock bluffs and rounded ridges of the Yukon-Tanana Uplands. The large alluvial slope has forced the main Tanana River channel to the north side of the valley, against the Uplands (Péwé, 1975). The valley is filled with 300-800 ft of Quaternary sediments and an unknown depth of Cenozoic sediments below.

During the Delta glaciation (of Illinois age), increased discharge and sediment load from the glaciers of the Alaska Range caused the Tanana River and its tributaries to aggrade rapidly. Aggradation by the Tanana dammed the lower reaches of several valleys of the Yukon-Tanana Uplands. A subsequent period of downcutting by the Tanana formed an upper terrace. During the Donnelly glaciation (of Wisconsin age), the Tanana again aggraded, although the floodplain was not built up as high as during the Delta period. Following the Donnelly glaciation, the river cut down again, forming a second, lower terrace (Péwé, 1975).

The recent history of the river is unclear, but it is probable that there have been fluctuating periods of minor aggradation and downcutting. Through dating of organic material and volcanic ash, Fernald (1965) obtained some data for filling rates in the floodplain and lower tributary valleys in the upper basin. The average rate of accumulation over the last 10,000 years has apparently been only about 1.5 ft per 1,000 years. Although this is not direct evidence of aggradation rates in the Fairbanks area, it may be indicative that the river system is more or less in a state of equilibrium.

Within the study reach near Fairbanks, the Tanana transitions from a braided river of unstable bars and multiple channels to an anastomosing pattern (Miall, 1977), consisting of several main channels with stable vegetated islands. Average meander wavelength for the main channel in the vicinity of the Chena mouth is approximately 8000 ft, and the width of the active floodplain ranges from 2000 to 7000 ft.

2.3 Human Activities - General

Flood control works, causeways, gravel extraction and other activities associated with urban development in the Fairbanks area have had a significant impact on the hydrology and morphology of the Tanana and Chena Rivers. These activities are described in Sections 2.4 and 2.5 below.

Table 2.1 lists a chronological sequence of the principal activities dating from 1945 to 1981.

The overall trend of these activities has been to divert flood flows in part from the Chena to the Tanana; to resist encroachment by the Tanana on its north floodplain and in places to push the river towards the south; to alter channel configurations substantially in the vicinity of Goose Island and of the Fairbanks International Airport; and perhaps to reduce river levels slightly by gravel extraction.

2.4 Flood Control Works

Moose Creek Dike. Moose Creek Dike, authorized in 1938 and finished in 1945, was designed to prevent flood waters of the Tanana River from entering Chena Slough, a secondary channel of the Tanana River that left the main channel south of the present Eielson Air Force Base and flowed north to join the Chena River approximately 10 miles east of Fairbanks. Early settlers regarded the channel through the town as an extension of Chena Slough rather than of the Chena River, but by the late 1930's the combined stream was commonly referred to as the Chena River.

Prior to construction of Moose Creek Dike, a considerable portion of the high-water flow in the lower Chena was contributed by Chena Slough, up to 50% or more. Local residents thought that the slough was enlarging each year, and that if nothing were done the greater part of the Tanana River flow might be diverted into the slough to destroy the townsite of Fairbanks. Since construction of the dike, all the flow in the lower Chena has originated from the Chena River. Chena Slough has filled in considerably and is supplied only from groundwater and local rainfall. The present channel geometry and meander pattern of the lower Chena River, which is considerably different from that of the Chena River upstream of Chena Slough, reflects this prior history of larger flows, so that the river can now be regarded as an 'under-fit' stream.

Fairbanks Flood Control Project. Plans for further flood control protection on the Chena and Tanana Rivers (U.S. Congress, 1955) were authorized by the Flood Control Act of 1958. They involved a diversion dam on the Chena River near present Fort Wainwright, a diversion channel from the Chena River to the Tanana River and about 12 miles of levee along the north side of the Tanana. Before these plans were implemented, however, the record flood of August 1967 led to an expanded project authorized by the Flood Control Act of 1968. This has evolved into the Chena River Lakes Project (or Fairbanks Flood Control Project) now being completed, the main elements of which are shown in Figure 1.1. The project involves Moose Creek Dam on the Chena River upstream of Fairbanks, a floodway channel above the dam leading to the Tanana River and a levee along the Tanana River. The dam regulates flood flows in the Chena through Fairbanks by diverting excess flows through the ungated floodway into the Tanana River. The Tanana River levee extends about 20 miles along the north bank of the Tanana from the Moose Creek Dam and floodway to the mouth of the Chena River. Three interior drainage channels were constructed to convey levee under-seepage flows to the Chena River.

The Tanana River Levee System was built from upstream to downstream in several stages. Phase I, extending about 12 miles downstream from Moose Creek Dam, was completed in October 1974. Phase IIA, a further 2.5 miles, was completed in August 1976. Phase IIB, extending a further 4 miles to just upstream of the Fairbanks International Airport, was completed in the fall of 1979, stopping short of the severe channel bend which was causing extensive erosion on the north shore at the time (Bend A). Phase III, completing the levee system, was finished in the summer of 1981. This section of the levee cut across the large bend of the Tanana River and included four groins and a pilot channel to redirect flow towards the south.

In response to continued erosion by the Tanana River a protective groin was built at a point about 8 miles downstream of the floodway. This groin, known as the North Pole Groin, was completed in the spring of 1975. A second groin was constructed at the floodway outlet to protect the sill structure. This groin, known as the Floodway Sill Groin, was completed in 1979.

2.5 Causeways, Revetments and Gravel Extraction

Several other in-river activities have had notable impacts on river morphology and behavior. These consist generally of causeways, roads and gravel extractions, and are included in Table 2.1. Reference should be made to Figure 2.1 for site numbers quoted in the following paragraphs. Estimated gravel extraction quantities are summarized in Table 2.2, but should be treated as very rough estimates because quantities and dates are hard to pin down.

During the period 1968-69, Chena Campground was built along the north bank of the Tanana River. A rock revetment was constructed just upstream of the campground for bank protection. Ungraded rock was placed 100-130 ft from the shoreline and the area between the natural bank and the rock facing backfilled to form a revetment.

During the period 1969-76, Alaska Aviation Division removed gravel from an area southwest of the airport (Site 1). In 1969 large-scale surface excavation took place throughout the point bar area in Bend B. A groin was built to protect the gravel extraction and stockpile area in October 1972. Surface mining of channel bars and some bailing of gravel from the active river channel continued until 1976. Extraction estimates total approximately 1,500,000 cubic yards between 1969 and 1976.

An encroachment took place in 1969 upstream of the airport (Site 2). A road was built across several secondary channels north of the main channel to provide access to the unauthorized excavation area. Construction of this road was followed by a large increase in erosion rates at the airport erosion area just downstream, and was probably an important contributing factor. (See also part 5 of this report.) Gravel amounting to 35,000 cubic yards was extracted in August 1969, and unknown amounts in 1970 and possibly later.

An unknown amount of gravel was removed from the north side of the channel north of Goose Island between 1970 and 1973 (Site 3).

Construction of the North Pole Groin in 1975 entailed excavation of about 248,000 cubic yards of material from a pilot channel in front of the groin location, of which about 77,000 cubic yards was used in groin construction (Site 4). The rest of the material was used to construct a berm along the north side of the pilot channel, which was subsequently eroded by the river and redeposited downstream.

In response to a need for a renewable gravel source, a causeway (east) was built to Goose Island during the winter of 1975-76, blocking off the north channel and diverting all flow to the south of Goose Island. In-river gravel extraction at the southeast end of Goose Island began in 1977 (Site 5). In 1978 a second (west) causeway was constructed to Goose Island, and in the spring of 1979 it was extended to a small island southwest of Goose Island. A dike was built around the small island and approximately 733,000 cubic yards of gravel was extracted from the island through 1979, mainly for purposes of levee construction (Site 6). In August 1981, the river broke through the dike and causeway extension between the two islands, reoccupying the blocked channel. Fairbanks North Star Borough has a permit from the Corps of Engineers and Alaska Department of Natural Resources to extract a total of 2,000,000 cubic yards of gravel from the river channel along the south side of Goose Island (Site 5).

TABLE 2.2

SUMMARY OF ESTIMATED GRAVEL EXTRACTIONS
FROM THE TANANA RIVER NEAR FAIRBANKS, ALASKA

Site No. (see Fig. 21.)	Years	Volume Removed	Volume Relocated in River	Total Volume Disturbed
1	1969-76	1,500,000	---	1,500,000
2	1969-70	35,000 +	---	35,000 +
3	1970-73	?	---	?
4	1974-75	77,000	171,000	248,000
5	1977-82	243,000	---	243,000
6	1979	733,000	---	733,000
7	1979	57,000	206,000	263,000
8	1981	113,000	211,000	324,000

Approximate amounts of gravel removed from the river at Site 5 are summarized below:

1977	76,000 cu yd
1978	28,400
1979	70,200
1980	38,000
1981	30,400
Total 1977-81	243,000 cu yd

In 1979 the Alaska Department of Transportation constructed approximately 1310 linear ft of rock revetment along the north bank of the Tanana River at the airport erosion area when it became apparent that completion of Phase III of the levee would be delayed. In 1980, 170 linear ft was added to the revetment.

During construction of the Floodway Sill Groin (Site 7) in 1979, approximately 263,000 cubic yards of material was excavated from the river in front of the groin to form a pilot channel. About 57,000 cubic yards was used in groin construction, and the rest was left in the river to form a temporary diversion; most of this has been eroded by the river and redeposited downstream.

In early 1981, the levee was extended across the main channel of the Tanana River near the airport, and four associated groins were built to protect the levee (Site 8). Approximately 324,000 cubic yards of material was excavated to form a pilot channel, most of which was deposited into a spoil pile along the north side of the pilot channel. By the fall of 1982 the river had eroded approximately 65% of the spoil pile. The remainder was removed to the north in early 1983 to reduce its availability for erosion and deposition.

2.6 Summary

Some key points from the foregoing overview of geographic and historical aspects of the Tanana River may be summarized as follows:

1. The Tanana River is mainly fed by the Alaska Range, and lies in the zone of discontinuous permafrost. White spruce is the dominant vegetation in the floodplain. In the Fairbanks area, the river has been pushed towards the north side of its valley by continued aggradation of an alluvial slope to the south. It is underlain by deep alluvial sediments. Over the last few millennia, it has apparently aggraded slowly.
2. The river in the Fairbanks area has been affected by a history of human activities, including flood control works, access causeways and gravel extractions. These have affected flows, erosion and sedimentation, and channel patterns and shifts.
3. Quantities of gravel extracted at various places and times are hard to elucidate from available records. It appears that some 2 to 3 million cubic yards was extracted between 1969 and 1981. The greater part of this came from perennial bars and islands rather than from the active channel.

4. Local effects of certain interferences on channel configurations and erosion appear to have been highly significant, particularly near the International Airport and at Goose Island.

3. RIVER HYDROLOGY AND HYDRAULICS

Reference should be made to annotated photomosaics, Figure 2.1 A and B, for locations referred to in the following text.

3.1 River Flows

A 10-year hydrograph of daily discharges (1973-82) at the Fairbanks gauging station is plotted in Figure 3.1.

Table 3.1 shows year-by-year and period-of-record statistics for mean, minimum and maximum flows, also monthly flows and averages over the highest 6-month and 3-month periods.

Table 3.2 compares mean flow and mean annual maximum at Fairbanks and at the longer-period stations of Tanacross and Nenana. This indicates that the 1973-81 period of record at Fairbanks was fairly representative of longer periods as to mean flow, but may have been low as to maxima.

Figure 3.2 shows flood frequency curves (i) for Fairbanks based on the 1973-81 record and (ii) for Nenana based on the 1963-81 record. These suggest that the 1973-81 flood experience at Fairbanks is low with respect to longer periods. Also shown is a curve (iii) based on extending the Fairbanks record to 1963-81 by correlation with Nenana and an extended record curve (iv) for Fairbanks that simulates operation of Moose Creek Dam over the period of 1963 to 1981. These curves are presented only to illustrate approximate flood frequency relations.

The following points are most relevant to subsequent analyses herein:

1. Flow volumes and peaks do not vary dramatically from year to year, coefficients of variation being only about 13%.
2. In the period 1973-81, the high year generally was 1979 and the low year 1976.
3. The mean annual flow is about 19,000 cfs, the mean 6-month May-October flow is about 32,000 cfs, and the mean 3-month June-August flow is about 43,000 cfs.
4. The mean annual maximum is about 62,000 cfs and the 10-year maximum may be about 92,000 cfs. Bankfull discharge, somewhat difficult to define exactly, has been variously estimated in the range of 60,000 to 80,000 cfs. Winter under-ice flows are approximately 5,000 cfs.

3.2 Stage-Discharge and Associated Relationships

Figure 3.3 shows a plot of stage vs. discharge data for the Fairbanks gauging station.* There has been considerable scatter over the 1973-81 period. It is difficult to discern any systematic trend with time or with river flows. The 9-year range in stage is approximately 2 ft for low flows and 1 ft for high flows.

Figure 3.4 shows a more or less average stage-discharge curve based on Figure 3.3, together with approximate mean stage-area and stage-velocity curves for cross section GSX2. The area and velocity curves were prepared by using the average stage-discharge curve in conjunction with the 1977-79 hydraulic geometry relationship shown in the sediment

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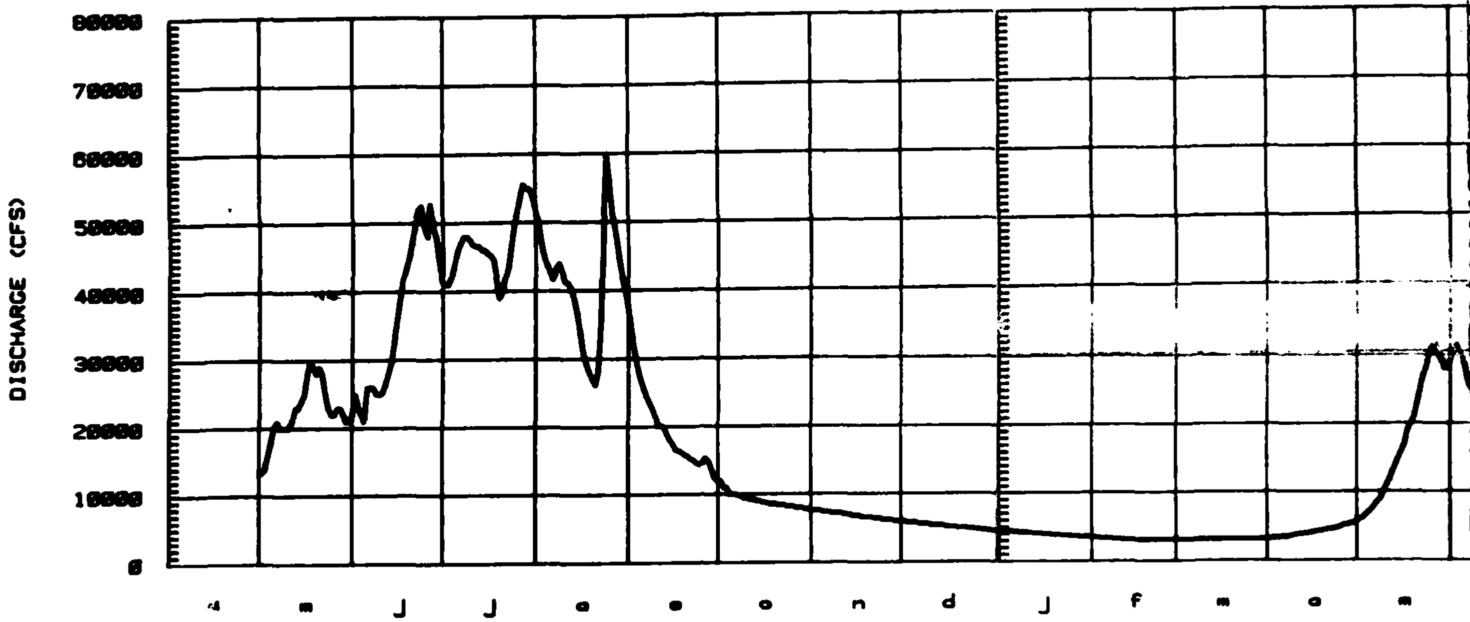
* Note that stages are measured at the Fairbanks gauging station (T-2) and discharges at section GSX2: see Figure 2.1A for clarification.

1973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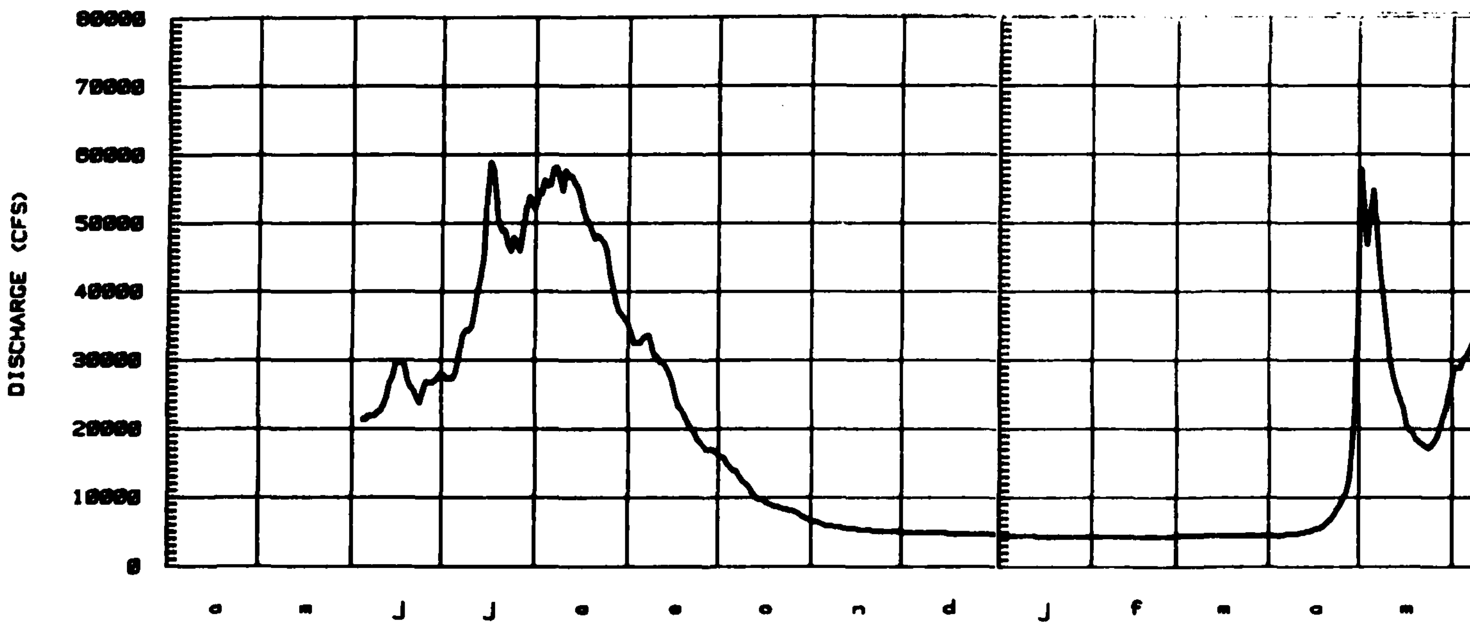
1978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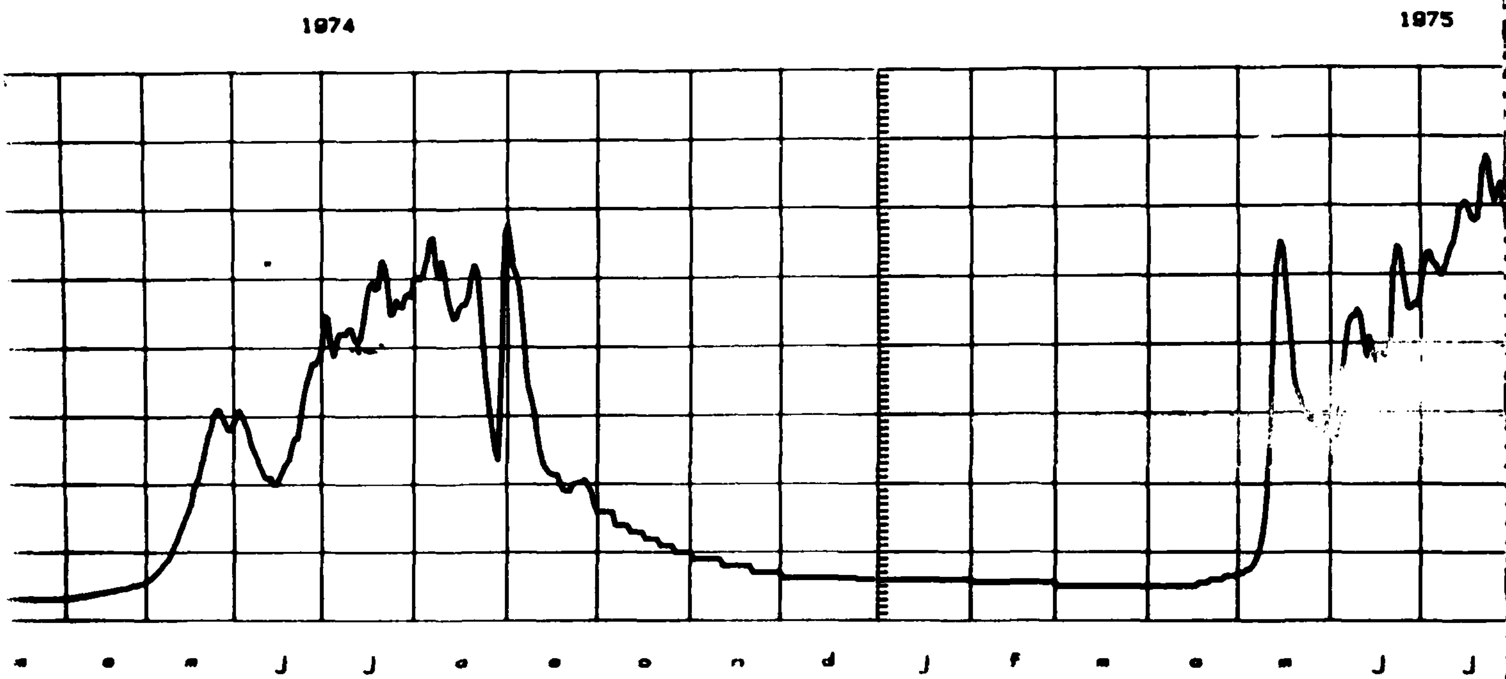
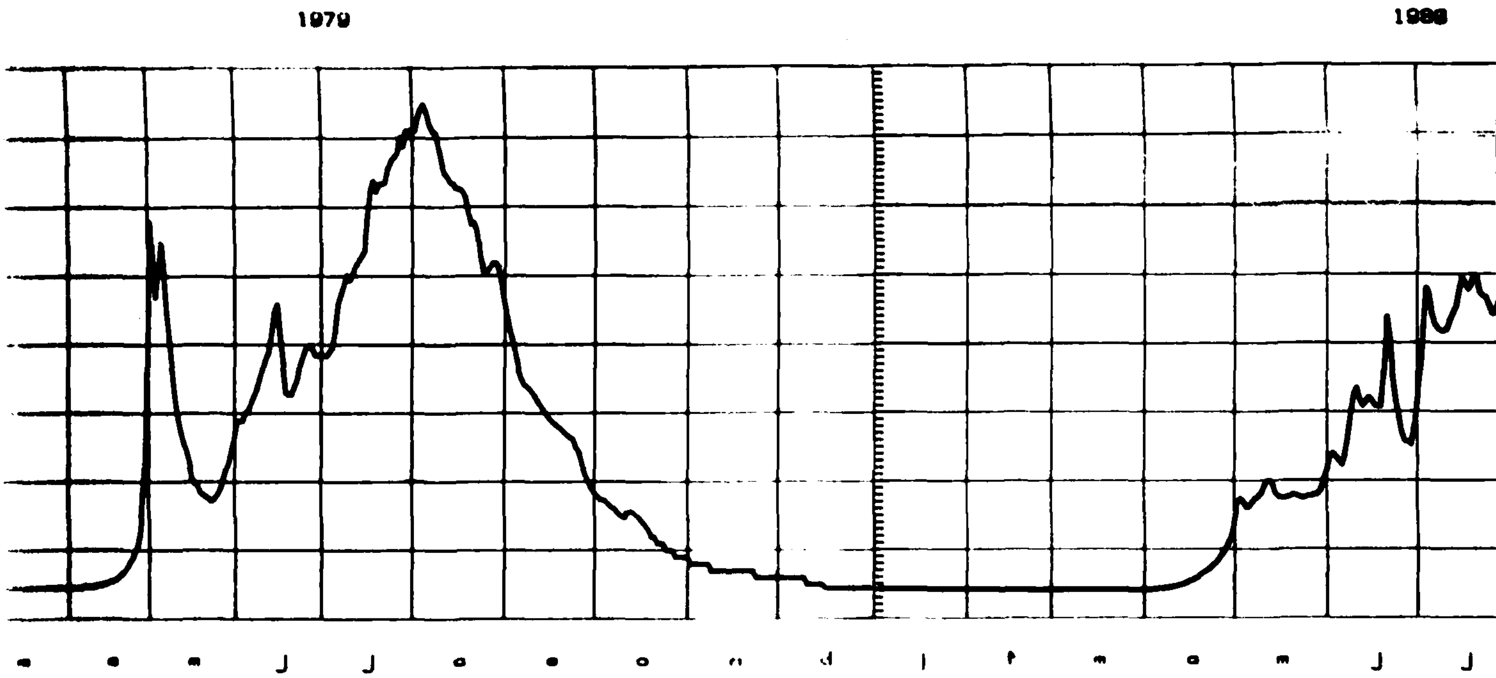
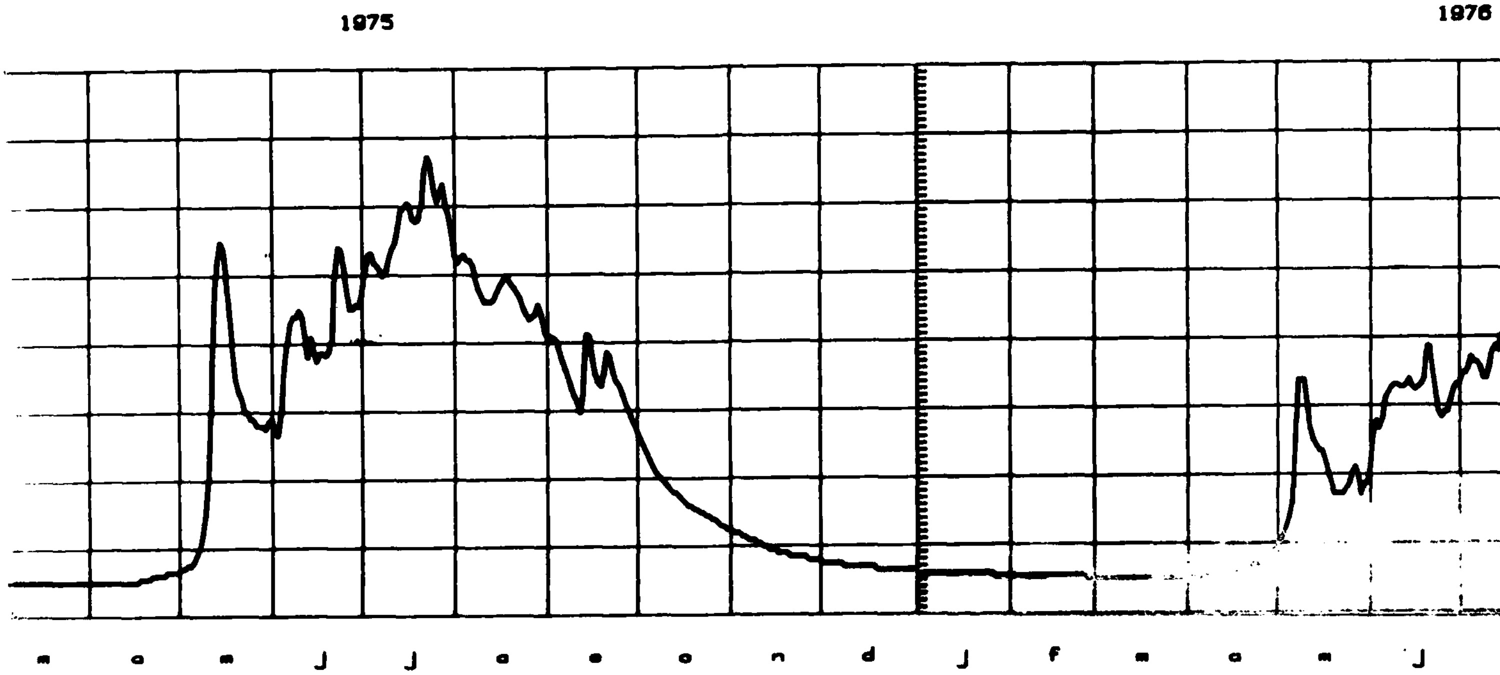
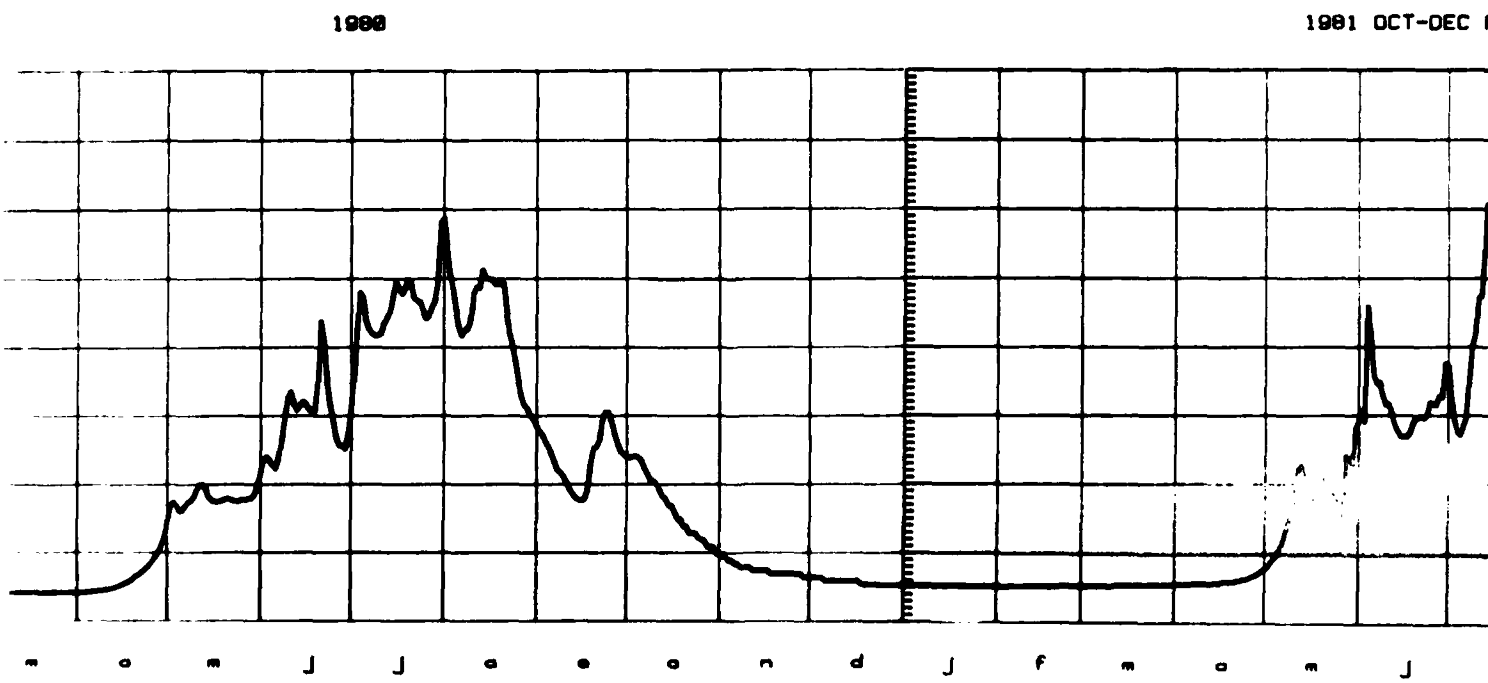
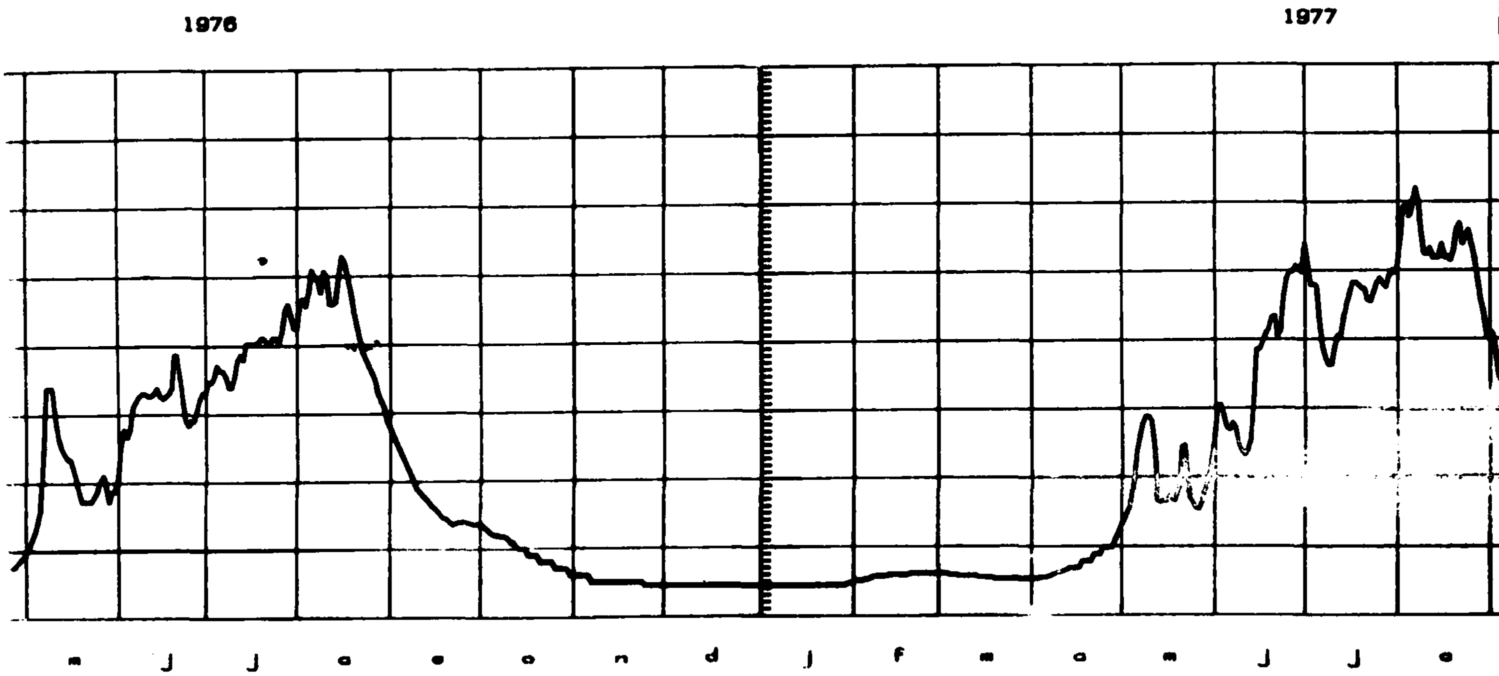

1974
1975

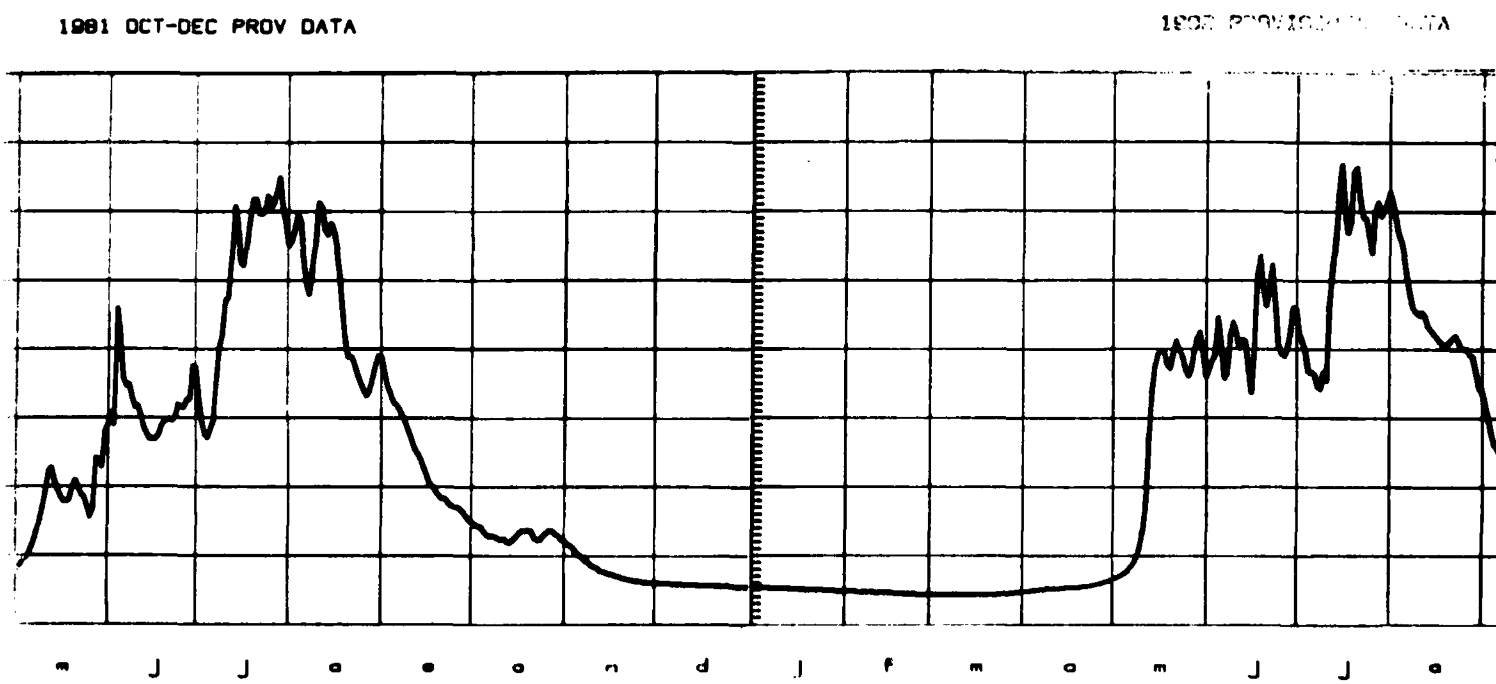

1979



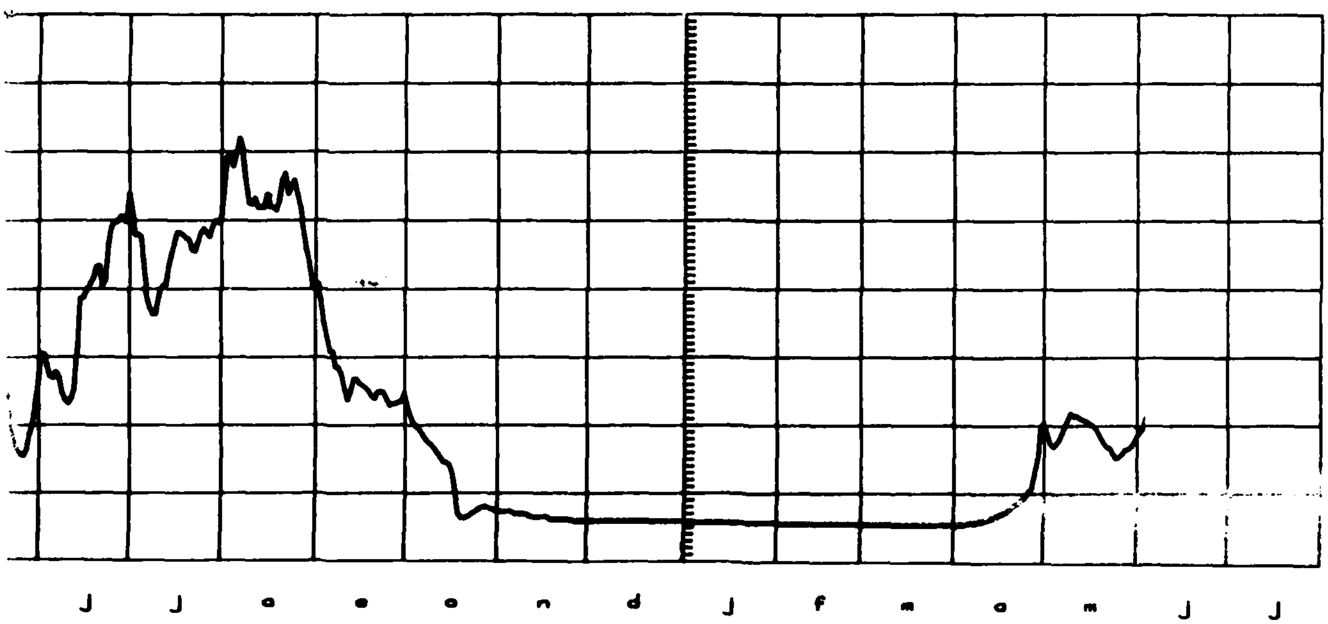


3


1976
1977
m j j a s o n d j f m a m j j a


1981 OCT-DEC PROV DATA
m j j a s o n d j f m a m j j a

1977 1978



92 PROVISIONAL DATA

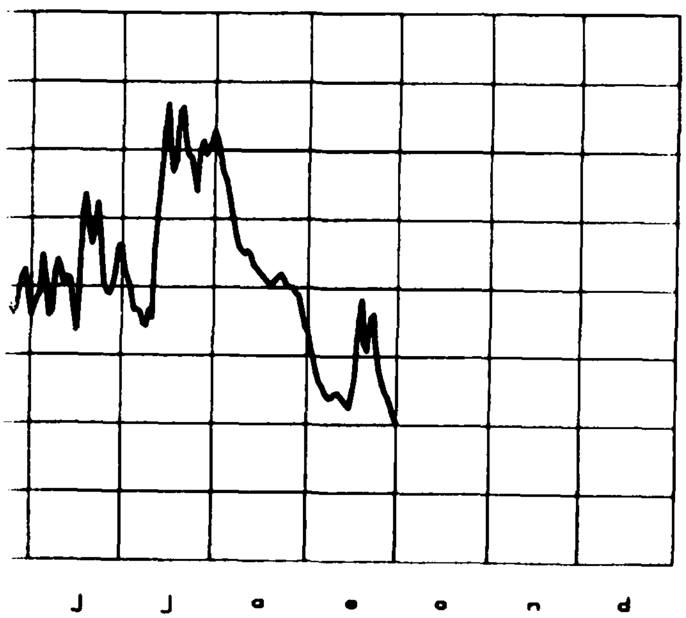


FIGURE 3.1

DISCHARGE HYDROGRAPHS TANANA RIVER AT FAIRBANKS 1973 TO 1982

5

Table 3.1. River flow statistics (cfs), Tanana River at Fairbanks.

CALENDAR YEAR		1973	1974	1975	1976	1977	1978	1979	1980	1981	MEAN OVER PERIOD $\bar{X}$	STD. DEVIATION S	$S/\bar{X}$
YEARLY	MEAN		17300	22300	16300	19500	17500	21900	17500		18900	2400	0.13
YEARLY	MAX.	52800	57800	67300	53000	62100	59000	74900	58900	64700	61200	7100	0.12
YEARLY	MIN.		3100	5000	4500	4500	4800	4400	4200	5300	4500	660	0.15
6-MONTH MEAN (MAY-OCT)			29500	37800	27100	32700	28800	38000	29700	31100	31900	4100	0.13
3-MONTH MEAN (J/J/A)		41400	39600	48900	38300	45400	39400	51500	39900	44450	43200	4700	0.11
MONTHLY MEAN	JAN		4000	6000	5900	4500	5800	4500	4400	5300	5400		
	FEB		3200	5600	5400	5900	5600	4400	4200	5600	5000		
	MAR		3100	5000	5000	5700	5500	4600	4200	5600	4800		
	APR		4200	5500	6600	7800	8600	8300	7000	7100	6900		
	MAY		18300	27800	21400	20200	18600	29700	18300	17800	21500		
	JUN	36700	27600	41900	32300	37400	25100	36100	30200	33800	33500		
	JUL	46800	45300	57400	39700	45600	43200	56800	47100	51500	48200		
	AUG	40900	45900	47400	42700	53300	50000	61600	42500	48000	48000		
	SEPT	19300	27300	34900	17000	27200	25400	29900	23800	23200	25300		
	OCT	9000	12600	17400	9300	12700	10400	13400	16400		12600		
	NOV	6800	8000	9600	5000	6600	5600	7000	6800		6900		
	DEC	5200	6200	6900	4500	6000	4900	5000	5300		5500		

Table 3.2. Comparison of river flow statistics for various record periods.

STATION	DRAINAGE AREA mi^2	STATISTIC	FLOWS IN CFS 1973-81	1963-81	1954-81
Tanacross	8550	Mean	8100	7900	7900
		M.A. Max.	31000	30000	30000
Fairbanks	20600	Mean	18900	-	-
		M.A. Max.	62000	-	-
Nenana	25600	Mean	22500	23500	-
		M.A. Max.	72000	81000	-

Note: Nenana data indicate that Fairbanks mean annual maximum 1973-81 may be low in relation to longer periods.

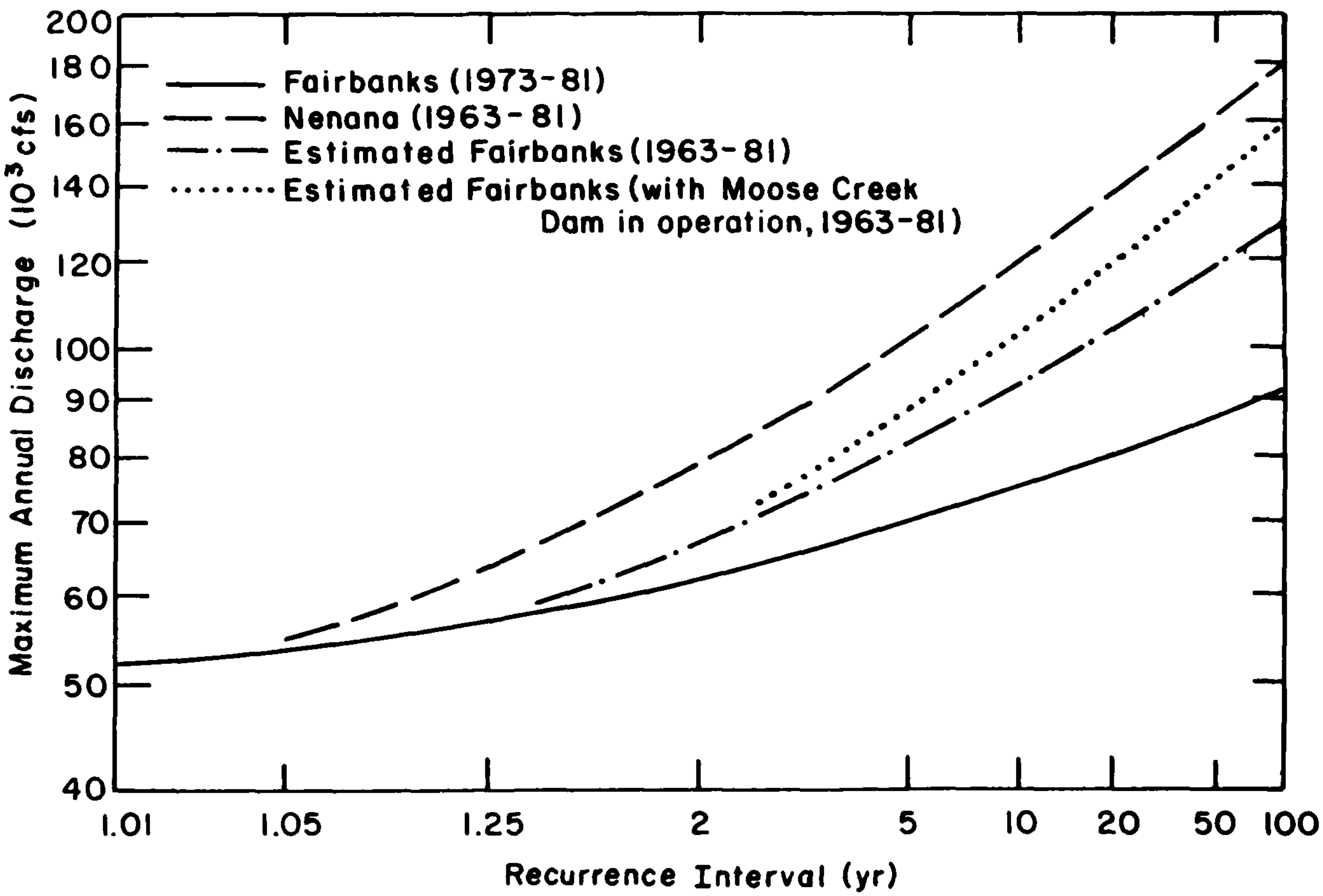


Figure 3.2. Flood frequency curves, Tanana River at Fairbanks and Nenana. (Log-normal fits.)

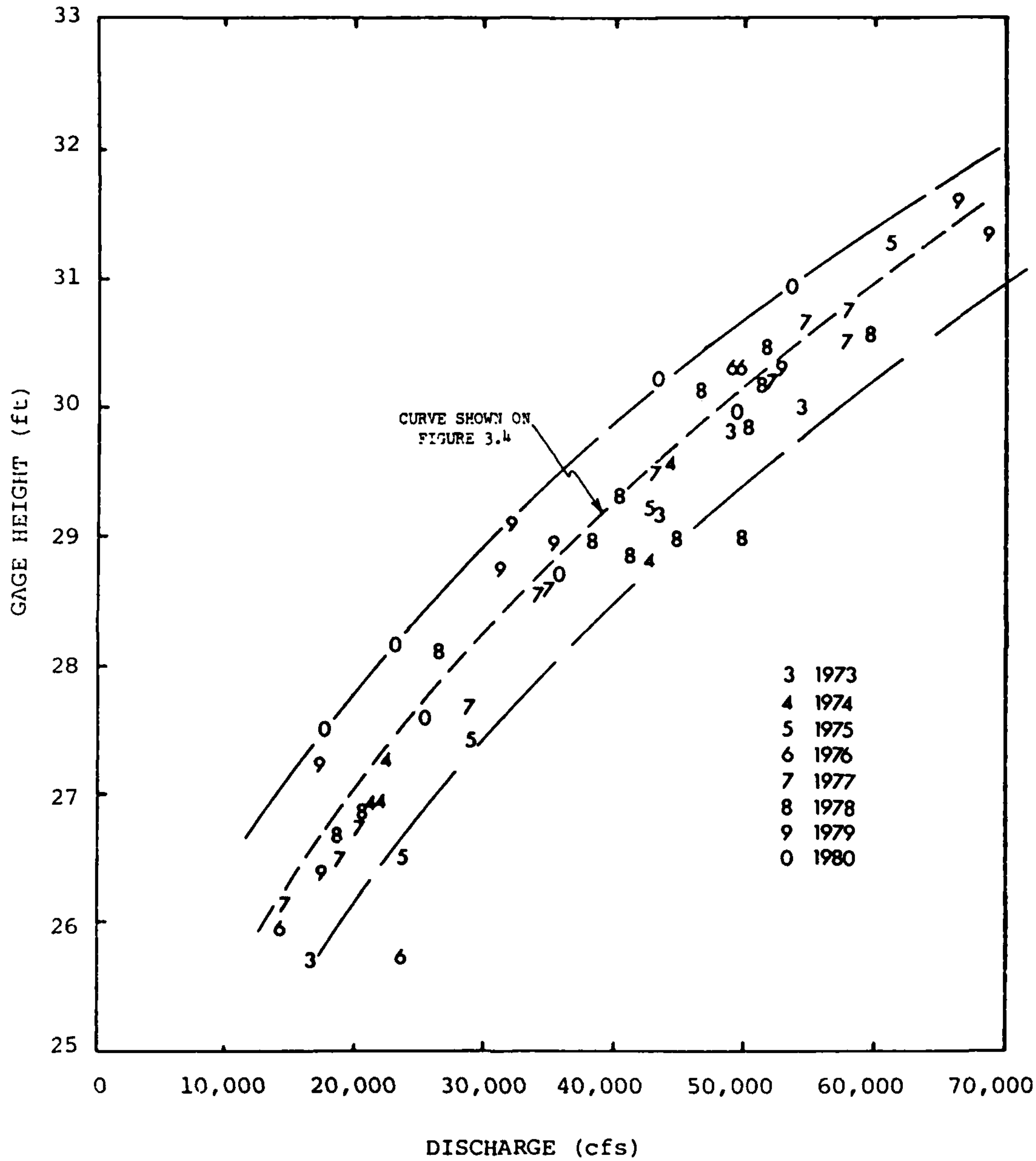


Figure 3.3. Stage-discharge plot, 1973-80, Tanana River at Fairbanks. (Note: g.h. = 0 is 400.0 ft above sea level, discharge actually measured at the cross section GSX2, gauge height actually measured at Fairbanks gauging station.

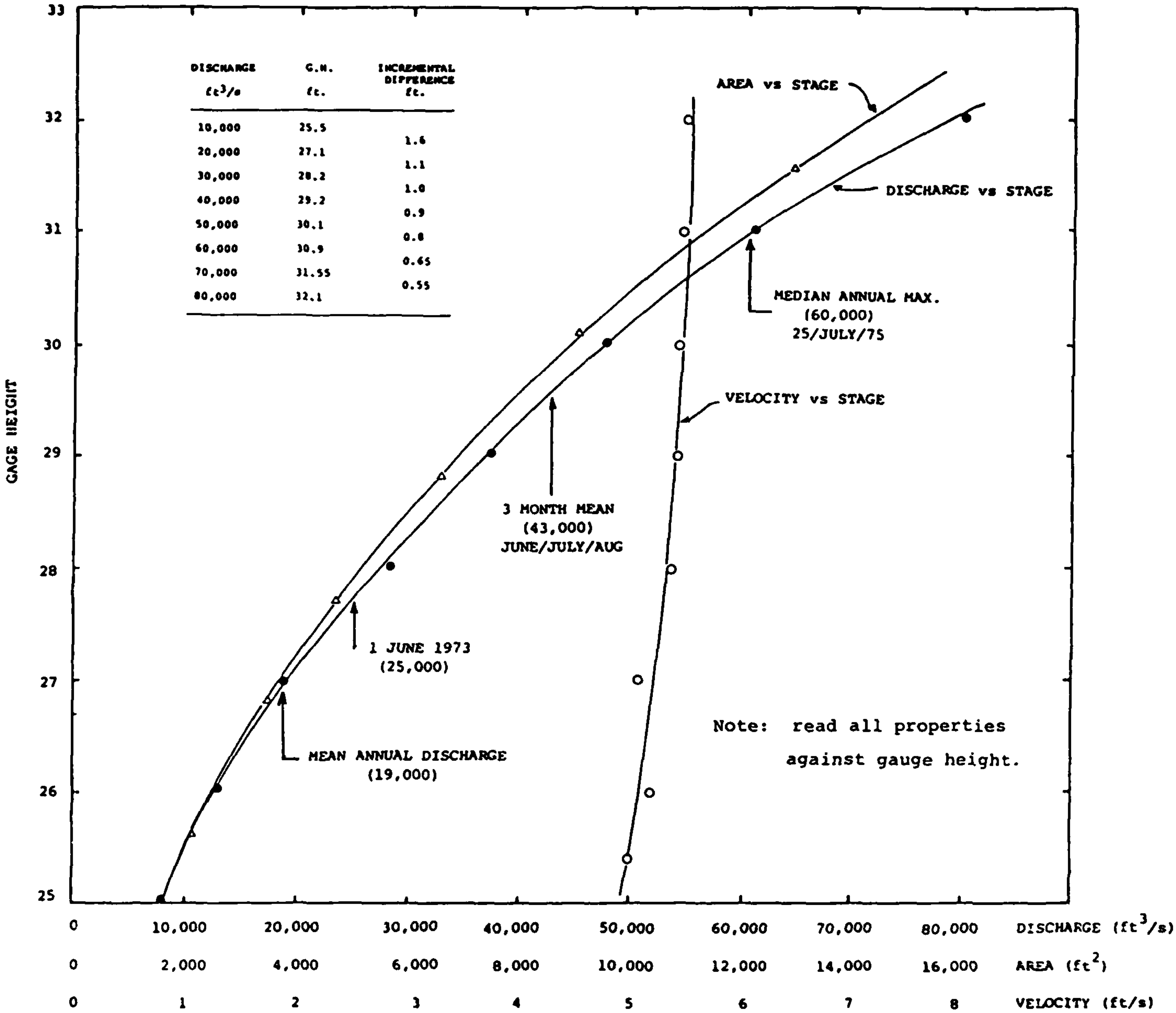


Figure 3.4. Approximate stage-discharge/area/velocity relationships for Tanana River at Fairbanks. (Note: Based on applying mean curve of Figure 3.3 to mean areas at the cross section of Tanana River at Fairbanks [GSX2].)

transport data report (Burrows et al., 1981). They should be treated as indicative only because the stage-discharge relation is subject to considerable year-to-year variations and is not necessarily applicable to the gauging cross section.

At the gauging section, area appears to increase almost proportionately with discharge, and mean velocity therefore increases only slightly from about 5 ft/s at 10,000 cfs to about 5.6 ft/s at 80,000 cfs. This is partly because the section tends to scour out somewhat at high flows and fill in at low flows, as shown by Figure 3.5, and partly because of the overall characteristics of Tanana River cross sections, wherein wetted perimeter increases rapidly as stage rises. Cross sections and velocities are discussed further in Section 3.4

3.3 River Slopes and Channel Patterns

Figure 3.6 shows a composite river slope profile based on the following data:

- USGS water level data from the 'T' sites (Fig 1.1) at a flow of about 60,000 cfs in 1975, between site T-14 upstream of Eielson Air Force Base and Byers Island, a distance of about 33 miles;
- similar data for flows of 25,000 and 60,000 cfs in 1973, over parts of the same length;
- top of ice data in 1939-40, over a length of about 24 miles downstream from Byers Island. (The data actually extend to the Yukon River.)

The profile is of fairly smooth concave-up type characteristics of a self-adjusted alluvial channel with no important geological or hydraulic structure controls. Upstream of Byers Island, lengths shown are measured along the middle of the active braided alluvial system, not following the meander-type bends of the main channel. Downstream of Byers Island, lengths are believed to have been measured along the main channel.

The average slope decreases progressively from about 1.3/1000 above Moose Creek Bluff, to about 1.0/1000 at North Pole, to about 0.5/1000 at Fairbanks, to about 0.3/1000 below Byers Island. The most rapid change occurs between Meridian and Byers Islands, where the slope drops in half over a length of only 10 miles. Within this length, the planform of the river changes markedly from a clearly braided pattern above Meridian Island to an anastomosing pattern below Byers Island; the latter consists essentially of a single main channel with irregular meanders plus one or more minor channels or 'sloughs' separated from the main channel by stable islands. The contrast in patterns is shown in Figure 3.7. As will be shown in Part 4, a notable change in bed-material composition also occurs in the vicinity of Byers Island.

As has been partly shown in previous reports (C of E, 1979; NHC, 1980), the slope/discharge/channel pattern relationships for the Tanana agree remarkably well with a well-known empirical plot by Leopold et al. (1964). This is shown in Figure 3.8 with points for the Tanana superimposed. The Leopold curve discriminating between braided and meandering patterns in terms of slope corresponds to a point between Fairbanks and Byers Island, which is a reasonable representation of the field situation if anastomosing is regarded as a form of meandering.

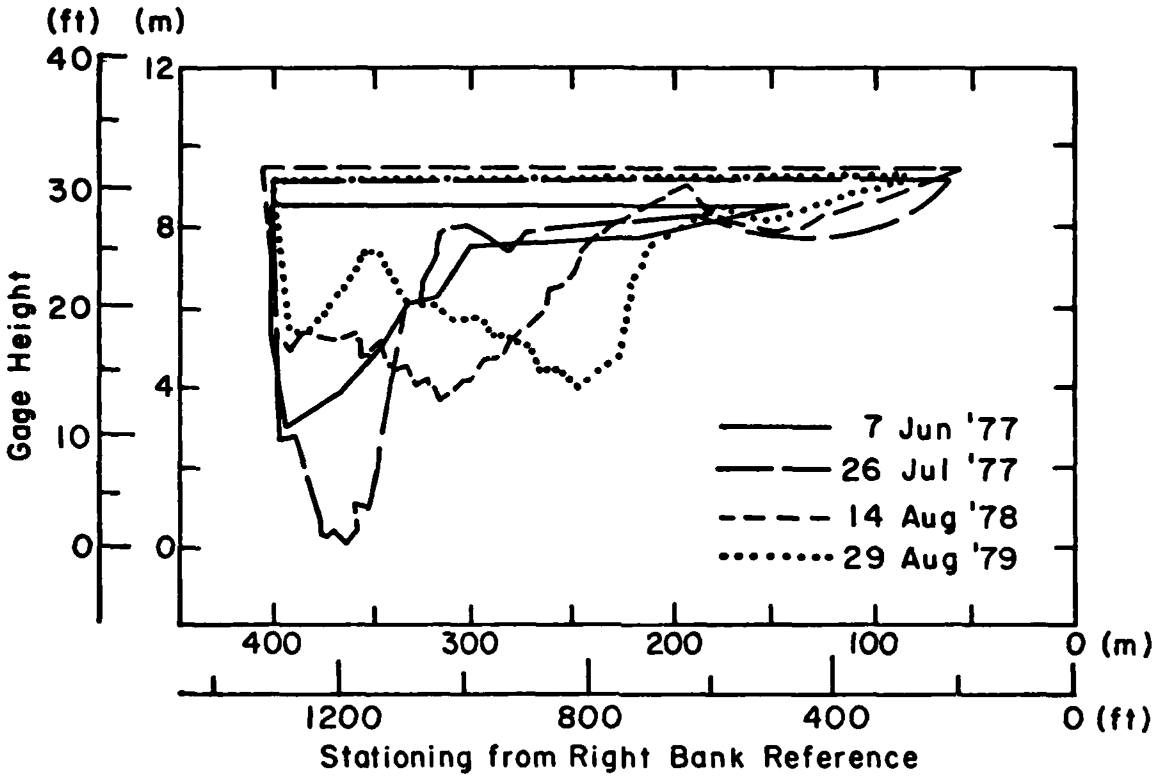


Figure 3.5. Selected changes in the cross section, GSX2, 1977-79.

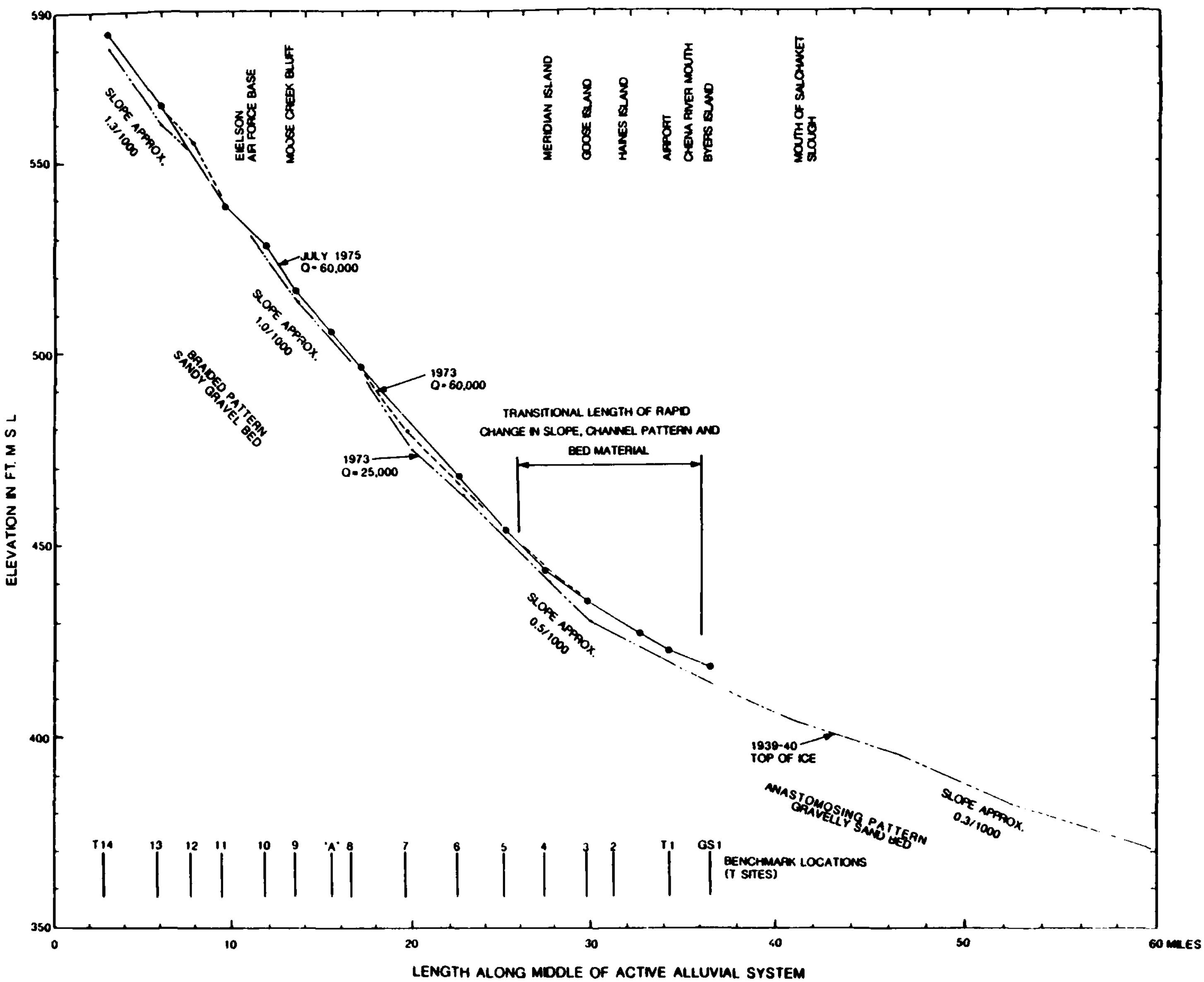
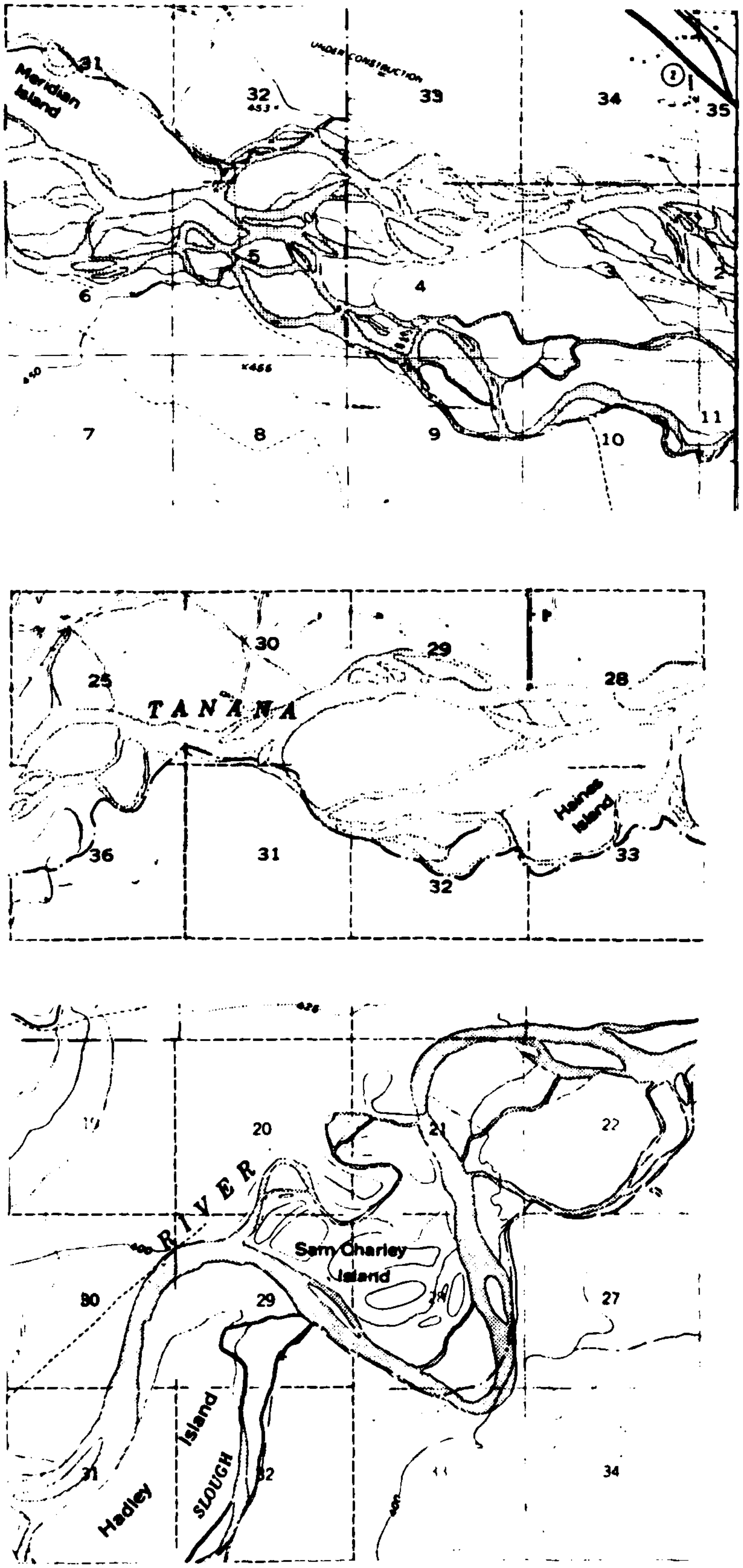


Figure 3.6. River slope profiles.



upstream of Meridian Island

slope ~ 1/1000

near Fairbanks

slope ~ 0.5/1000

below Byers Island

slope ~ 0.3/1000

Figure 3.7. Typical channel patterns associated with different river slopes.

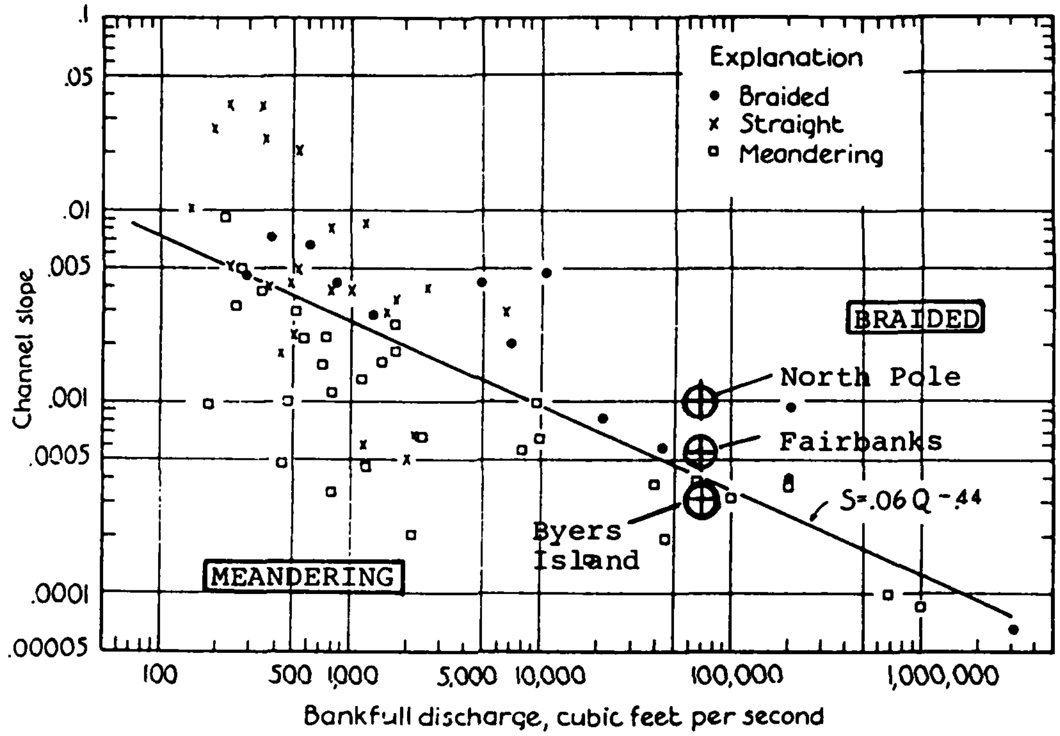


Figure 3.8. Slope-discharge plot distinguishing meandering and braided channels (from Leopold, Wolman and Miller, 1964).

3.4 Cross Sections and Velocities

Attention is restricted here to hydraulic geometry of cross sections, morphologic changes being considered under Channel Processes (Part 5). Hydraulic geometry is considered at a flow of 60,000 cfs, which corresponds approximately to mean annual flood and which may be regarded tentatively as a channel-forming or dominant discharge. As previously noted, it is close to a bankfull discharge at many sections.

In order to estimate cross-sectional properties at a common high discharge of 60,000 cfs, water levels at time of survey were adjusted by means of stage-discharge plots such as shown in Figure 3.3. Similar plots were prepared for other locations using water-level observations as tabulated by USGS for the "T" sites. This approach is open to objection and is admittedly somewhat crude, but is considered justified as a means of examining the average variation in cross-sectional characteristics along the river.

Results of hydraulic geometry analysis are presented in two parts. In the Phase III area, between cross section 6A (USGS gauging section GSX2, Tanana River at Fairbanks) and cross section X2 below Byers Island, sections were surveyed on several occasions from 1977 through 1981. Data for this reach are shown in Table 3.3. Some of these surveys were done at moderately high discharges and can be extrapolated to 60,000 cfs with good reliability. Some of the sections are single-channel, others have double or multiple channels. Discounting some 1981 surveys where cross sections were obviously affected temporarily by Phase III construction, the average cross-sectional area appears to be about 10,800 ft^2 and the average cross-sectional mean velocity about 5.6 ft/s. These average properties are quite similar to those of the Fairbanks gauging station (see Section 3.2 and Figure 3.4). It should be noted, however, that areas and mean velocities are somewhat biased by double-channel sections where in fact the greater part of the discharge flows at considerably higher velocities in the larger channel*. There is little indication of a systematic change in cross-sectional properties of this length of approximately 5 miles.

Upstream of the Phase III area, most of the available cross-sectional plots are based on low-stage surveys of 1977, and more uncertainty is involved in adjusting water levels to 60,000 cfs, especially as most of the cross sections involve multiple channels. Approximate properties over a length of about 16 miles, extending upstream from cross section 6A to cross section 21 near the USGS (North Pole) gauge T-8, are shown in Table 3.4. It is immediately evident that upstream of cross section 13, located just above Meridian Island, the sections are wider and shallower but not notably different in area: this change corresponds to the change from a transitional to a fully braided channel pattern as indicated on Figure 3.6.

Comparing Tables 3.3 and 3.4, the most curious feature is that cross-sectional mean velocities in Table 3.3 are generally larger than in Table 3.4 despite the flatter slopes, and that mean velocities appear to increase in the downstream direction. The main reasons are that where the

* Local velocities of up to 10 ft/s were measured in 1979 at the airport erosion area (Burrows, 1980).

Table 3.3. Approximate hydraulic geometry of cross sections in Phase III area, 1977-81.

X-SECTN. (combined where appropriate)	DATE OF SURVEY	CORRESP. DISCHARGE cfs	APPROX. PROPERTIES EXTENDED TO FLOW of 60,000 CFS				MEANS OVER PERIOD				NOTES
			AREA (A) ft^2	SURFACE WIDTH (W) ft	MEAN DEPTH (A/W) ft	MEAN VELOCITY (Q/A) (ft/sec)	A	W	d	V	
6A (USGS Gauge)	July/77	44800	9700	1120	8.6	6.2					
	Aug/77	49800	10400	1010	10.3	5.8					
	July/78	58200	10300	1140	9.0	5.8	9800	1080	9.1	6.1	
	Aug/78	57900	10500	1070	9.8	5.7					
	July/79	70000	9300	1040	8.9	6.5					
	Aug/79	66400	8400	1120	7.5	7.1					
5A/5B	Sept/77	25000	13600	1550	9.0	4.3					
	Oct/79	16300	12100	1780	6.9	4.9	12200	1710	7.1	4.9	
	Oct/80	10500	10900	1800	6.0	5.6					
	June/Oct/81						(7400	760	9.8	8.0	Pilot channel post-construction
4A/4B	Sept/77	20500	9500	1700	5.6	6.3	9700	1820	5.4	6.2	
	Oct/79	16300	9700	1800	5.4	6.2					
	Oct/80	10500	10000	1950	5.1	6.0					
	May/Oct 81						(8000	1000	8.0	7.5)	Pilot channel post-construction
3A	Sept/77	25000	9600	1330	7.2	6.2					
	Oct/79	16700	10500	1370	7.7	5.7					
	Oct/80	11900	10400	1370	7.6	5.8	10300	1360	7.6	5.8	
	June/81	31300	10600	1370	7.7	5.7					
	Oct/81		(16900)								Severely skewed to realigned flow
N1	June/81	38500	10500	1350	7.8	5.7	10500	1350	7.8	5.7	Post-construction
N2	June/81	31400	14500	3300	4.4	4.1	13700	3000	4.6	4.4	Post-construction
	Sept/81		13000	2700	4.8	4.6					
2A	Sept/77	25000	10500	1590	6.6	5.7					
	Oct/79	16700	13300	1680	7.9	4.5					
	Oct/80	11900	11700	1690	6.9	5.1	11600	1660	7.0	5.2	
	May/81	16200	12100	1670	7.2	5.0					Post-construction
	Oct/81		10500	1690	6.2	5.7					Post-construction
X4	Sept/78	16300	7600	780	9.7	7.9					
	Oct/79	17200	8400	670	12.5	7.1	8000	760	10.5	7.5	
	Oct/80	13500	8300	800	10.4	7.2					
	Sept/81	21700	7500	800	9.4	8.0					Post-construction
X3A/X3B	Oct/78	16000	11500	1900	6.1	5.2					2 components very different in properties
	Oct/79	17200	12000	1860	6.5	5.0					
	Oct/80	16600	11000			5.5					
	May/81	18900	11500	2000	5.8	5.2	11600	2000	5.8	5.2	Post-construction
	Oct/81		12000	2300	5.2	5.0					Post-construction
X2	Oct/78	14500	10500	1880	5.6	5.7					
	Oct/79	17400	10800	1940	5.6	5.6	11100	1940	5.7	5.4	
	Oct/80	19000	11700	1750	6.7	5.1					
	Oct/81		11500	2190	5.3	5.2					Post-construction
					Overall Means Excluding Pilot Channel		10800	1670	7.1	5.6	
					Standard Deviation		1570	610	1.8	0.85	
					s.d./mean		0.14	0.37	0.25	0.15	

Table 3.4. Approximate hydraulic geometry of cross sections upstream of Phase II area, based on 1977 surveys.

X-SECTION (combined where appropriate)	APPROX. PROPERTIES EXTENDED TO FLOW OF 60,000 CFS				LOCATION (see Fig 2.1)
	AREA (A) ft^2	SURFACE WIDTH(W) ft	MEAN DEPTH(A/W) ft	MEAN VELOCITY(Q/A) ft/sec	
10 A/B	9600	1780	5.4	6.2	South of Goose Is.
11A/B	14000	2300	6.1	4.3	Upstream of Goose Is.
12A/B	14000	2300	6.1	4.3	Downstream end of Meridian Is.
13A/B	14500	2900	5.0	4.1	Upstream of Meridian Is.
14A/B	14200	4400	3.2	4.2	Between Meridian Is. and N. Pole groin
17A/B/C/D	12600	4200	3.0	4.8	Above N. Pole groin
18A	18700	5000	3.6	3.3	Downstream of T-7
19A/B/C/D	16900	5200	3.3	3.6	Upstream of T-7
20A/B	17700	4400	4.0	3.4	Downstream of T-8
21/X/A/B/C	13200	4000	3.3	4.5	At T-8
Average	14500	3650	4.0	4.1	

channel is more braided, total river sections include more small, inefficient channels, and more of the section is skewed to the main flow direction. The picture of channel hydraulics presented by the tabulation is therefore somewhat distorted.

It is useful, in relation to post-construction Phase III changes discussed in Part 5 and 6, to consider the dimensions of sections where virtually all the flow passes through a single channel of restricted width and substantial depth, free of significant side or midstream bars. Plots of such sections are available (Burrows and Harrold, 1982) for the USGS sites GSX1 (Tanana River at Byers Island) and GSX3 (Tanana River below Goose Island). Averaging between the two sections and between 1980 and 1981 surveys, properties for a flow of 60,000 cfs appear to be approximately as follows:

$$\text{area} = 9700 \text{ ft}^2$$

$$\text{surface width} = 690 \text{ ft}$$

$$\text{mean depth} = 14 \text{ ft}$$

It is interesting to note that stable channel dimensions according to the empirical 'regime' relations of Lacey (1929-30), for a dominant discharge of 60,000 cfs and a 'silt factor' of 2.0 (fine gravel), are as follows:

$$\text{area} = 9600 \text{ ft}^2$$

$$\text{surface width} = 655 \text{ ft}$$

$$\text{mean depth} = 14.6 \text{ ft}$$

which are quite similar to the actual properties quoted previously.

3.5 Hydraulic Roughness and Bed-Forms

The average roughness coefficient (Manning's n) for a flow of 60,000 cfs at Fairbanks appears to be about 0.024. A value of 0.027 was given in DM #27 (C of E, 1979) for a flow of 80,000 cfs. These values are based on the slope down the middle of the active channel system, using average cross-sectional properties. If the slope along the main channel or thalweg were used, slightly lower values would result.

These n values appear to be quite low considering the nature of the bed and the channel cross sections. Based on the grain roughness of the bed gravel alone, a value of 0.020 or greater can be estimated. Considering bed-forms and the high degree of irregularity in channel cross-sections and planform, a greater excess over grain roughness might be expected. With regard to bed-forms, longitudinal echo-sounding profiles run on 23 June 1981 at a flow of about 31,000 cfs around the right-hand bend (B) upstream of the Chena mouth indicated a variety of bed configurations ranging from flat bed to waveforms about 50 ft long x 2 ft high (Figure 3.9). It may be that these waveforms denote mainly areas of exposed sand and that their roughness is not much greater than that of gravel areas. Galay (1967) has reported quite similar bed-forms in a

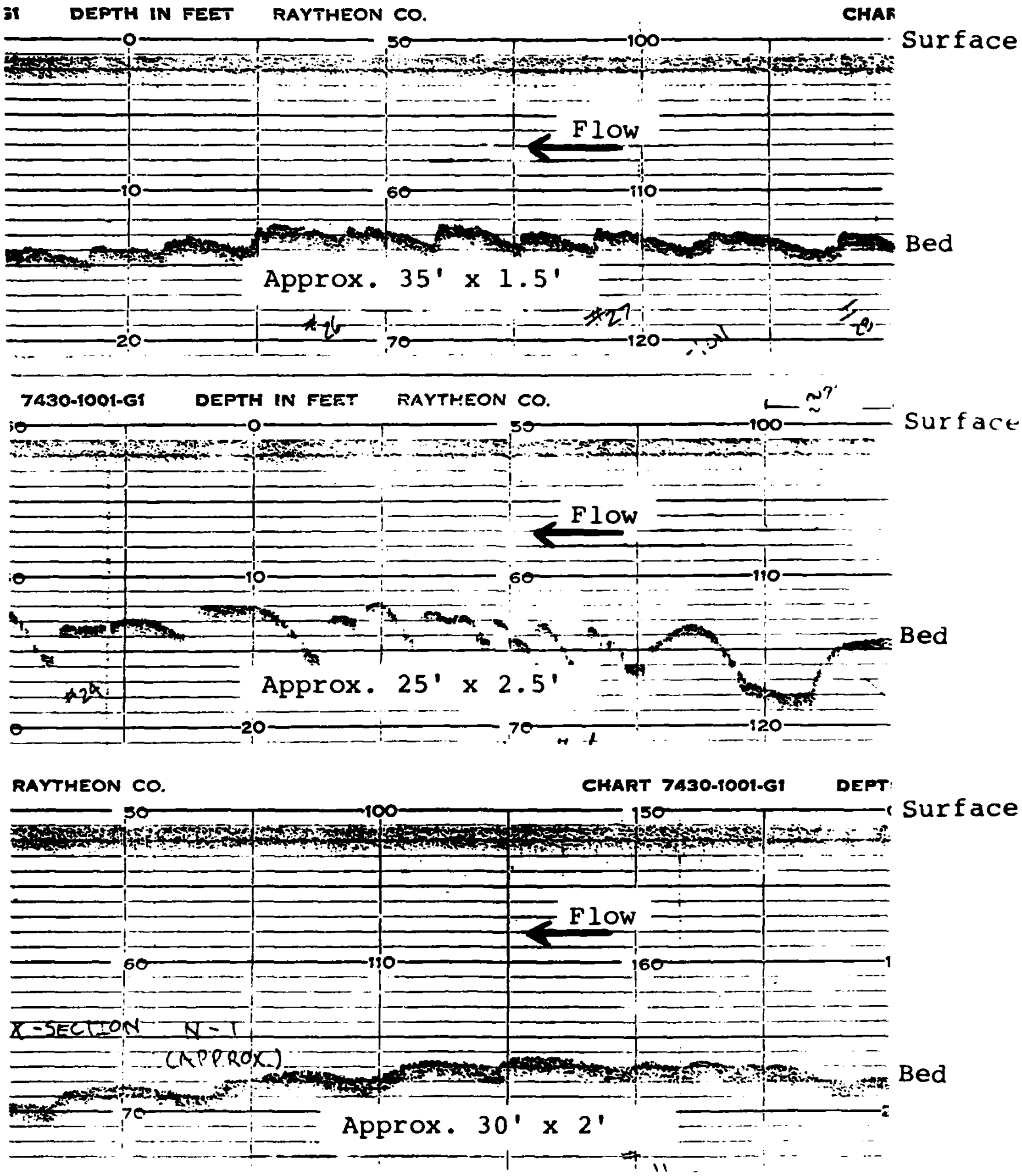


Figure 3.9. Example of bed-forms on longitudinal soundings, Bend 'B,' June 1981.

coarse gravel river of somewhat similar channel characteristics in Alberta, where overall n values were apparently somewhat higher than for the Tanana.

3.6 Beginning of Bed Movement

It is generally accepted that in channels with gravel beds, a valid criterion for beginning of bed movement is given by a threshold value of the 'Shields number', that is:

$$\tau_o/\gamma_s'D = 0.04$$

where: τ_o = bed shear stress = γ RS

γ_s' = submerged specific weight of bed material

D = representative diameter of bed material

Substitution of appropriate values at the Fairbanks gauging site using a median bed-material diameter of 8 mm (Burrows et al., 1981) indicates that bed movement can be expected whenever mean depth exceeds approximately 4 feet, that is, under virtually all open-water flow conditions. Sediment transport data discussed in Part 4 following appear to confirm that there is in fact significant bed movement under almost all open-season conditions, and even in certain under-ice conditions.

3.7 Summary

Key points in the foregoing review of hydrology and hydraulics may be summarized as follows:

1. Discharge hydrographs are quite similar from one year to another, with coefficients of variation for annual means and peaks of approximately 13%. The mean annual maximum of about 62,000 cfs is close to a bankfull condition. Open-season (May-October) flow averages about 32,000 cfs and winter (November-April) flow about 5000 cfs.
2. Stage-discharge relations show considerable scatter due to channel shifts and erosional-depositional activity. Mean velocities, as calculated for total cross sections, do not increase much with rising stage.
3. River longitudinal slope decreases rapidly between Meridian and Byers Islands, from about 1.0 to 0.3 ft per 1000 ft. This corresponds more or less to a transition in channel pattern or planform from braided to anastomosing.
4. The variation in properties between successive cross sections is so great that it is difficult to discern systematic down-river changes. In the braided length above Meridian Island, sections are generally wider and shallower. Constricted single-channel sections free of bars appear to correspond approximately to 'regime' sections.
5. Overall hydraulic roughness can be represented by Manning's n values in the range of 0.024 to 0.027. Beginning-of-movement criteria indicate that significant bed movement can be expected under all open-water flow conditions.

4. SEDIMENT SIZES AND TRANSPORT

This chapter is based on material from U.S. Geological Survey documents, selected and interpreted for the purpose of explaining certain aspects of river behavior and assisting prediction of response to imposed changes. Unless otherwise indicated, the interpretations are those of the writers and should not be taken as representing the conclusions of the USGS. It is expected that an interpretation of USGS sediment data covering the sediment measurement period 1977-82 will be published at a later date by Survey personnel. References to locations "Fairbanks" and "North Pole" signify USGS cross sections GSX2 and GSX5 respectively: see Figures 2.1A and B.

4.1 Bed-Material and Bed-Load Sizes

A published report (Burrows et al., 1981) shows grain-size distributions for bed material in place and for bed load as trapped in a Helley-Smith sampler, at both Fairbanks and North Pole gauging sections. Bed-material data are for September 1979 only; bed-load data cover a number of dates through 1977-79. An unpublished preliminary report (Burrows and Harrold, 1982) provides additional data to 1981 and includes data for four other sites: at Byers Island, below and above Goose Island, and above Moose Creek Dam (3.5 km upstream of North Pole gauging section).

Tables 4.1 and 4.2 show summary data for bed-material size distributions at Fairbanks and North Pole respectively for the period 1979-81, both as averages for each year and as averages for the period. At Fairbanks, data are for the main channel; at North Pole, they are averages of north and south channels. Tables 4.3 and 4.4 show corresponding transport-weighted bed-load size distributions for the period 1977-81. The period averages for these four tables (last column in each table) are plotted in Figure 4.1.

Tables 4.5 and 4.6 show summary data averaged for 1980-81 for the additional four sediment stations instituted in 1980. These distributions are compared with the Fairbanks and North Pole data in Figure 4.2. Key statistics down-river are compared in Table 4.7.

All sites show a markedly bimodal size distribution with almost total deficiency in the 0.5-mm to 5-mm size range. With the exception of the Byers Island site, there appears to be little systematic down-river trend in proportions of sand and gravel; bed material averages roughly 65% gravel to 35% sand, and bed load roughly 50% of each. At Byers Island the proportions of gravel are notably smaller: gravel to sand percentages are approximately 33:65 and 22:78 for bed material and bed load respectively.

The change in grain-size percentiles down-river is generally somewhat erratic (Table 4.7), particularly in the median (D_{50}) size, which is quite variable because of the bimodal distribution. Sampled bed load is everywhere considerably finer than bed material in place; this may be a function of sampler characteristics as well as a result of selective transport at lower flows. At the D_{75} percentile, which is more or less in the middle of the gravel fraction, there is a fairly systematic down-river reduction in bed-material sizes, but very little change in bed-load sizes except at Byers Island. Figure 4.3 plots the down-river change in D_{75} vs. river slope: the fitting line indicates a more or less constant ratio

Table 4.1. Composite size distributions of bed material in place, 1979-81 at Fairbanks.[a]

GRAIN SIZE (mm)	PERCENT FINER THAN (BY WEIGHT) 1979	1980	1981	AVERAGE 1979-81
128	--	100	--	100
64	100	99	100	100
32	92	89	92	91
16	75	69	66	70
8	51	48	48	49
4	40	41	41	41
2	38	40	39	39
1.0	37	40	39	39
0.5	36	39	38	38
0.25	27	35	33	32
0.125	6	22	7	12
0.062	2	13	2	6

Sources: Burrows, Emmett and Parks (1981), Table 8
Burrows and Harrold (1982), Tables 25 and 26
[a] USGS discharge-measuring section, main channel (GSX-2)

Table 4.2. Composite size distributions of bed material in place, 1979-81 at North Pole.

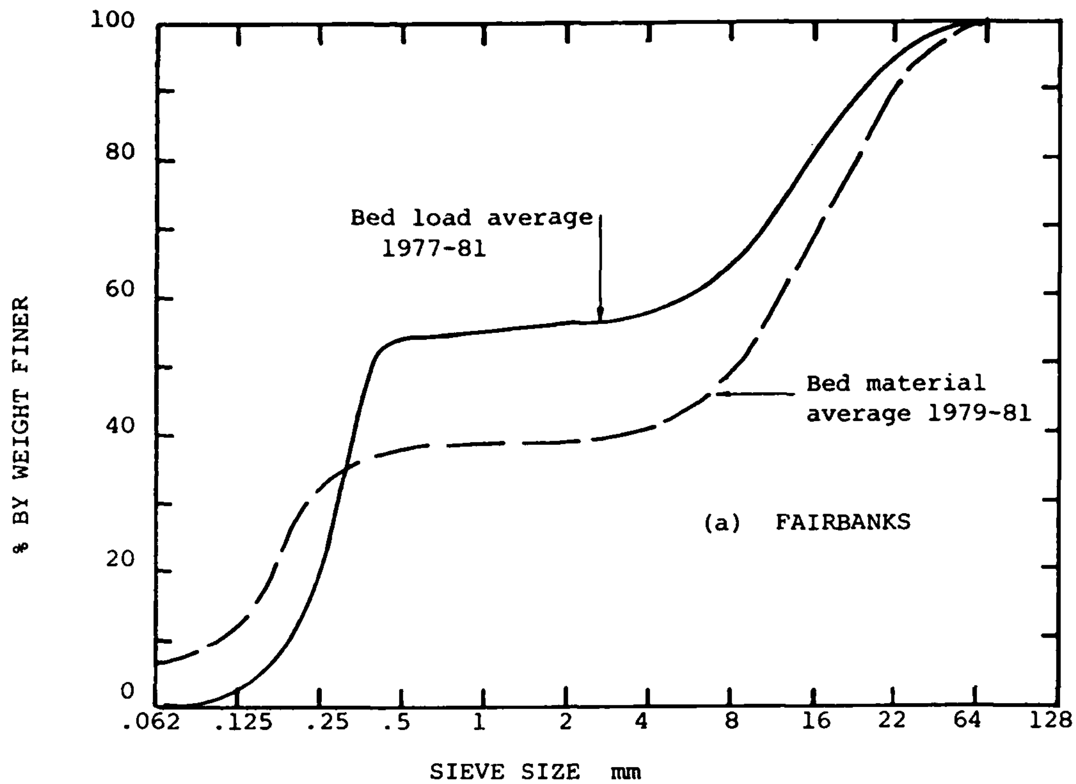
GRAIN SIZE (mm)	PERCENT FINER THAN (BY WEIGHT) 1979[a]	1980[b]	1981[b]	AVERAGE 1979-81
128	100	100	100	100
64	92	94	94	94
32	59	69	76	68
16	39	54	52	48
8	26	45	40	37
4	21	42	[illegible]	33
2	20	41	[illegible]	32
1.0	19	41	36	32
0.5	19	40	36	32
0.25	14	36	30	27
0.125	7	20	7	11
0.062	3	8	1	4

Sources: Burrows, Emmett and Parks (1981), Table 8
Burrows and Harrold (1982), Tables 25 and 26
[a] main channel only
[b] arithmetic average of north and south channel values

Table 4.3. Composite transport-weighted size distributions of bed-load, 1977-81 at Fairbanks.

GRAIN SIZE (mm)	PERCENT FINER THAN 1977	1978	1979	1980	1981	AVERAGE 1977-81
64	99	100	100	100	100	100
32	89	94	99	97	98	95
16	64	87	87	81	88	81
8	44	81	73	56	73	65
4	36	78	66	44	66	58
2	35	[illegible]	64	40	64	56
1	35	[illegible]	64	39	63	55
0.5	34	[illegible]	62	38	62	54
0.25	14	[illegible]	18	17	24	22
0.125	1	[illegible]	3	2	3	3
0.062	--	[illegible]	1	--	--	--

Sources: Burrows, Emmett and Parks (1981), Table 22
Burrows and Harrold (1982), Tables 57 and 58



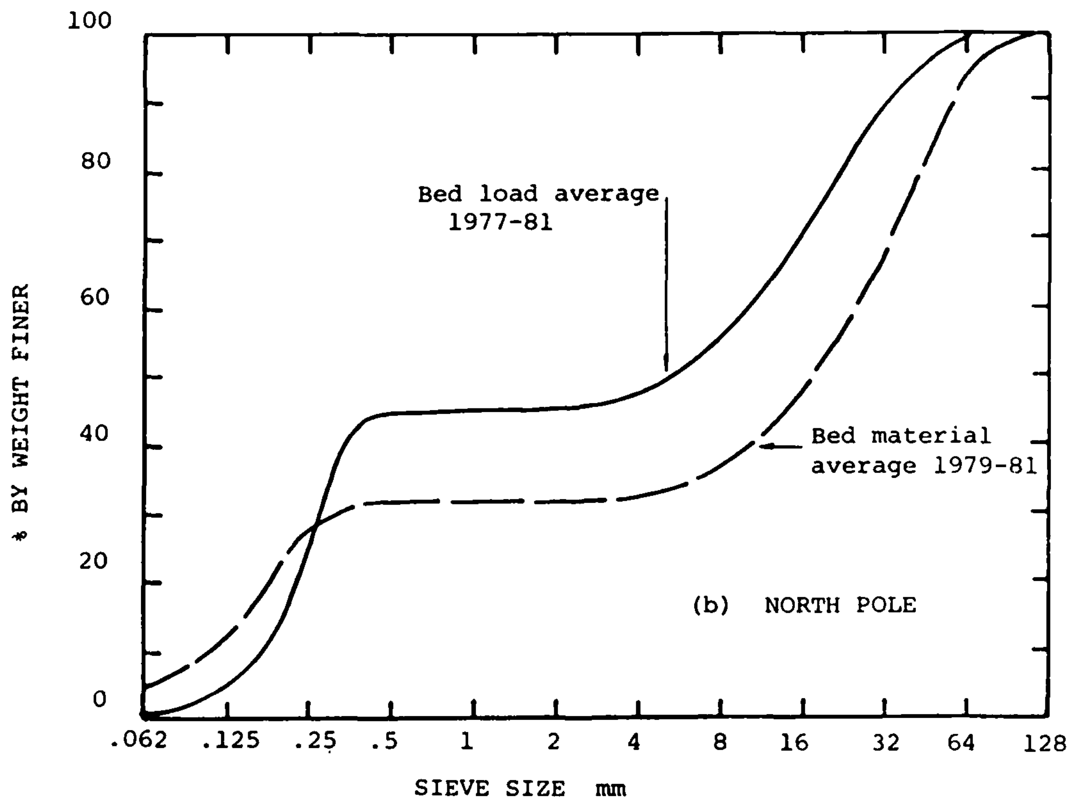


FIGURE 4.1 Composite size distributions for bed material in place and bed load at (a) Fairbanks and (b) North Pole.

Table 4.4. Composite transport-weighted size distributions of bed-load, 1977-81 at North Pole.

GRAIN SIZE (mm)	PERCENT FINER THAN 1977	1978	1979	1980	1981	AVERAGE 1977-81
64	100	100	100	100	99	100
32	84	91	91	92	91	90
16	64	74	70	77	77	72
8	40	62	49	60	62	55
4	33	57	40	55	55	48
2	32	55	37	54	54	46
1	32	54	36	53	53	46
0.5	32	52	35	52	52	45
0.25	16	29	11	25	30	22
0.125	3	4	2	5	4	4
0.062	1	1	1	1	--	1

Sources: Burrows, Emmett and Parks (1981), Table 22
Burrows and Harrold (1982), Tables 57 and 58

Table 4.5. Composite size distributions of bed material in place, 1980-81 at Byers Island, Goose Island and Moose Creek.

GRAIN SIZE (mm)	PERCENT FINER THAN, AVERAGE OF 1980 AND 1981 Byers Is. N. Channel	Below Goose Is.	Above Goose Is.	Moose Cr. Av. of N & S Channels
128	—	100	100	100
64	100	99	98	92
32	89	86	80	73
16	79	67	56	56
8	70	50	38	46
4	67	42	30	43
2	67	39	28	42
1	67	39	28	42
0.5	66	38	28	41
0.25	49	30	23	35
0.125	19	3	8	18
0.062	8	--	2	6

Source: Burrows and Harrold (1982), Tables 26 and 26

Table 4.6. Composite transport-weighted size distributions of bed load, 1980-81 at Byers Island, Goose Island and Moose Creek.

GRAIN SIZE (mm)	PERCENT FINER THAN, AVERAGE OF 1980 AND 1981 Byers Island	Below Goose Is.	Above Goose Is.	Moose Creek
64	100	100	100	100
32	99	92	94	90
16	94	75	78	74
8	85	58	65	60
4	79	49	59	54
2	78	46	56	52
1	77	45	56	51
0.5	68	44	46	49
0.25	33	21	19	22
0.125	6	2	3	4
0.062	1	0	0	1

Source: Burrows and Harrold (1982), Tables 57 and 58

Table 4.7. Comparative size statistics down-river for bed material and bed-load.

Site	Sample Type	D_{90}	Grain Size Percentiles D_{75}	D_{50}	D_{25}	D_{10}	Gravel %	Sand %
Moose Creek	Bed	59	35	11.7	.16	0.08	58	42
North Pole	Material	56	40	13.3	.25	0.11	68	32
Above Goose Is.		46	27	17.5	.28	0.14	72	28
Below Goose Is.		39	22	8	.2	0.15	61	39
Fairbanks		30	17	8.5	.2	0.10	61	39
Byers Island		35	13	0.26	.15	0.07	33	67
Moose Creek	Bed	33	16	0.62	.28	0.16	48	52
North Pole	Load	33	17	5.1	.28	0.16	54	46
Above Goose Is.		26	15	0.56	.3	0.17	44	56
Below Goose Is.		30	16	4.4	.28	0.17	54	46
Fairbanks		23	13	0.42	.28	0.17	44	56
Byers Island		12	0.8	0.34	.2	0.14	22	78

Based on period averages as plotted in Figure 4.2.

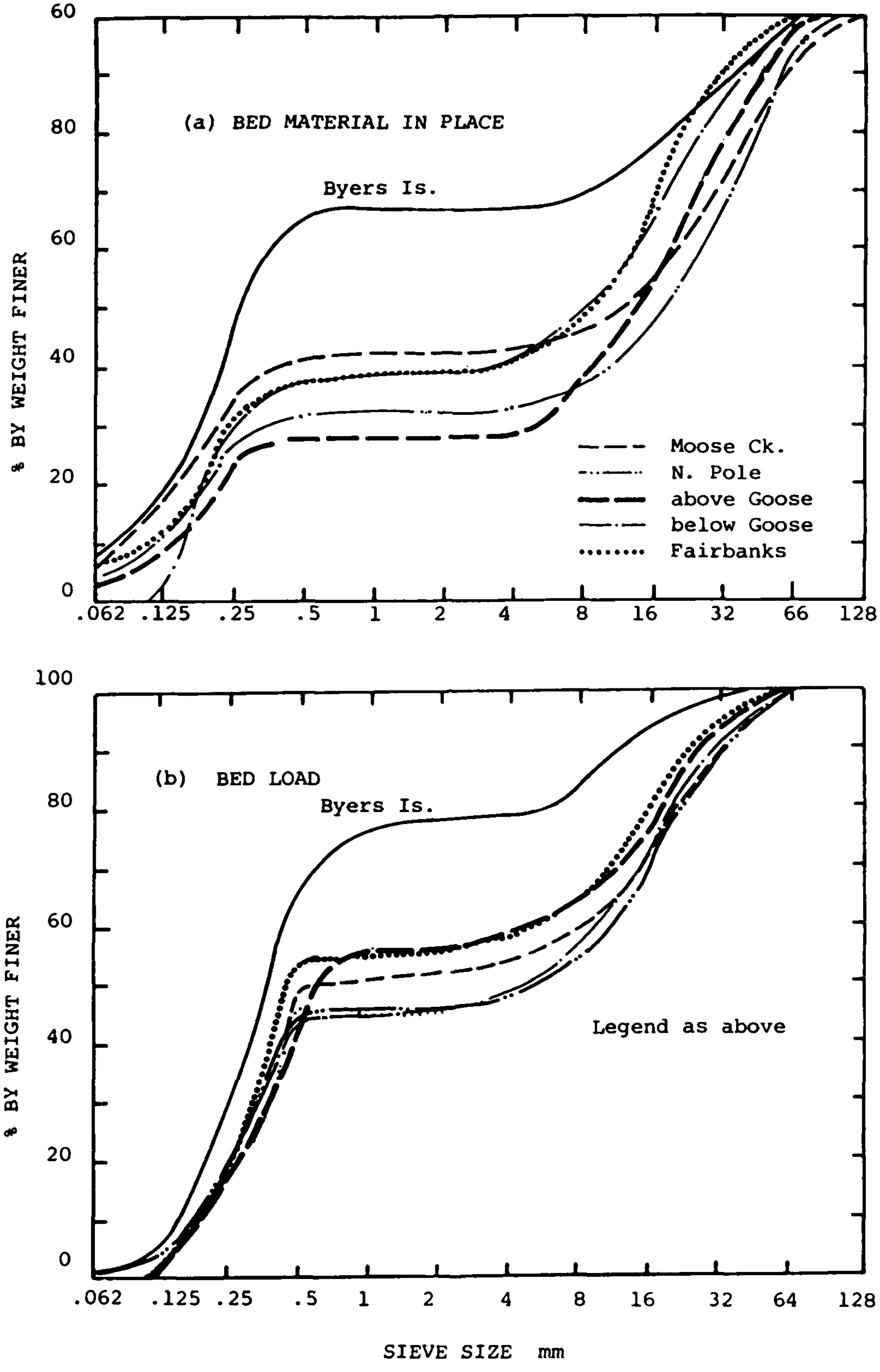


FIGURE 4.2 Comparative size distributions at all sites for (a) bed material and (b) bed load.

Bed material: samples at 15 m intervals and top 20 cm of active width, Sept. 1979, July 1980, Aug. 1981.

Bed load: samples at 15 m intervals, duration 30 seconds, 1977 through 1981.

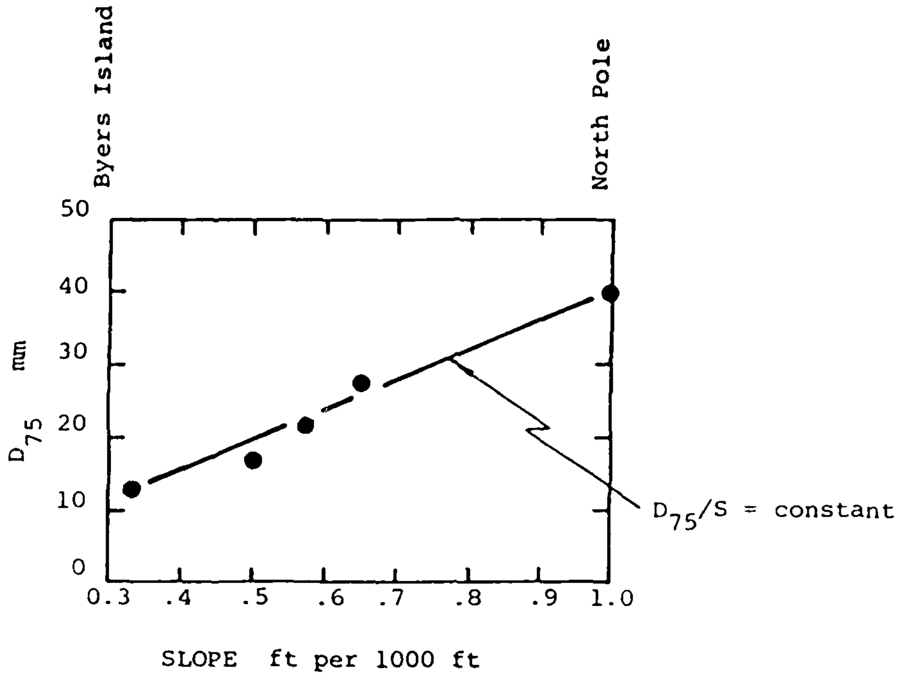


Figure 4.3. Plot of D_{75} bed-material sizes vs river slope.

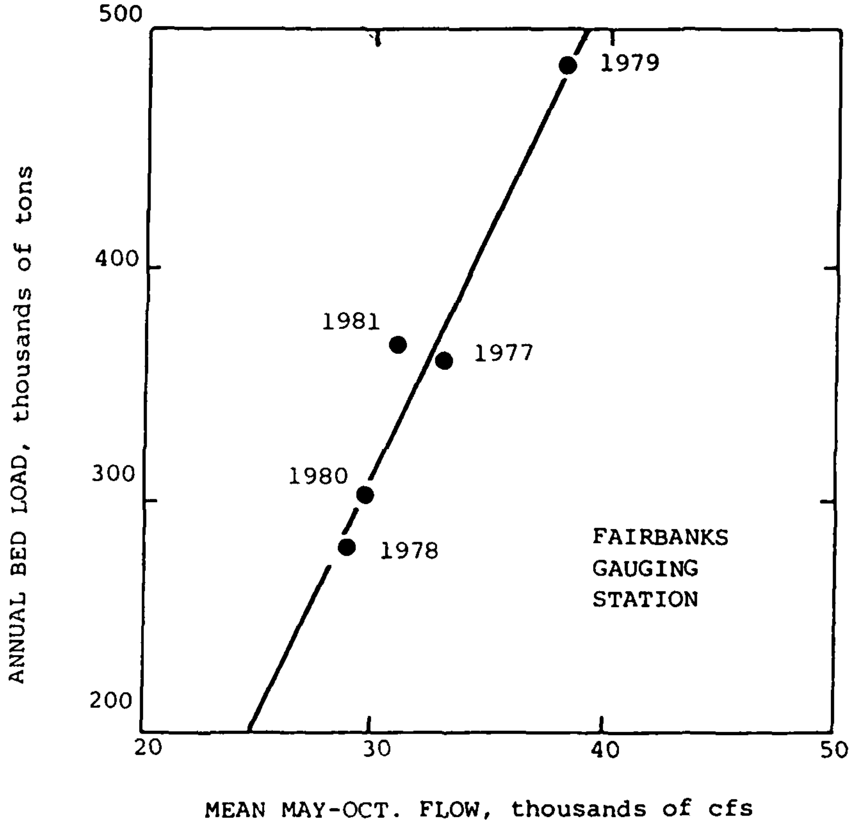


Figure 4.4. Annual bed load vs mean May-October flows, 1977-81.

between D_{75} and slope. Similar empirical findings are reported by Sundborg (1956) and Scheidegger (1961).

It is interesting that a somewhat similar relationship is implied by the Shields criterion for initial movement of coarse materials:

$$\tau_o/\gamma'_s D = \text{constant}$$

which may be written

$$\frac{RS}{(s-1)D} = \text{constant}$$

where R = hydraulic radius, S = slope, s = relative density of bed material, and D = representative size, usually taken as D_{50} for unimodal distributions. If changes in R are relatively small, D will then be roughly proportional to S at conditions of initial movement.

4.2 Measured Bed-Load Transport

In general, channel shift and processes of scour and fill are intimately related to bed-load transport. Bed-load transport data reported by Burrows et al. (1981) and by Burrows and Harrold (1982) are therefore important for assessing the response of the river to construction activities, gravel extraction, and natural events.

Table 4.8 summarizes annual bed-load totals at the Fairbanks station and compares them with flow statistics. As shown in Figure 4.4, there is a very good correlation between annual bed load and mean May-October flow. Quantities of gravel extracted annually from the river channel at Goose Island, as quoted in Section 2.2, are quite small by comparison.

Figure 4.5, based on a USGS plot (Burrows et al., 1981, Figure 16) extended with 1980-81 data, shows both bed-load and suspended-load transport rates as functions of discharge for Fairbanks and North Pole. There is little basis for distinguishing statistically between these two sites with respect to the bed-load/discharge relation. Comparison with similar plots of 1980-81 data for Moose Creek Dam, above and below Goose Island, and Byers Island indicates that only at Byers Island is there a detectable difference, bed loads at this site being generally lower by a factor in the order of 2 to 3. This reduction presumably reflects the markedly lower proportions of gravel available at Byers Island (Table 4.7)*.

By dividing reported bed-load transport rates by contemporaneous flow rates, it is possible to express bed-load transport as equivalent 'concentration'. Figure 4.6 shows a plot of bed-load 'concentration' vs. discharge as calculated from 1977-79 USGS data tables*. A visual fitting line through the scatter indicates that the mean range of concentration over the measured range of discharge is only from about 10 to 30 parts per million by weight, and that (by extrapolation) there is probably some bed load movement even under winter flows beneath the ice.

* The curves in Figures 4.5 and 4.6 labelled 'Meyer-Peter and Muller' are discussed in Section 4.3 following.

Table 4.8. Annual sediment loads vs flow statistics, 1977-81, Fairbanks Station.

YEAR	TOTAL BED LOAD tons	TOTAL SUSP. LOAD tons/10^6	MEAN ANN. FLOW cfs	MEAN MAY-OCT FLOW cfs
1977	359,000	29.5	19,500	32,700
1978	280,000	23.4	17,500	28,000
1979	485,000	30.3	21,900	38,000
1980	300,000	24.3	17,500	29,700
1981	367,000	30.5	28,500	31,100
Mean 1977-81	358,000	27.6	19,000	32,100

Sources of data: Burrows, Emmett and Parks, 1981.
Burrows and Harrold, 1982.

Table 4.9. Estimated distribution of bed-load by months.

MONTH	MEAN FLOW cfs	APPROX. BED-LOAD CONCENTRATION ppm	BED-LOAD IN MONTH tons		% OF TOTAL
JAN	5,000	5	2,100		0.6
FEB	5,000	5	2,100		0.6
MAR	4,800	5	2,000		0.6
APRIL	6,900	5	2,800		0.9
MAY	21,500	15	26,500		7.9
JUNE	33,500	20	55,100		16.4
JULY	48,200	25	99,100	95.7 (MAY–OCT)	29.6
AUG	48,000	25	98,700		29.4
SEPT	25,300	15	31,200		9.3
OCT	12,600	10	10,400		3.1
NOV	6,900	5	2,800		0.9
DEC	5,500	5	2,300		0.7
		TOTAL:	335,100		100.0

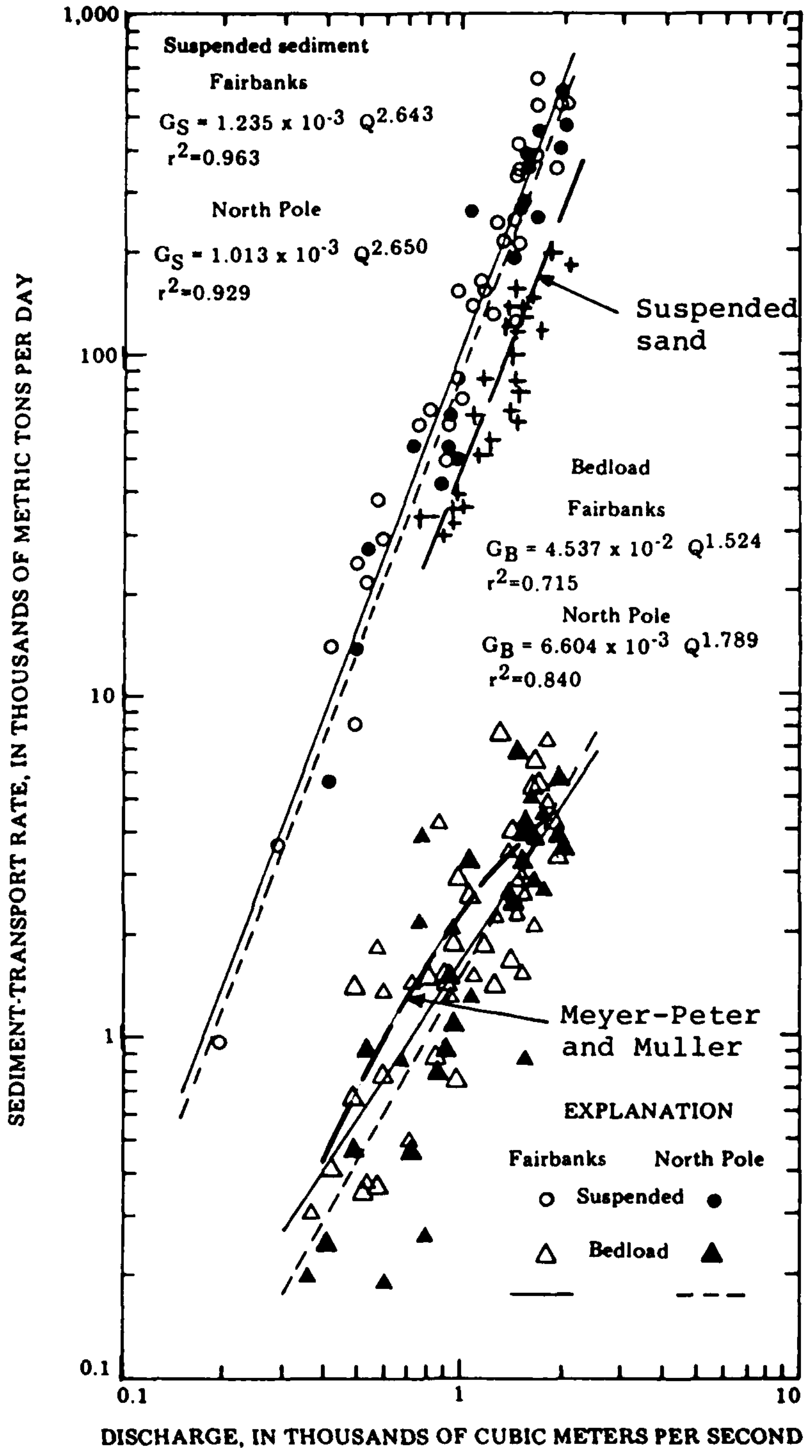


FIGURE 4.5 Sediment-transport rate as a function of discharge, Tanana River at Fairbanks and near North Pole, 1977-81.

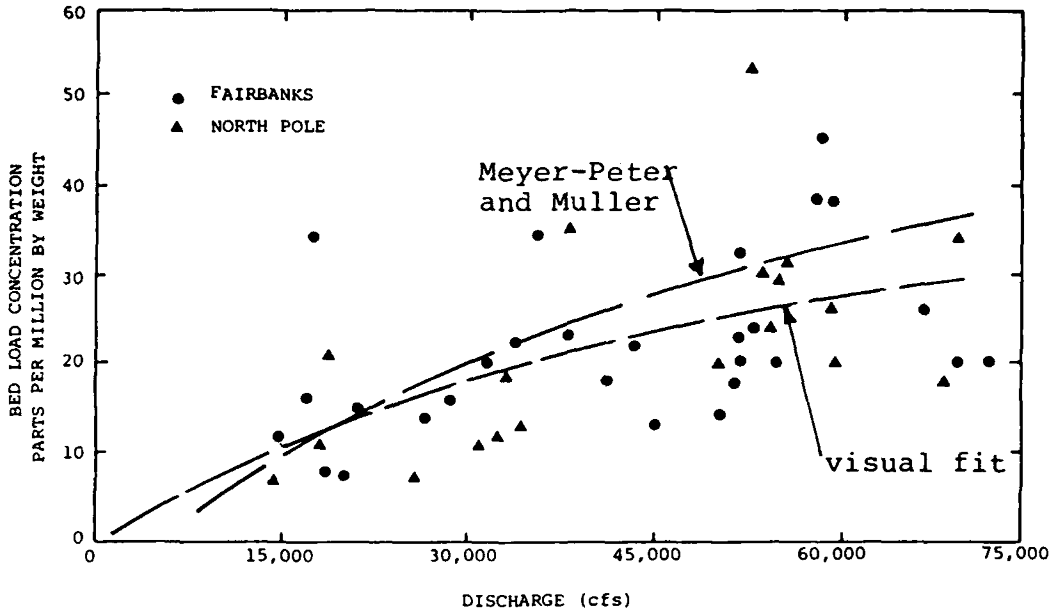


Figure 4.6. Bed-load 'concentration' vs discharge.

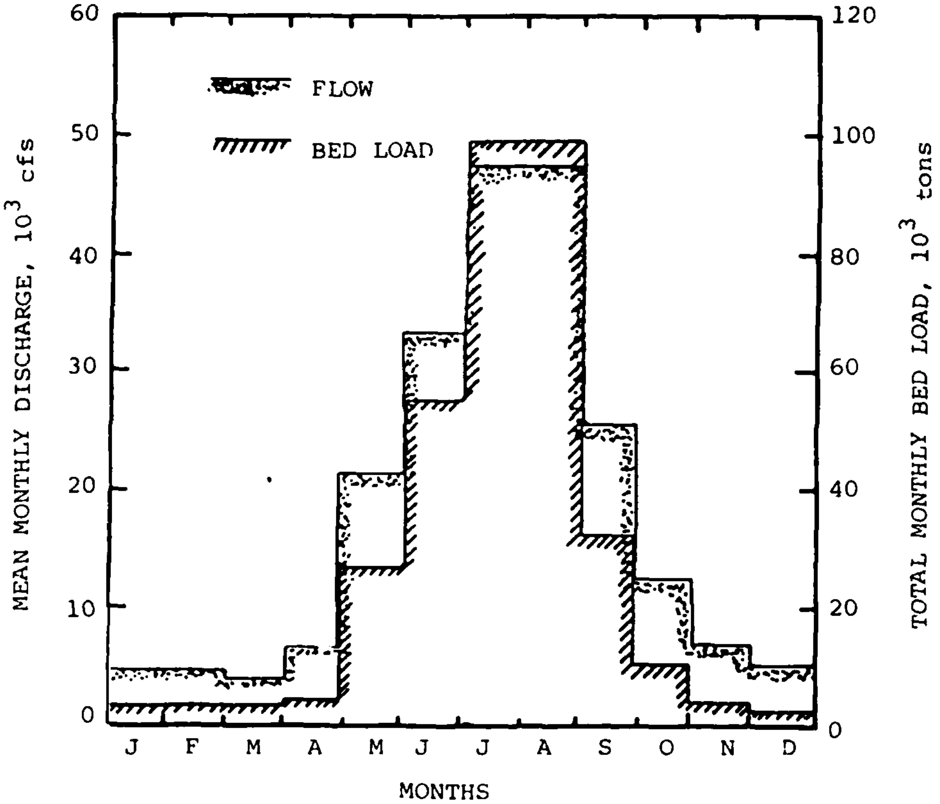


Figure 4.7. Average month-by-month distributions of flow and bed load. (Note: Bed-load distributions are derived using Figure 4.6.)

Table 4.9, on the basis of Figure 4.6 and Table 3.1, computes estimated bed load by months in an average year. The estimated total of 335,000 tons is comparable with the reported average of 358,000 tons for 1977-81 (Table 4.8). Month-by-month distributions of estimated bed load and water flow are illustrated in Figure 4.7; it should be noted that estimates for winter months are inferred only on the basis of open-water data, and may be inaccurate.

4.3 Comparison of Measured vs. Calculated Bed Load

In this section the relatively consistent USGS measurements of bed-load transport in the Tanana are compared with values calculated by hydraulic relationships.

Numerous hydraulic relationships for calculating bed-load and bed-material transport have been published (ASCE, 1975). For a given channel, a wide range of estimates can be obtained, depending on the relationship utilized and on the assumptions made in applying it. It is important to select a relationship that is appropriate for the type of sediment environment under investigation, bearing in mind the source data and the intent of the formulators. Since most relationships allow some latitude in selection of coefficients, application becomes to some extent a calibration procedure to produce the best reasonable fit, at least where field or experimental data are available.

The Swiss formula by Meyer-Peter and Muller (1948) was based mainly on flume transport experiments using coarse sand and fine to medium gravel, travelling essentially as bed load. It is an empirical formula with a simple theoretical basis, expressing transport rate per unit width as proportional to the 1.5 power of bed shear stress excess above a threshold value. Corrections are included to allow for loss of transporting power in bed-form roughness. The formula can be arranged into a non-dimensional form that is compatible with similarity considerations for sediment transport. Yalin (1972) discusses its theoretical interpretation and advises restriction to material of 2 mm diameter or larger. Amin and Murphy (1981) report that the formula over-predicted at low transport rates when compared with measurements in a sand-bed river. On the basis of its source data and on theoretical considerations, it should be appropriate for the Tanana River.

In Design Memo No. 27 (C of E, 1979) a curve based on the MPM formula was compared with 1977-78 data from the Tanana. Some assumptions used in deriving the curve were as follows:

median bed-material diameter	10 mm
grain roughness (D_{90})	30 mm
unit weight of bed material	114 lb/ft^3

The basis for a variation in hydraulic properties with discharge was not given.

For purposes of a recheck using the MPM formula, the following assumptions were adopted:

effective grain size for transport	10 mm
effective grain size for roughness	20 mm
threshold Shield's number	0.047
dry specific gravity	2.5
mean depth rage (Q=14000 to 70000 cfs)	6.0 to 8.5 ft
mean velocity range	5.0 to 6.2 ft/s

effective bed-width range 330 to 660 ft
constant hydraulic slope 0.00053

The variation of hydraulic properties with discharge was based roughly on data for the Fairbanks gauging section shown by Burrows et al. (1981).

Results are plotted in terms of bed load in Figure 4.5 and in terms of bed-load 'concentration' in Figure 4.6. Correspondence with data appears to be reasonably good. It should be realized, however, that the formula is being applied to a bimodal distribution whereas its source data were for unimodal distributions. The formula and a calculation table are given in Appendix E.

Bagnold (1980) has published another relatively simple relationship for bed-load transport which expresses transport rate per unit width as proportional to the 1.5 power of excess stream power, where stream power = bed shear stress x mean velocity. Figure 4.8 shows a plot by Bagnold wherein he checked Tanana River data against his relationship, the latter calculated on the basis of (i) modal size of gravel fraction and (ii) modal size of sand fraction. Measured data appeared to fall generally between the two calculated sets, but as the range between them covers approximately one order of magnitude it is difficult to draw useful inferences. Bagnold's relationship embodies a set of reference values derived from flume experiments with 1-mm sand, but these can be replaced by any other desired reference values.

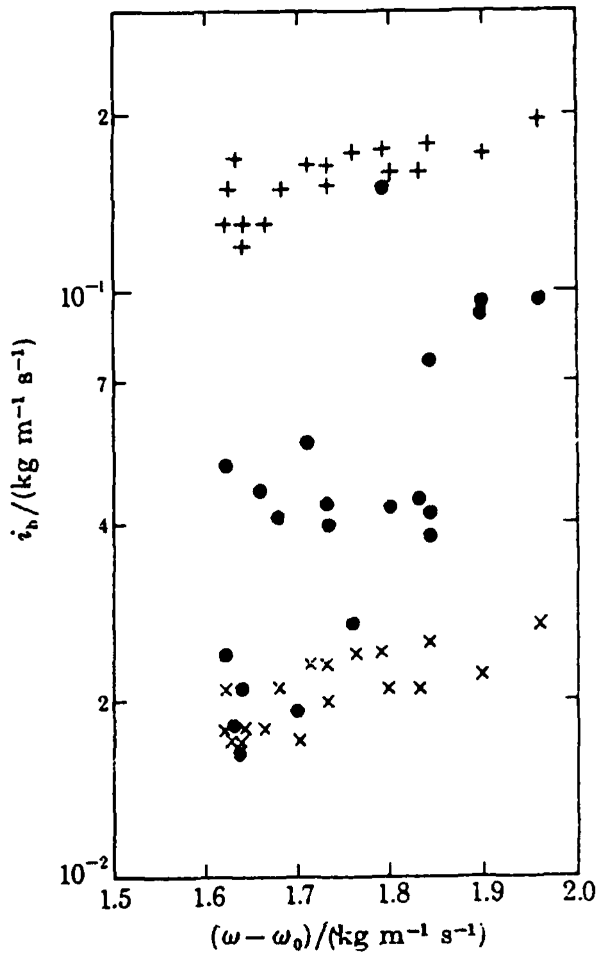
An independent check was made by applying the Bagnold relationship directly to the Tanana, using the same assumption as given above for application of the MPM formula: this yielded transport values that were too low by an order of magnitude. The effective grain size for transport was then taken as the geometric mean of sand and gravel modes (2 mm); results were then closer to measurements but still low by a factor of 2 or so. However, when Bagnold's recommended set of reference values was replaced by a set of data for the Tanana at a discharge of 35,000 cfs, his formula gave a good representation of the variation of transport rate with discharge. This does not constitute an independent check of the formula in total, only of its functional form.

4.4 Travel Rates of Bed Load

Estimates of average travel rates of bed load can be made using certain assumptions based on river channel characteristics. The most important item is the average thickness of bed material participating in bed-load movement in the course of a year at a given cross section. Survey information on cross-sectional changes, e.g. as in Figure 3.5, suggests that this is on the order of 6 ft over an active width on the order of 500 ft.

One method of reasoning is to consider the rate of advance of a bar or waveform. On the basis of airphotos and cross-sectional surveys, a typical major bar can be taken as approximately 3,000 ft long by 500 ft wide by 6 ft high, with a volume of $0.5 \times 3{,}000 \times 500 \times 6 = 4.5 \times 10^6$ ft^3 and a weight of approximately 225,000 tons (Figure 4.9). For an average bed-load transport of 358,000 tons/year (Table 4.8), the required advance rate is 358,000/225,000 = 1.6 wavelengths or 4,800 ft/year for a wavelength of 3000 ft.

The same result can be obtained from an equation of sediment continuity:



Tanana River. ●, measured i_b; ×, computed i_b for D(gravel) mode; +, computed i_b for D(sand) mode. Measured i_b values fall at random between these limits.

Figure 4.8. Plot from Bagnold (1980, Fig. 4) showing measured and calculated bed-load transport vs excess stream power.

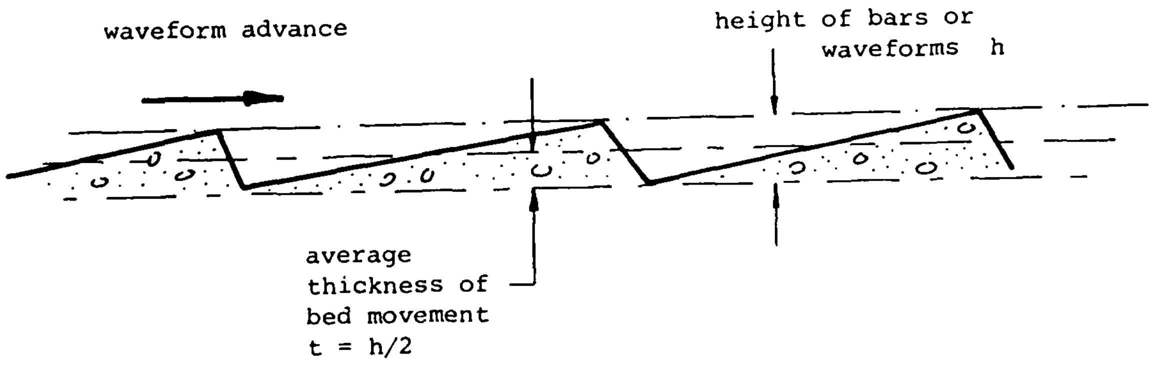


Figure 4.9. Diagram illustrating concept of estimating rate of bed-load travel.

$$Q_s = b\ t\ V_s$$

where Q_s = volumetric sediment discharge, b = effective width, t = mean thickness of mobile sediment layer, and V_s = mean rate of sediment travel (Figure 4.9). Converting the average annual bed-load transport to volume at 100 lb/ft^3 and taking b = 500 ft and t = 3 ft (based on waveforms 6 ft high) yields V_s = 4800 ft/year. It can be seen that calculated travel rate is actually independent of assumed length of waveforms.

It therefore appears that in the natural river, average travel rate of bed load is on the order of 1 mile per open-water season. Under disturbed conditions, as in the Phase III area in 1981 where slopes were increased and additional quantities of sediment were made available by pilot channel excavation, travel rates can be expected to increase somewhat. The distance from the pilot channel area to the mouth of the Chena is only about 2 miles and could possibly be covered in one year in disturbed conditions. On the other hand, the distance from Goose Island to the Chena mouth is approximately 6 miles, most of which was not affected by construction: changes due to gravel extractions at Goose Island might therefore take several years to propagate to the Chena mouth area.

These estimates of travel rates refer to the centroid of a bed-material slug and do not consider longitudinal dispersion of material, which cannot be estimated from the available measurements.

4.5 Suspended Sediment Sizes

Approximate mean grain-size distributions at Fairbanks based on USGS data tables (Burrows et al., 1981) are shown in Figure 4.10 and key statistics are shown in Table 4.10. The data are shown grouped according to season, because it is evident from the original tables that the distribution is significantly coarser for flows of less than 25,000 cfs early and late in the season. Probable explanations are that ice and frost reduce the availability of finer sediments and that lower temperatures increase the suspendability of coarser sediments. Water temperatures range typically from 32°F in winter to 60°F in summer months.

The simplest criterion for suspension of sediment is a threshold value of V_*/w, where V_* = shear velocity and w = settling velocity of sediment in still water. Raudkivi (1976) quotes a value of $V_*/w \geq 0.8$ derived from Bagnold (1966), and also a value of about 1.2 from another source. Adopting $V_*/w \geq 1$ for the Tanana at Fairbanks under summer flow conditions, it is found that the upper limit of suspendable size should be approximately 0.8 mm. The actual upper limit of suspended material appears to be about 0.5 mm.

Another criterion of $V_*/w \geq 4$ has been given by Egiazaroff (1965) to determine the maximum size that will be transported as suspended load with no bed-load transport phase: that is, it cannot remain on the bottom if exposed to the flow. Applied to the Tanana under summer flow conditions, this yields a maximum size of about 0.25 mm, the upper limit of the fine sand class. As shown in Figure 4.10, 97% of the material in suspended sediment samples under summer conditions is finer than this. The coarser remainder probably represents saltating particles rather than fully suspended load.

Table 4.10. Typical grain-size statistics for suspended sediment (at Fairbanks).

STATISTIC	JUNE-JULY-AUG-SEPT Q > 25,000 cfs	APR,MAY,OCT Q < 25,000 cfs
Median (D_{50})	0.04 mm	0.15 mm
% medium sand (0.5 to 0.25 mm)	3	9
% fine and very fine sand (0.25 to 0.06 mm)	37	62
% silt (0.06 to 0.004 mm)	44	22
% clay (<0.004 mm)	16	7

Source: Burrows et al., 1981, Tables 14 and 15.

Table 4.11. Comparison of transport-weighted suspended and bed-load grain-size distributions at Fairbanks.

SIZE CLASS	SUSPENDED SAMPLES %	BED-LOAD SAMPLES %
Gravel and coarse sand (> 0.5 mm)	0	43
Medium sands (0.5 to 0.25 mm)	2	35
Fine sand (0.125 to 0.25 mm)	15	18
Very fine sand (0.06 to 0.125 mm)	19	3
Silt and clay	64	1
	100	100

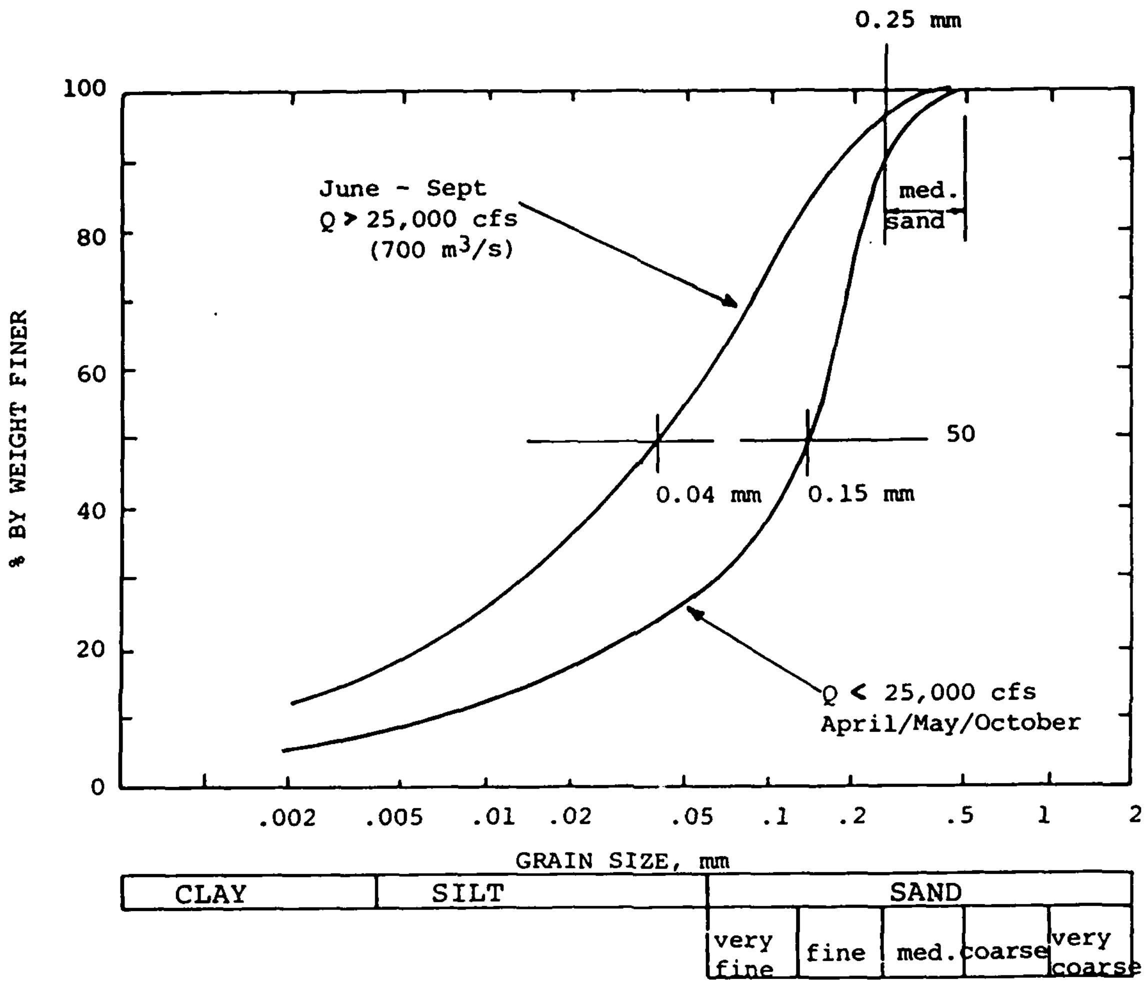


Figure 4.10. Mean grain-size distributions for suspended sediment at Fairbanks.

Table 4.11 shows a simplified comparison of grain size classes between suspended and bed load at Fairbanks, based on a transport-weighted average qver the period 1977-79. The major overlap between the two sample types is in the fine sand class, 0.125 to 0.25 mm, which constitutes about 15% of suspended load samples and about 18% of bed-load samples. The implications of this are discussed further in Section 4.6 below.

4.6 Suspended Sediment Transport

Suspended sediment in the Tanana River contains significant proportions of sand, silt and clay. The silt and clay fractions probably originate largely from a multiplicity of sources distributed over the drainage basin. It seems likely, however, that at least part of the sand fraction exchanges with sand fractions in the channel and floodplain sediments as the river shifts its bed, erodes its banks, and creates new floodplain out of channel bars.

Table 4.8 summarizes annual suspended load totals at Fairbanks and compares them with flow statistics, and Figure 4.11 shows a graphical correlation with mean May-October flows. Figure 4.5 reproduces consolidated USGS plots of sediment transport rates vs. discharge, showing quite a close correlation between daily suspended load and daily discharge. Data have been added to this plot to show the sand fraction of suspended transport separately, as discussed below.

Table 4.12 shows reported annual tonnages of suspended and bed load for 1977-79 divided into grain-size classes. A significant overlap in tonnages occurs in two classes, as illustrated in Figure 4.12. Medium sand (0.25 to 0.5 mm), although constituting only 2% of total suspended tonnage, appears to account for a suspended tonnage greater than total bed-load tonnage of all sizes. Fine sand (0.125 to 0.25 mm) accounts for a suspended tonnage about 60 times greater than bed-load tonnage in the same class. For all sand classes together, suspended tonnage of sand is approximately 25 times greater than bed-load tonnage of sand, and constitutes approximately 15% of total sediment tonnage.

The interrelationship of suspended sand transport with bed-material constitution and bed-load transport is somewhat problematic. The reported annual suspended transport of fine and medium sand (coarser than 0.125 mm) amounts to approximately 4×10^6 tons/year. If it is assumed that this material is picked up from bank erosion and bed shifting and is redeposited some distance downstream, it is possible to apply an equation of sediment continuity, as done for bed load in Section 4.4 preceding, to estimate the average travel rate of fine and medium sand particles in suspension, as follows:

$$\text{Volume of sand} = 4 \times 10^6 \times \frac{2000}{100} = 80 \times 10^6 \text{ ft}^3/\text{yr.}$$

Average thickness of bed movement (Figure 4.9) = 3 ft.
Equiv. thickness of sand (40% of bed material) = 1.2 ft.

$$\text{Mean rate of sediment travel} = \frac{80 \times 10^6}{500 \times 1.2 \times 5280} = 25 \text{ miles/yr}$$

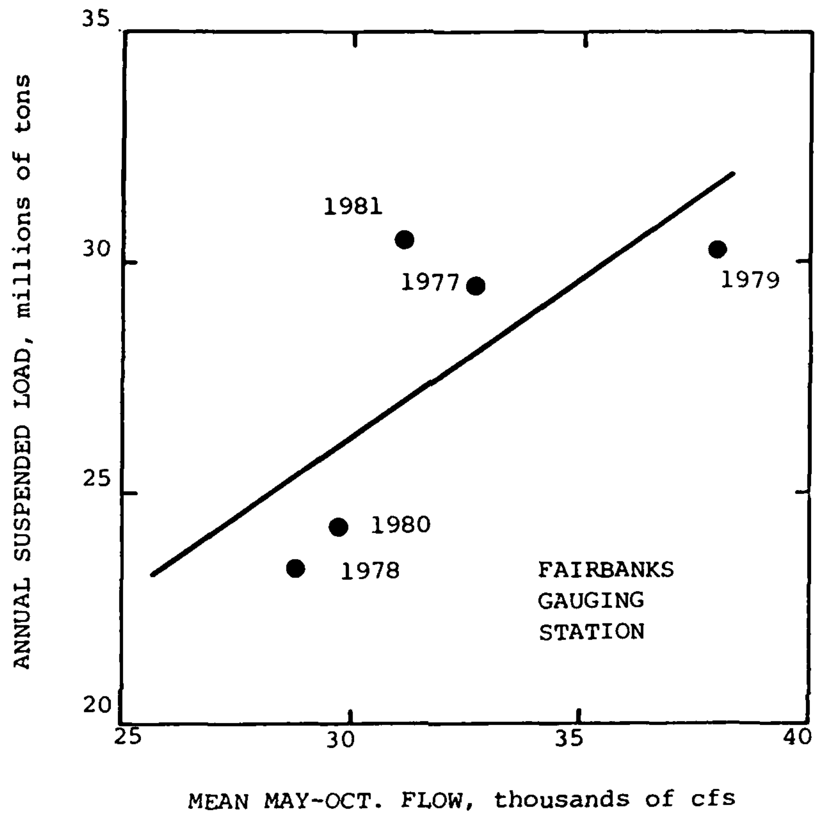


Figure 4.11. Annual suspended load vs mean May-October flows, 1977-81.

Table 4.12. Distribution of suspended and bed-loads by grain-size classes.

Particle size (mm)	Annual sediment load (thousands of tons)			
	Suspended load		Bedload	
	North Pole	Fairbanks	North Pole	Fairbanks
128			0	0
64			0	.5
32			33.9	17.1
16			57.6	46.4
8			57.2	45.0
4			21.9	20.8
2	0	0	5.9	4.4
1	0	89	1.9	1.6
.5	0	5	2.4	3.6
MS .25	353	495	67.8	112.9
FS .125	2,475	3,661	44.6	57.8
VFS .062	3,684	4,448	6.3	8.3
.031	3,440	3,271	2.5	2.6
.016	2,332	2,798		
.008	2,314	2,566		
<.008	6,402	6,667		
Total	21,000	24,000	297.0	321.0

significant overlap between suspended and bedload (MS .25 and FS .125 rows)

Source: Emmett and Burrows, 1982, Table 5. Based on 1977-79 data.

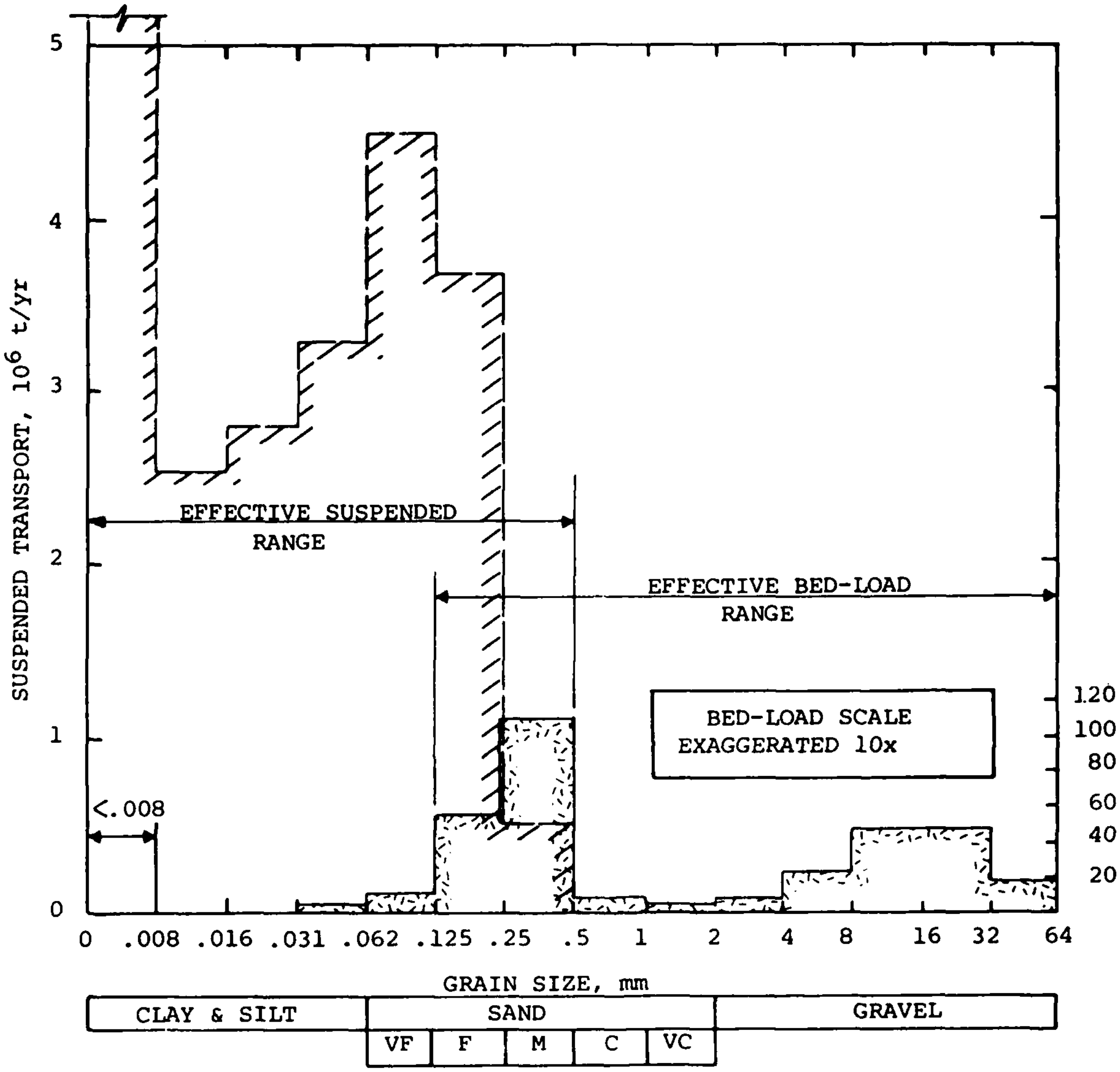


Figure 4.12. Distributions by size classes of suspended and bed-load.

Relative sediment concentration profiles for various sediment sizes may be estimated for typical medium flow conditions at the Fairbanks gauge according to conventional equations (ASCE, 1975). This results in the curves shown in Figure 4.13 for medium, fine and very fine sand. These indicate that medium sand is heavily concentrated in the bottom 20% or so of the depth, fine sand is mostly in the lower 50%, and very fine sand is relatively uniformly distributed.

The question arises as to whether assumptions entailed in calculating suspended sediment loads from samples are valid for the coarser fractions. Sand travelling close to the bed may constitute a saltating rather than a suspended load, and the assumption that it travels at the average speed of the water column may result in transport rates being somewhat overestimated.

4.7 Summary

Key points in the foregoing overview of sediment transport may be summarized as follows:

1. Bed material is a sand and gravel mixture, approximately 2 parts gravel to 1 part sand except at Byers Island where proportions are more or less reversed. The grain-size distribution is highly bimodal, with almost total deficiency in the 0.5 to 5 mm range. Representative grain sizes of the gravel fraction diminish more or less systematically down-river in proportion to channel slope.
2. Bed-load samples are generally similar to bed material in place but are somewhat finer, consisting approximately of 1 part gravel to 1 part sand except at Byers Island where proportions are roughly 1 to 4.
3. Annual bed-load totals at Fairbanks, which average about 360,000 tons/year, correlate closely with mean May-October flows. Preliminary examination of comparative data at six sites along the river indicates that there is little difference between sites except for Byers Island, where bed load appears to be significantly less. Data check reasonably against the Meyer-Peter and Muller bed-load formula. Approximately 96% of bed load is transported in the period 1 May to 31 October.
4. Rate of travel of bed load under natural undisturbed conditions is estimated to be about 1 mile per year in the Fairbanks area. This estimate is based on continuity considerations and on evidence of cross-sectional changes in bed levels.
5. In the June to September period, suspended sediment consists mainly of silt, fine sand and clay with a small percentage of medium sand. In April, May and October, when flows are generally less than 25,000 cfs, suspended sediment is notably coarser than in the summer months and consists predominantly of sand with some silt.
6. The principal overlap in grain sizes between bed-load and suspended-load samples occurs in the fine sand class, 0.125 to 0.25 mm, which constitutes roughly 16% by weight of both types of sample. The physical significance of this overlap, in terms of transport mechanics and hydraulic phenomena near the river bed,

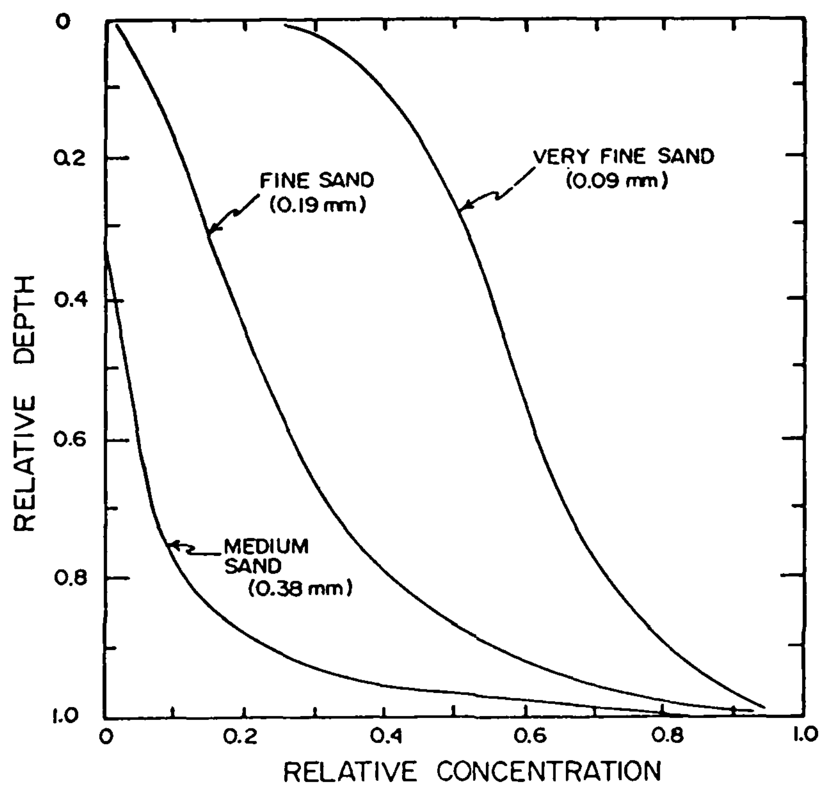


Figure 4.13. Estimated concentration-depth profiles for suspended sand sizes at Fairbanks gauge.

has not been closely examined. Coarser sizes make up only 2% of suspended-load samples, and finer sizes only 4% of bed-load samples.

7. Annual suspended-load totals, which average about 28 x 10^6 tons/year at Fairbanks, correlate reasonably with mean May-October flows. Approximately 15% of this total appears to consist of fine and medium sand sizes that are found in appreciable proportions in river bed material. If this suspended sand is considered to exchange with the channel boundaries, its average travel rate can be estimated as on the order of 25 miles per year.

5. CHANNEL PROCESSES

The channel processes of a partially braided river system like the Tanana involve complex three-dimensional interactions between bank and island erosion, bar and island formation, cross-sectional changes, and sediment transport, all subject to changing rates as flow conditions vary, and in the case of the Tanana, all affected to some degree by man-imposed changes. This part of the overview report describes selected features of planimetric and cross-sectional changes, and analyzes relationships between morphologic changes and sediment transport at a preliminary level.

5.1 Source Documents

Source documents, four of which are attached as Appendices, included the following:

(1) D.M. 24, Supplement no. 1 (C of E, 1980)
(2) D.M. 27 (C of E, 1979).
(3) Progress Report on the Tanana River Monitoring and Research Program, April 1981.
(4) The Effects of Phase III Construction of the Chena Flood Control Project on the Tanana River Near Fairbanks, Alaska - A preliminary analysis, September 1982 (Appendix A herein)
(5) Relationship Among Bank Recession, Vegetation, Soils, Sediments, and Permafrost on the Tanana River near Fairbanks, Alaska, May 1983 (Appendix B herein).
(6) Bank Recession and Channel Changes in the Area near the North Pole and Floodway Sill Groins, Tanana River, Alaska, May 1983 (Appendix C herein).
(7) Erosion Analysis of the North Bank of the Tanana River First Deferred Construction Area, September 1982 (Appendix D herein).

Table 5.1 shows the coverage of these documents with respect to length of river and time period. In the following discussion, they are referred to by number as listed above.

5.2 Planimetric Changes

A complete analysis of historic channel shifts in the whole length of river under consideration is not available. The source documents listed above contain partial analyses of different areas over various time intervals. These are summarized below.

Source Document (1) contains a set of colored maps, extending over about 22 miles from the Moose Creek floodway to downstream of the Chena mouth, which compare main channel and bank locations in 1938 and 1979. An extract in the vicinity of Meridian Island is shown in Figure 5.1. Although these maps can be criticized on the grounds of subjective interpretation of main channels and banks, they appear to demonstrate reasonably the gross changes that occurred over a 40-year period. Some key features may be noted as follows:

(i) Upstream of North Pole, mapped changes in main channel location do not appear to follow any very systematic pattern.
(ii) Downstream of North Pole, the pattern of the largest channel partly resembles a series of irregular meander loops. Some of these loops appear to have migrated downstream by approximately

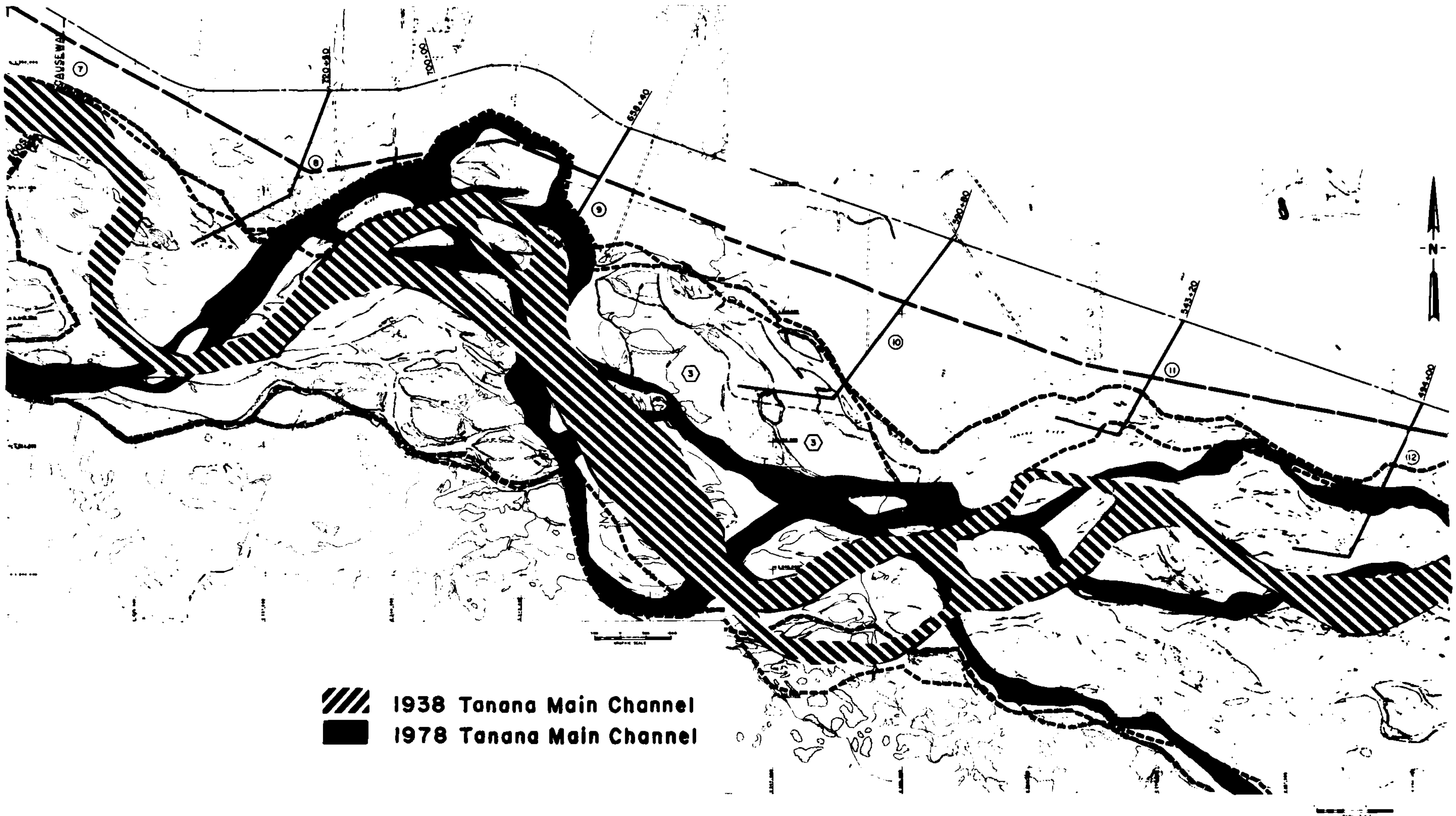


Figure 5.1. Apparent downstream migration of main channel loops upstream of Goose Island, 1938-1978.

1,200 ft in a 40-year period, an average rate of about 30 ft per year (Figure 5.1).

(iii) Upstream of North Pole, encroachments by the river into wooded floodplain areas beyond the limits of the active channel system appear small relative to internal changes. Downstream of North Pole, such encroachments appear more substantial.

Source Document (2) contains a sequence of 14 airphoto mosaics demonstrating channel changes in the Phase III area between 1938 and 1979. Detailed analysis was confined to Bend 'A' alongside the railroad and airport, where the main river bank eroded at about 100 ft per year between 1970 and 1979 (Figure 5.2). Riprap protection was placed along the eroding bank in the summer of 1979, and the bend was cut off by Phase III pilot channel and groin construction in early 1981.

This local rate of bank recession, which appears to be uniquely high, may have been accelerated by unauthorized closure of secondary channels to the north which took place in 1969. Other possibly influential factors are gravel extraction operations in bend B downstream (which might have increased local slope and velocities) and closure of the north channel at Goose Island, which may have altered channel shift tendencies for a considerable distance downstream. Locally high rates of main bank erosion elsewhere along the river may also reflect human activity, documented or otherwise.

Source Document (3) contains small-scale airphoto mosaics of 1970 extending from about the Moose Creek floodway to below Byers Island, on which are marked principal areas of main bank and island shore erosion from 1970 to 1975 and from 1975 to 1980. Table 5.2, based on approximate analysis of these mosaics, shows that the more significant main bank erosion sites are typically a few thousand feet long and a mile or two apart, and exhibit recession rates at their worst points of 20 to 50 ft per year. The airport site (Bend A) shows a rate several times higher than the others, as previously mentioned.

Source Document (4) contains a detailed analysis of areal and volumetric erosion in the Phase III area between 1970 and 1981, and some mapping of change over the preceding decade. The area, shown in Figure 5.3, is considered to consist of three bends, A, B and C, and quantities of erosion after 1970 are tabulated for each bend between each pair of aerial surveys. Table 5.3, based on data tabulated in the report, consolidates information on areal and volumetric erosion rates. It indicates that from 1970 to 1980 areal erosion rates in Bends B and C, just upstream and downstream of the Chena mouth respectively, averaged only about 20% of those in Bend A. In Bend A, rates were relatively consistent over the period; in Bends B and C separately they were highly variable, but when added together they were much more consistent, being largely complementary.

Source Document (5) is mainly concerned with examining relationships between bank recession, vegetation and sediment, but none of significance were discerned. The possible effect of permafrost was not examined due to lack of reliable data. The report tabulates and plots bank sediment information as indicated by well logs along the north bank. At the airport erosion site (Bend A), numerous well logs indicate that floodplain material is mainly silt and sand above low water levels, and a sand-gravel mixture below. Along the north bank between Goose Island and the airport, plotted and tabulated recession rates are up to 50 ft per year

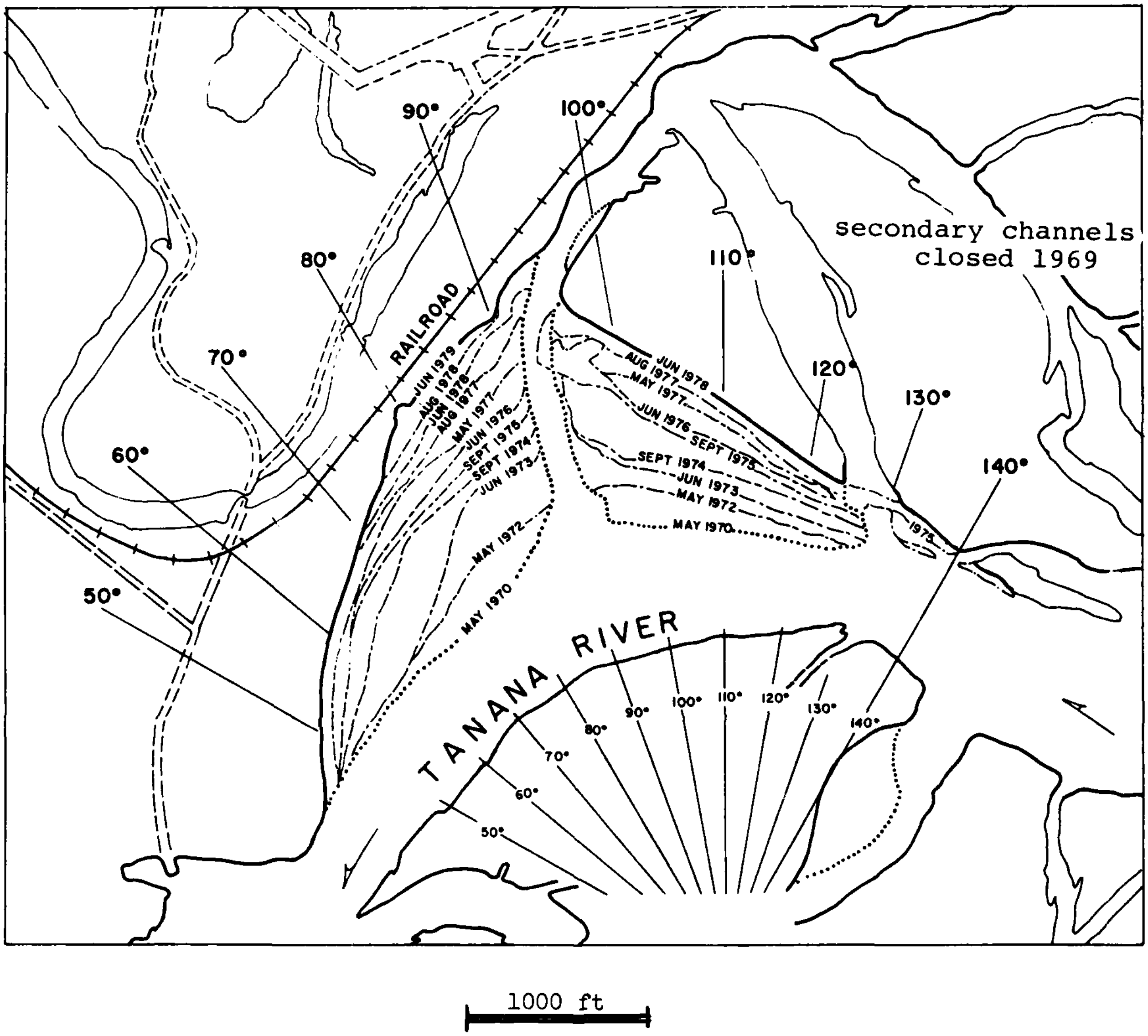


Figure 5.2. Bank recession, 1970-79, in Bend A, Phase III area. Based on D.M. 27 (Corps of Engineers, 1979).

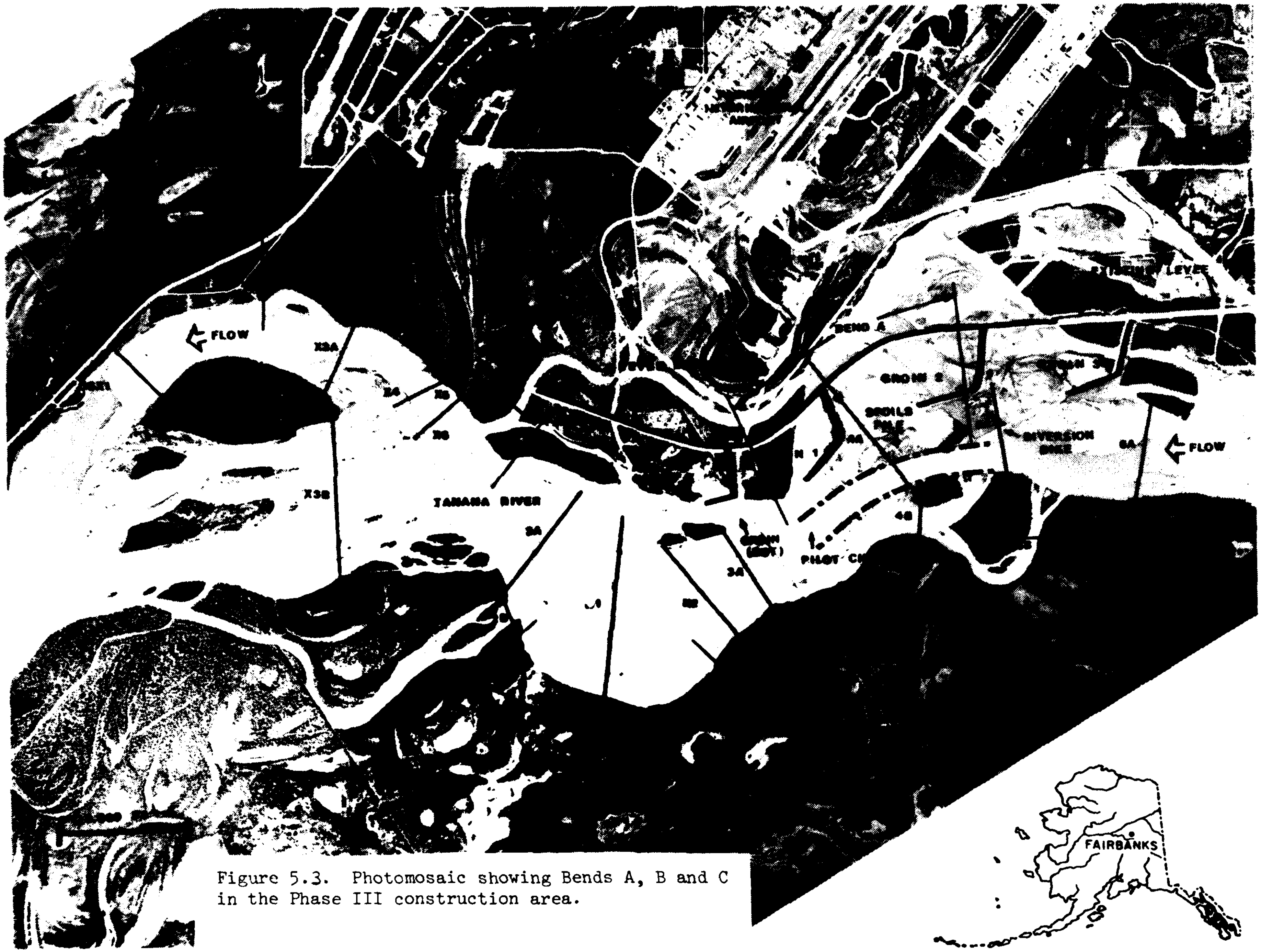


Figure 5.3. Photomosaic showing Bends A, B and C in the Phase III construction area.

Table 5.1. Documentation of planimetric changes by length and period.

Source Document	Length of River Covered	Period Covered
(1) D.M. 24 Suppl. no. 1 (1980)	Floodway Sill to below Chena mouth	1938-79
(2) D.M. 27 (1979)	Phase III area	1938-79
(3) CRREL Progress Rpt. April 1981	Above Floodway Sill to below Byers Is.	1947-80
(4) CRREL Report May 1982 (App. A)	Phase II area	1961-81
(5) Recession-vegetation-sediment report May 1983 (App. B)	North bank, Goose Is. to airport	1948-80
(6) Recession near groins report May 1983 (App. C)	Floodway Sill groin to North Pole groin	1948-81
(7) Deferred construction area report Sept 1982 (App. D)	Goose Is. to Phase III groin no. 3	1948-82

Table 5.2. Comparison of 1970-80 bank recession rates at principal erosion locations (based on CRREL progress report of April 1981).

Location	Approx. Length of Eroding Bank ft	Local Max. Rate of Recession Averaged 1970-80* ft/yr
N. bank u/s of Floodway sill groin	2000	40
S. bank d/s of Floodway sill groin	2000	20
S. bank 2 mi. u/s of N. Pole groin	2000	50
N bank 1 mi. u/s of N. Pole groin	3000	40
S. shore of Meridian Is.	3000	30
N. bank d/s of Meridian Is.	5000	20
S. shore of Goose Is. (gravel extraction site)	1500	40
Upstream end of Haines Is.	1000	40
N. bank N. of Haines Is.	10000	30
N. bank nr. airport (Bend A)	2500	100
S. bank at airport (Bend B)	6000	20
N. bank d/s of Chena mouth	3000	20

* Local maximum rates shown apply at the points of maximum recession within each length tabulated.

Table 5.3. Areal and volumetric erosion rates at Bends A, B and C, Phase III area.

From	To	Effective Period Years[a]	Areal Erosion Rates sq ft/year Bend A	Bend B	Bend C	Volumetric Erosion Rates cubic yds/year Bend A	Bend B	Bend C
Pre-Construction								
12 May 70	17 Jun 73	3.25	270,000	-	15,000	300,000	-	16,000
27 Jun 73	19 Sep 74	1.46	297,000	-	16,000	330,000	-	17,000
12 May 70	19 Sep 74	4.71	278,000	105,000	15,000	309,000	97,000	16,000
19 Sep 74	26 Sep 75	1.04	423,000	62,000	88,000	470,000	57,000	95,000
26 Sep 75	4 Jun 76	0.38	300,000	18,000	279,000	334,000	16,000	300,000
4 Jun 76	17 May 77	0.90	378,000	16,000	83,000	420,000	14,000	89,000
17 May 77	4 Jun 78	1.10	305,000	28,000	76,000	338,000	26,000	82,000
4 Jun 78	3 Jul 79	1.16	257,000	37,000	100,000	285,000	34,000	108,000
3 Jul 79	7 May 80	0.69	193,000[c]	28,000	35,000	214,000[c]	26,000	38,000
12 May 70	7 May 80	9.98	298,000	67,000	57,000	331,000	62,000	61,000
Post-Construction								
6 Mar 81	29 May 81	0.15	(1,993,000)[b]	-	-	(1,320,000)[b]	-	-
7 May 80	29 May 81	1.12	-	64,000	30,000	-	60,000	32,000
29 May 81	20 Oct 81	0.79	568,000	16,000	81,000	461,000	15,000	87,000
6 Mar 81	20 Oct 81	0.94	796,000	-	-	598,000	-	-
7 May 80	20 Oct 81	1.91	-	45,000	51,000	-	41,000	55,000

a Based on effective erosion year of 6 months, 1 May to 31 October.

b Figures somewhat misleading because of short period; re-aligned pilot channel area.

c Riprapped period.

For details of calculations see Appendix A.

for the period 1970-75, somewhat higher than indicated in Table 5.2 for the period 1970-80.

Source Document (6) is mainly concerned with evaluating local response to construction of the North Pole and Floodway Sill groins in 1975 and 1979 respectively, and comparing post-construction changes with historical changes as indicated by airphotos dating back to 1948. Data tabulated and graphed in the report indicate historical bank recession rates in the range of 10 to 30 ft per year, when averaged over a period of years and over a length of several miles; these averaged figures are somewhat less than local rates at principal erosion locations shown in Table 5.2.

Source Document (7) deals with the north bank over a length of 2.5 miles between Goose Island and the upstream Phase III Groin 3. It covers the period 1948-82 and overlaps with Source Document (5) discussed above. Between 1948 and 1975 areal erosion averaged about 150,000 ft^2 per year over the length, corresponding to a rate of bank recession of about 12 ft per year. During 1976, following construction of the Goose Island causeway which blocked off the channel to the north of Goose Island and diverted most of the river flow against the north bank downstream of Goose Island, areal erosion rates were about six times the historic average. From 1977 on they returned to more or less the historic average.

To sum up the available information on planimetric erosion, it appears that long-term bank recession rates, averaged over lengths of actively eroding river bank ranging from 1,000 to 10,000 ft, have generally been in the range of 10 to 30 ft per year, and perhaps up to 50 ft or more per year locally.

5.3 Cross-Sectional Changes

Information on cross-sectional changes is contained in USGS sediment transport reports (Burrows et al., 1981; Burrows and Harrold, 1982) and in the CRREL Phase III report (Appendix A). These documents contain plots of cross-sectional changes from 1977 to 1981 at USGS gauging sites and at cross sections in the Phase III area; the latter reflect response to Phase III construction in early 1981 as well as prior changes generally thought to be associated with natural processes. Changes in the Fairbanks discharge-measuring cross section GSX2 are plotted in Figure 3.5, and data on cross-sectional geometry changes are listed in Table 3.3

Generally speaking, cross-sectional areas and shapes at a given flow have remained relatively consistent from one survey to another, except where sections were affected by construction-induced planimetric changes in 1981. Most of the surveyed sections in the Phase III area are in bends, where plan curvature and secondary circulation induce a more or less triangular type of section with a deep thalweg near the outside bank and a tendency to outward migration (Figure 5.4). At these locations, changes between surveys mainly reflect channel migration and changes in deepest scour elevations in the thalweg. At most sections, the deepest scour levels were observed in 1979, the year of greatest flow peak and volume (see Table 3.1).

The Fairbanks discharge-measuring cross section GSX2, located not in a bend but just below the confluence of two major channels divided by a large island, does not follow the above pattern but exhibits major changes in shape over the 1977-79 period, having had at different times a thalweg on the right, on the left, and on both sides (see Figure 3.6). Some of these changes may be associated with activity around Goose Island; however, this behavior is in accordance with general experience regarding the instability of straight and cross-over sections in rivers with substantial bed-load transport. Presumably similar behavior would be found at many sections upstream of Goose Island, where irregular braiding mostly replaced stable bends.

Plots of other USGS gauging sections are available for 1980 and 1981 only; they show fairly substantial changes from one survey to another within this period (see Burrows and Harrold, 1982), especially the multi-channel sections near North Pole and above Moose Creek Dam.

5.4 Volumetric Changes

Volumetric changes over a given time period can be considered in two ways, as follows:

(i) The planimetric area of erosion associated with bank recession over a given reach, as determined by airphoto analysis, can be multiplied by a height from top of bank to bottom of thalweg, to indicate the volume of material eroded between two dates. This has been done in the CRREL Phase III report (Appendix A), and volumetric erosion rates based on this method are listed in Table 5.3 along with areal rates already discussed in Section 5.2. The variation in computed volumetric rates parallels that of computed areal rates, Bend A showing much greater volumes than Bends B and C. A striking point is that mean annual erosion rates from Bend A are very similar to mean annual bed-load transport rates as indicated in Table 4.8. Some implications of this similarity are discussed in Section 5.5 following.

(ii) Individual cross sections as surveyed on different dates can be compared to determine cross-sectional areas of erosion and fill, which can be converted to volumes if an appropriate channel length can be associated with each section or pair of sections. Table 5.4 lists approximate areas and volumes based on analysis of eight cross sections between the Fairbanks discharge-measuring cross section GSX2 and cross section X2 downstream of Byers Island. Areal changes are shown for a 2-year period and averaged over intervening lengths of main channel to give approximate volumes of erosion and fill per year.

Table 5.4 indicates that erosion and fill tend to balance out to a substantial extent at each section, and to alternate from left to right sides between successive cross sections. Averaged over the eight sections, area of erosion and area of fill differ by only 12%. These figures are considered further in Section 5.5 below.

5.5 Relationship of Volumetric Changes to Sediment Transport

It appears intuitively evident that some kind of relationship must exist between (i) rates of erosion and deposition and (ii) transport rates of sediment in the size classes that are eroded and deposited. For the restricted case of down-valley migration of meanders through an alluvial floodplain, Neill (1971) presented the analysis shown in Figure 5.5, and showed that the process gives rise to a volumetric transport rate given by:

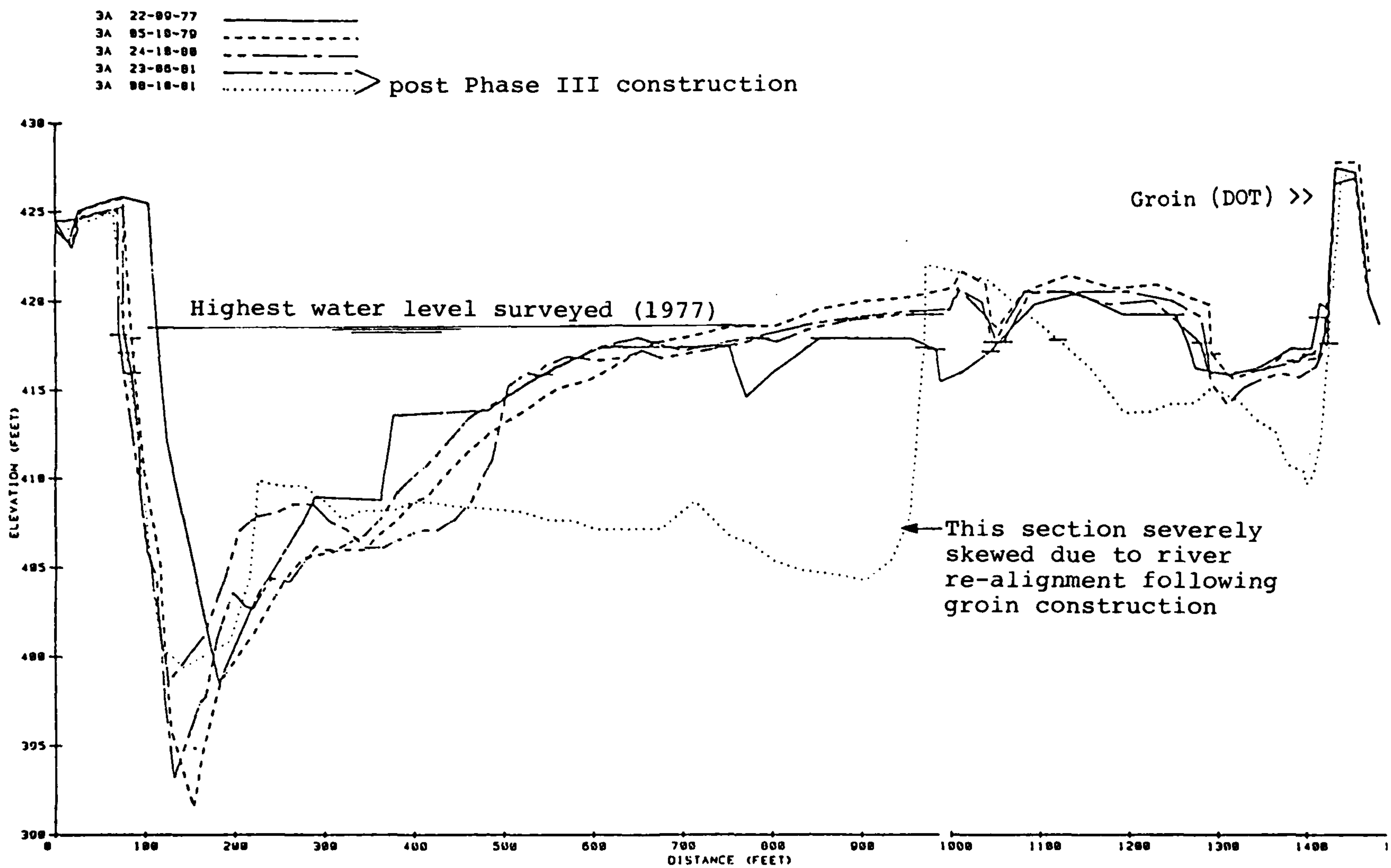


Figure 5.4. Typical bend cross section in Phase III area.

Table 5.4. Cross-sectional scour and fill over 2-year intervals, pre-construction, Phase III area.

Cross-section[a]	Scour		Fill		Approx. Distance	Av. Volume of scour/fill between sections[b]
	Area ft	Left or Right	Area ft	Left or Right	ft	cu yds
Sept/Oct '77 to Sept/Oct '79						
GSX2	2600	R	4000	L/R		
					2400	331,000
5A	3800	L	4500	R		
					2800	412,000
4A/B	4200	R/L	3400	L/R		
					3600	380,000
3A	2400	L	1400	R		
					4800	413,000
2A	3800	R	1700	L		
Sept/Oct '78 to Sept/Oct '80					3300	263,000
X4	2000	L	1100	R		
					1650	128,000
X3A	2200	R	3100	L		
					9200	1,175,000
X2	4700	L/R	3800	R		
2-Year averages	3210		2875			444,000
1-year averages		1520			3960	222,000

a For cross-section plots see Appendix A.

b Computed as (average of 4 scour and fill areas) x distance.

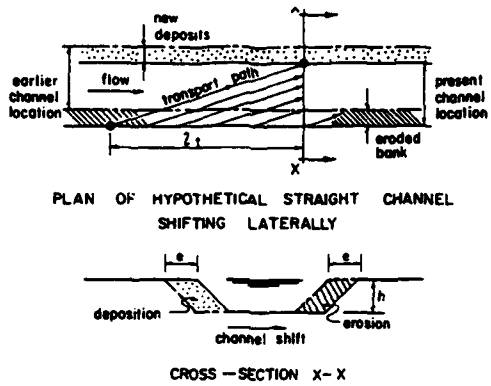


FIG. 1.—IDEALIZED LATERAL SHIFT PROCESS IN STRAIGHT CHANNEL IN STATE OF DYNAMIC EQUILIBRIUM (l_t = average travel distance of particles between erosion and deposition; e = width of erosion from right bank in specified time = width of accretion on left bank in same time; and h = height of eroding bank)

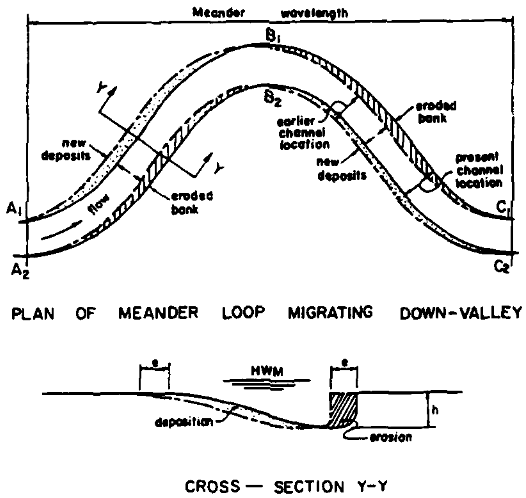


FIG. 2.—SIMPLIFIED MEANDER SWEEP PROCESS IN NATURAL RIVER [Assumptions: (1) Material deposited on bank A_1-B_1 has come from upstream; (2) material eroded from bank A_2-B_2 is deposited on B_2-C_2; (3) material eroded from bank B_1-C_1 is deposited downstream; and (4) average length of travel between erosion and deposition = length of channel in half meander wavelength] (Note—measured area of erosion A in one wavelength in specified time = Σ areas of erosion A_2-B_2 and B_1-C_1)

It can be seen from Fig. 1 that the volumetric rate of transport across any section X-X = volumetric rate of erosion from length l_t = $l_t \times h \times (de/dt)$ in units of volume/time.

Figure 5.5. Meander migration process. (From Neill, 1971.)

$$Q_s = l_t \times h \times de/dt$$

where Q_s = average volumetric transport rate
l_t = average travel length of sediment particle from point of erosion to point of deposition (this was assumed to be the length of a meander loop or half-waveform)
h = height from top of eroding bank to bottom of scour or thalweg
de/dt = average rate of bank recession

Consideration of the Tanana information suggests further generalization of these principles in the following propositions:

(i) In an alluvial river in equilibrium, the average annual volume of bed-material erosion from a single channel loop cannot exceed the average annual volume of similar sediment transported across a section. When the two are equal, as illustrated in Figure 5.6, incoming sediment to the reach is deposited to form new floodplain on one side, while erosion removes old floodplain on the other, thereby providing bed-material transport to replace the loss of incoming sediment to deposition.

(ii) The volumetric transport rate of bed material is equal to the rate of cross-sectional areal change multiplied by the average travel length of particles between erosion and deposition. This applies whether cross-sectional changes are taking place by (a) bank erosion and bank/bar deposition as illustrated in Figure 5.5 and 5.6; (b) thalweg and bar shifts within fixed banks as illustrated in Figure 5.7; or (c) a combination of both processes. It follows that in a given river, high rates of cross-sectional change are associated with short travel lengths (sharp curvature) and low rate with long travel lengths (flat curvature).

These propositions can be tested against Tanana data. The 10-year average rate of erosion from Bend A (Table 5.3) is approximately 330,000 cubic yards per year. According to well-log data (see Section 5.1), perhaps 25% of this erosion is fine sand and silt material that would pass into suspension, leaving say 250,000 cubic yards per year for bed-load transport. According to USGS measurements at the Fairbanks measuring cross section just upstream (Table 4.8) the average bed-load transport is about 360,000 tons, or say 260,000 cubic yards per year. This suggests more or less complete exchange of material in Bend A, incoming bed load having deposited on the accreting inside bar and been replaced by outside bank erosion material. Given the severe curvature that existed, such a complete exhange is hydraulically credible.

The second proposition may be tested against Table 5.4, which indicates an overall average of scour and fill areas of about 1500 ft^2 per year. The river length encompassed by these sections consisted essentially of three irregular meander loops (or 1.5 complete meander waveforms) and the average channel length in each loop was about 8000 ft. Assuming as a first approximation that this represents the average travel length of bed-material particles, we obtain an estimated volumetric transport rate of 1500 x 8000/27 = 440,000 cubic yards per year approximately. A certain proportion of this, however, is fine material that passes into suspension; allowing 25% reduction, the estimated bed load is 330,000 cubic yards per

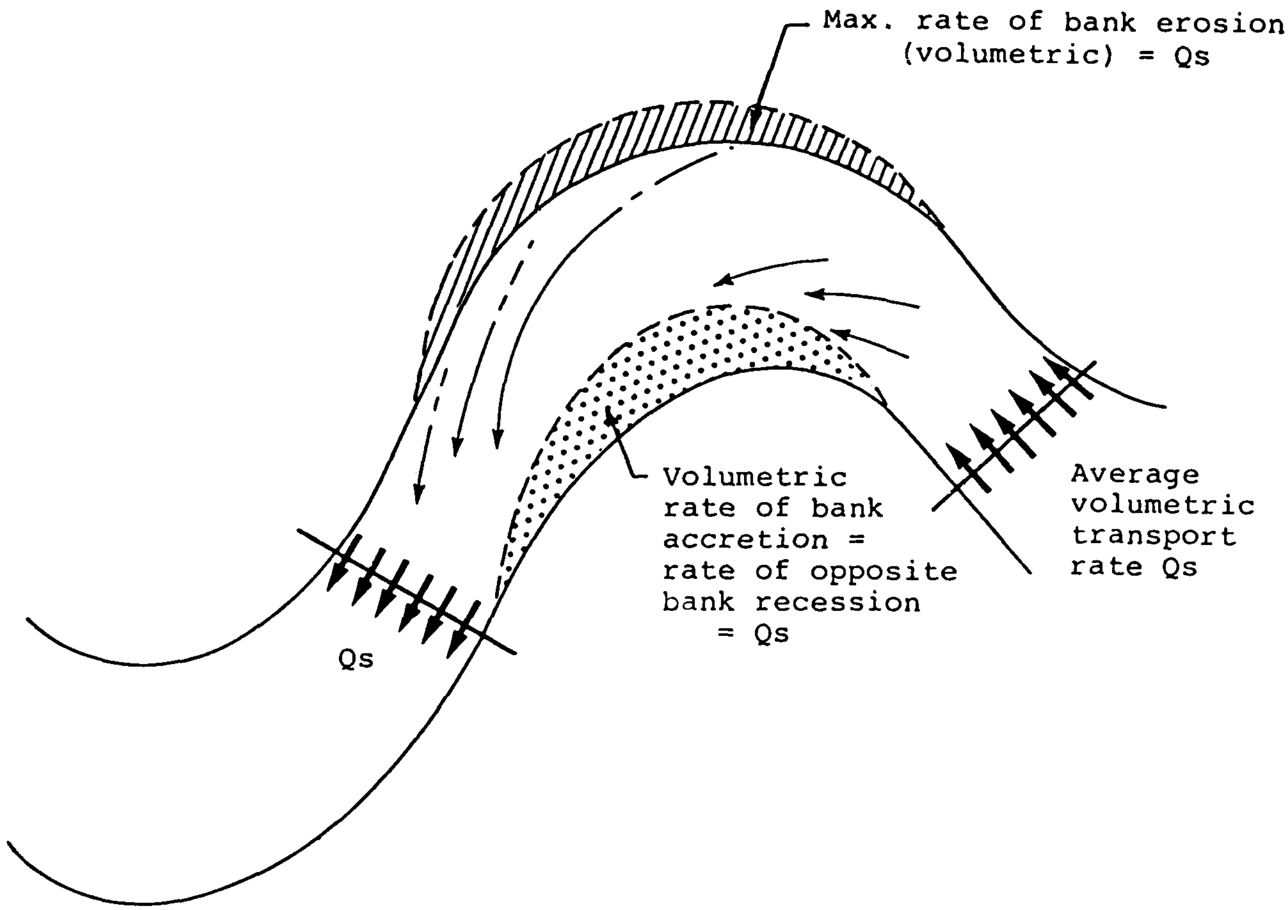


Figure 5.6. Bed-material exchange in channel bed. (Note: This represents an idealized process of complete exchange and is not necessarily exact for any particular site on the Tanana River.)

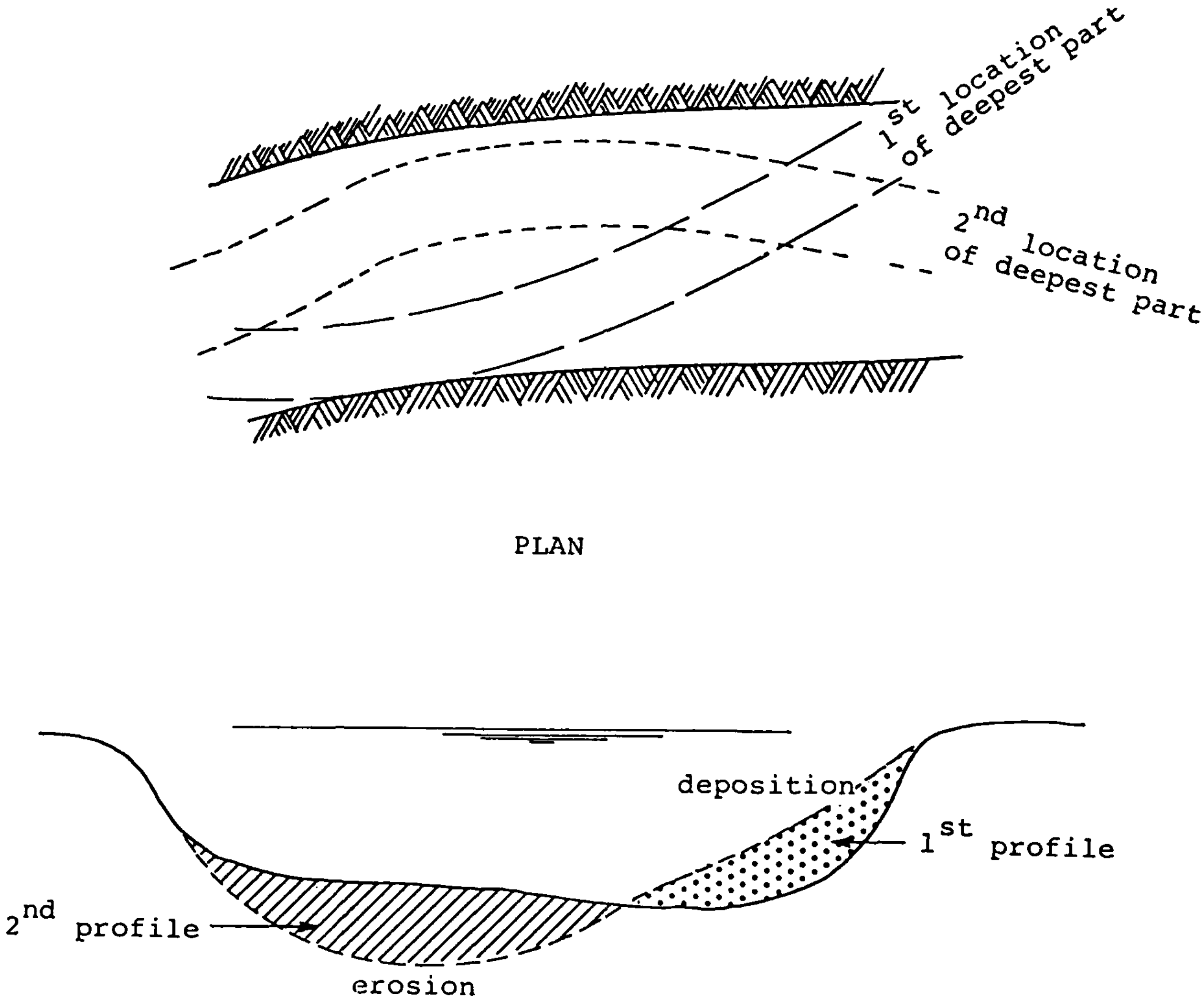


Figure 5.7. Cross-sectional changes within fixed banks. Volume of sediment transported = average of erosion/deposition × average distance travelled between erosion and deposition.

year, against a measured bed-load transport of say 260,000 cubic yards. Again, the comparison appears to support the proposition reasonably.

5.6 Summary

Key points in the foregoing review of channel process may be summarized as follows:

1. Available analyses of planimetric changes, which give only a partial picture in relation to space and time, show a wide variety of forms of channel migration, bank and island erosion, and bar and island formation.
2. Average recession rates of principal river banks, where active bank erosion is in progress, are typically in the range of 10 to 30 ft per year, locally up to 50 ft per year or more. The higher erosion rates observed generally seem to be associated with some form of intrusion or channel development; for example the sharp bend (Bend "A") near the airport which eroded at about 100 ft per year between 1970 and 1980.
3. There is no apparent correlation between bank erosion and floodplain vegetation and sediments. The influences of permafrost cannot be evaluated from available data.
4. Cross-sectional changes with time depend on channel planform at the section. Bend sections migrate outwards but tend to retain their shapes; cross-over sections are quite unstable.
5. In special reaches of severe curvature and rapid bank erosion, average annual volumes of erosion can more or less equal average annual bed-load transport.
6. It has been demonstrated that multiplying cross-sectional areas of scour and fill by estimated distance of bed-material travel between erosion and deposition yields volumetric estimates that are reasonably compatible with measurements of bed-load transport.

6. RESPONSE TO IN-RIVER CONSTRUCTION AND GRAVEL EXTRACTION

The preceding Part 5 was concerned mainly with channel processes of the Tanana River in a general sense. The following sections deal with discerned response of the river to specific human activities previously itemized in Part 2.

6.1 Moose Creek Dike

Moose Creek Dike, partially constructed during 1939-40 and completed in 1945, was designed to prevent floodwaters of the Tanana River from entering Chena Slough. It was 3 miles long and 8 ft high, and ran due west from Moose Creek Bluff to the right bank of the Tanana River (Figure 1.1). The dike blocked flow into the Chena Slough by diverting flows from Piledriver Slough and several other sloughs and creeks back into the Tanana River. Part of the dike was removed during construction of the Chena River Lakes Project. Overflows from the Tanana River are now blocked by the Floodway Sill Groin and Moose Creek Dam (Figure 1.1).

Prior to the construction of Moose Creek Dike, Piledriver Slough, Chena Slough and the other sloughs in the area were active channels of the Tanana River. Following completion of the dike, the area south (upstream) of the dike aggraded to within 3 to 4 ft of the dike top by 1960 (Péwé, 1966), and extensive stands of willow and alder developed in the aggraded area. The blockage of Chena Slough reduced flood flows in what is now the lower portion of the Chena River through Fairbanks, and may have accelerated the shift of the main Tanana channel, downstream of the Chena mouth, to the north of Byers Island (Plates 3-5, DM 27).

6.2 DOT Groin

The DOT Groin was built in 1972-73 by the Alaska Aviation Division (now part of Alaska Department of Transportation) to protect gravel extraction and stockpile operations on the Tanana River in the area just south of the Fairbanks International Airport. The DOT Groin was the first major intrusion into what was later called the Phase III construction area. The groin reduced the active channel width by about 540 ft or 30% of the pre-construction width of 1,760 ft. The residual active channel width of about 1,220 ft in 1973 had widened to about 1,370 ft by 1982.

The DOT Groin is still in place following Phase III construction, and is diverting the river flow well to the south of the levee (Figure 2.1). The shorter Phase III Groin 0 was built at the same location but is presently relatively ineffective because the DOT Groin is still in place. Rediverted flow from the pilot channel is presently flowing directly against the DOT Groin. It is difficult to distinguish the river's response to this groin from response to other disturbances and gravel extraction in the immediate vicinity.

6.3 North Pole Groin

The North Pole Groin was constructed during the winter of 1974-75 and completed by May 1975. This L-headed groin, 6,900 ft long, was designed to divert the main flow of the Tanana River to the south away from the north bank, where erosion was encroaching on the specified 500-ft-wide

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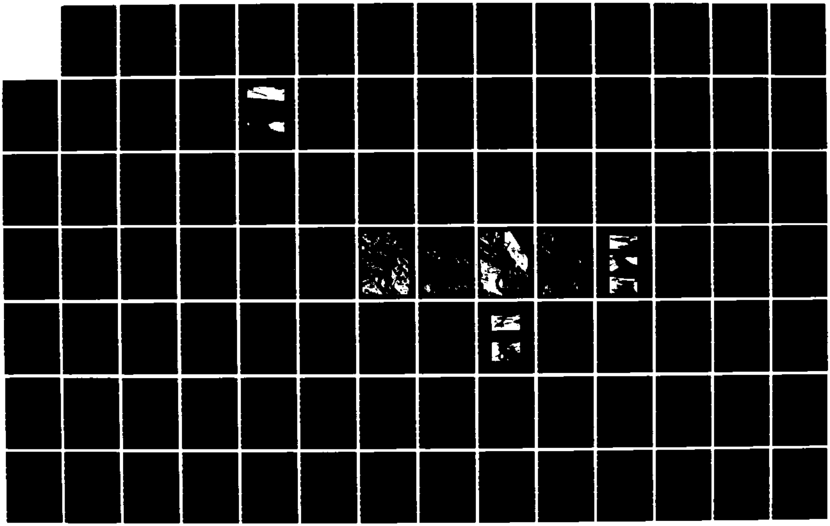

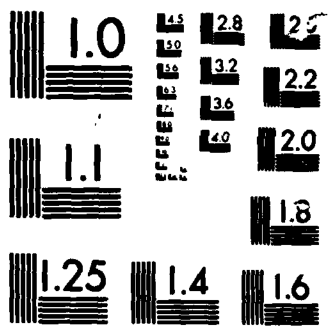

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natural silt blanket on the floodplain in front of the flood protection levee. The groin reduced the active channel width from 5,900 to 2,600 ft. It was constructed using a channel closure and a pilot channel about 9,300 ft long by 80 ft wide with 2 to 1 side slopes. Excess material from the excavation of the pilot channel was spoiled along its north bank.

From 1948 to 1964, prior to construction of the North Pole Groin, the main flow had been in the northern part of the channel, and a broad meander was migrating northward against the north bank. Table 6.1, summarized from Appendix C, shows that 95 acres of the north bank eroded during that period along a 3-mile reach, an average rate of 3.5 acres per year. The broad meander tightened in the later years and bank erosion was concentrated along a 1-mile reach. Table 6.1 indicates that of the total pre-construction areal erosion in the groin area, 86% occurred along banks and islands of the north channel; however, data for the south channel are incomplete. It is considered that for the 1948-74 period, the distribution of pre-construction areal erosion was more likely 60% in the north channel and 40% in the south channel.

The North Pole Groin completely cut off the large meander in the north channel and diverted the river away from the north bank over a length of 1.3 miles. The groin protected the threatened area completely, but erosion of the north bank and islands continued downstream. Table 6.1 shows that in the post-construction period 1975-81, most of the erosion occurred along the islands and south bank. North bank erosion rates were reduced by 60%, and south channel erosion rates mirrored the pre-groin north channel rates. The apparent increase in total areal erosion rates is misleading, reflecting lack of pre-construction airphoto coverage for the south channel. In general, the river is responding to the presence of the groin by redistributing the erosion along the islands and south bank, which now account for 86% of the total areal erosion in the groin area.

The minimum and maximum distances between the north bank location of 4 June 1982 and the outer limit of the 500-ft silt blanket zone required for seepage control are 500 ft and 1,400 ft respectively. Estimates of the shortest time required for north bank erosion to encroach on the zone downstream of the groin range from 5 to 13 years according to locality. These estimates are based on a maximum historical north bank recession rate of 110 linear feet per year (see Appendix C), which is assumed to be capable of occurring anywhere downstream of the groin.

6.4 Goose Island Causeway

The eastern Goose Island Causeway between the north bank of the Tanana River and Goose Island was constructed in late 1975, completely blocking off the north channel at Goose Island. The causeway, 2,500 ft long and 40 ft wide with a two-lane roadway on top, reduced the active river width to 1,000 ft in a single channel, from a combined pre-construction width of 3,750 ft. This causeway is the largest structural intrusion in place south of the levee. The western Goose Island Causeway was completed in early 1978 to allow additional access for gravel extraction. As discussed in Section 5.2 and Appendix D, the average areal erosion of the north bank downstream of Goose Island was about 150,000 ft^2 per year prior to causeway construction. In 1976, after construction, north bank erosion rates were about six times the historic average. This high temporary erosion rate was

Table 6.1. Areal erosion and areal erosion rates near the North Pole Groin.

	Pre-Construction Period 20 May 1948 to 31 Oct 1974 (26.90 effective erosion years)			Post-Construction Period 1 May 1975 to 20 Oct 1981 (6.94 effective erosion years			
	Erosion Acres	%	Erosion Rate Acres/yr	Erosion Acres	%	Erosion Rate Acres/yr	Percent change From Pre-Construction Rate
North Bank	95	52	3.5	10	14	1.4	-60
Islands North Channel	63	34	2.3	20	28	2.9	+26
Islands-South Channel*	20	11	0.7	19	26	2.7	*
South Bank*	5	3	0.2	23	32	3.3	*
Total*	183	100	6.7	72	100	10.3	*

* Photo coverage of the southern part of the channel in 1948, 1961, 1970 and 1973 was incomplete, consequently the pre-construction areal erosion areas and rates are too low. The percent change values were correspondingly too high and are not presented.

For details see Appendix C (river reach considered 3.6 miles).

due to redirection of flow around Goose Island and back into the north channel, where the flow acted directly against the north bank. From 1977 onward, as the south channel downstream of Goose Island opened up and accepted more flow, areal erosion rates on the north bank returned to more or less the historic average. Extensive aggradation has occurred on the upstream side of the eastern Goose Island Causeway, estimated to be 3 to 4 ft thick in some areas. No new vegetation has established itself on the aggraded area to date.

During the spring of 1979, the western Goose Island Causeway was extended to the small island southwest of Goose Island. A dike was constructed across the upstream end of the channel between the two islands and around the perimeter of the small island, and the gravel within the small island's perimeter dike was extracted for use in Phase IIB levee construction. The small channel which was blocked off had carried up to 20% of the river's flow at medium to high stages; its blockage reduced flow in the north channel downstream of Goose Island and decreased north bank erosion in 1979. The perimeter dike around the gravel extraction area was not maintained, and in August 1981 the river broke through the dike and west causeway extension, allowing the river to flow in a more direct path towards the north bank. This has been followed by an apparent but yet unmeasured increase in erosion along the north bank downstream of Goose Island.

Figures 6.1 and 6.2 show cross-sectional changes which reflect the activities at Goose Island. Figure 6.1 shows cross section 7A in the north channel downstream of Goose Island, Figure 6.2 shows cross section 7C in the south channel, and Table 6.2 compares changes at 7A and 7C. A water surface elevation of 423.9 ft was used as a basis for comparison since it was an average of the water surface elevations measured during the surveys; the corresponding discharge was in the vicinity of 20,000 cfs. The distribution of flow area at this condition in 1977 was 56% in the north channel and 44% in the south channel. By 1982 these proportions had changed to 40% in the north channel and 60% in the south channel. Marked changes in cross-sectional shape also occurred within each of the main channels.

6.5 Floodway Sill Groin

The Floodway Sill Groin was constructed to protect the floodway sill structure from scour by the Tanana River. The L-headed groin, completed in March 1979, was constructed using a diversion dike and a pilot channel in front of the groin. Excess material from the pilot channel excavation was used in the diversion dike. The groin reduced the active channel width from 6,200 ft to 4,400 ft. The Floodway Sill Groin constituted less of a disturbance than the eastern Goose Island Causeway or the North Pole Groin. It is similar in design to the North Pole Groin in that both groins are relatively isolated from other large in-river structures, and both use a 40-ft-wide prism of riprap placed on natural ground as the protective facing.

Prior to construction of the Floodway Sill Groin, the distribution of areal erosion rates (Table 6.3) was similar to that estimated for the North Pole Groin, 62% of the erosion occurring in the channels north of the islands and 38% south of the islands. Pre-construction erosion rates across the channel ranged from 2.1 to 3.7 acres per year, slightly higher than those measured in the North Pole Groin area.

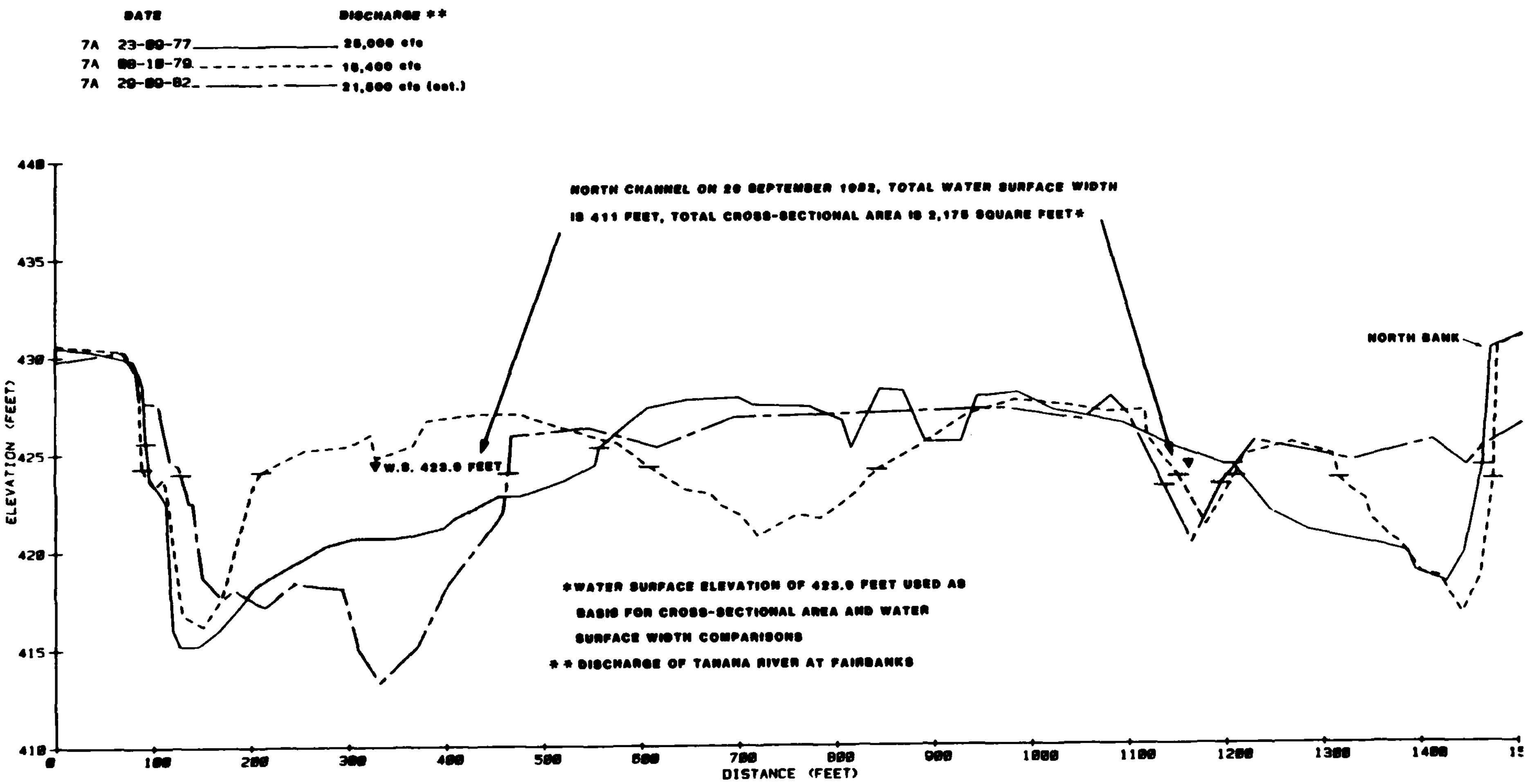

Figure 6.1. Comparison of cross-sectional changes in the north channel downstream of Goose Island, cross section 7A.

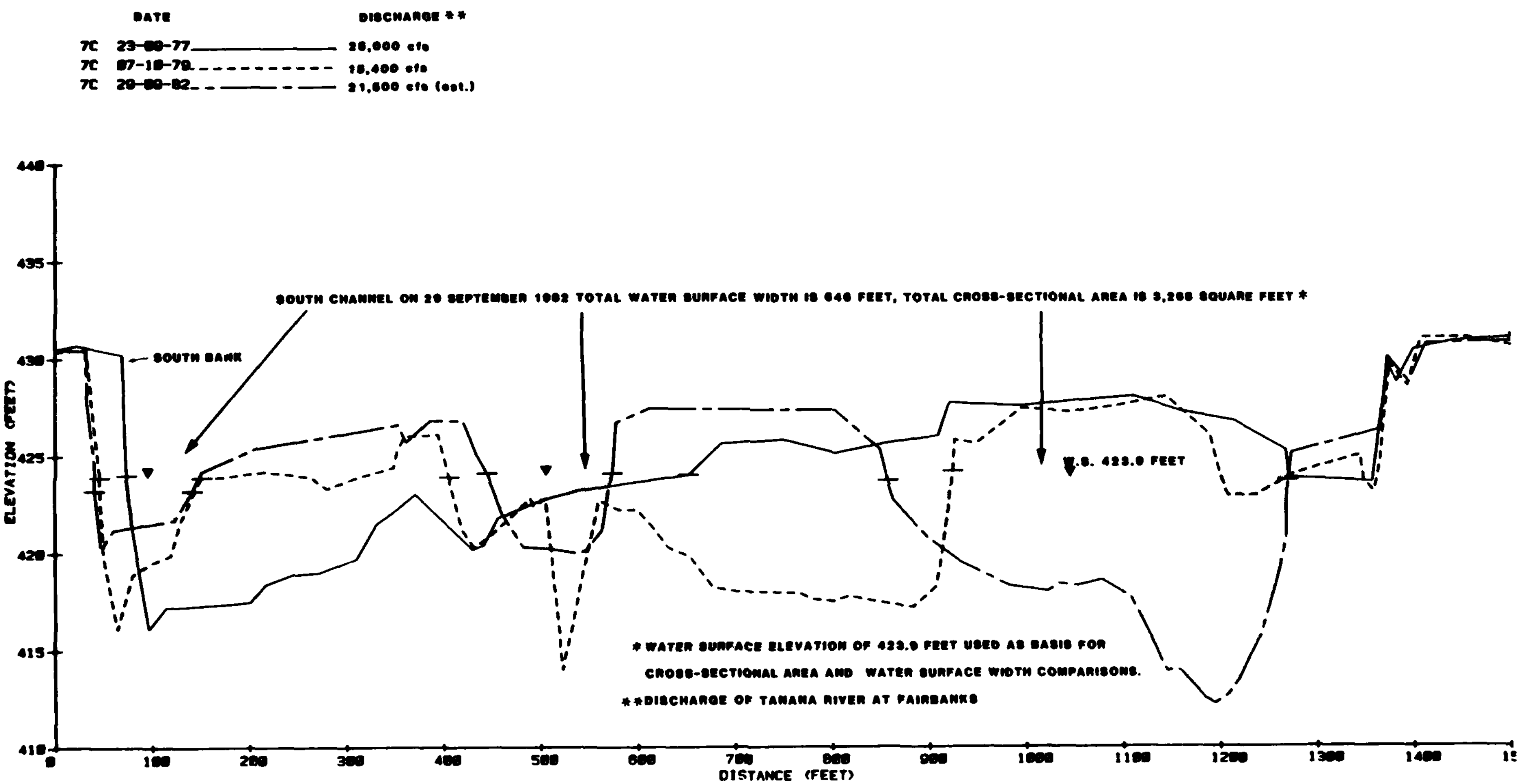

Figure 6.2. Comparison of cross-sectional changes in the south channel downstream of Goose Island, cross section 7C.

Table 6.2. Comparison of water surface width and cross-sectional area changes in the North and South channels (cross sections 7A and 7C), downstream of Goose Island.

		Date of Survey			Percent Change	Percent Change	Percent Change
		23 Sep 77	7 Oct 79	29 Sep 82	77-79	79-82	77-82
North Channel Cross-Section 7A	Area (Square Feet)	2,416	1,571	2,175	-35	+38	-10
	Surface Width (Feet)	688	558	441	-19	-26	-40
Total Channel Cross-Section 7C	Area (Square Feet)	1,866	2,851	3,268	+53	+17	+75
	Surface Width (Feet)	655	759	646	+16	-15	-1
Total Channel Cross-Section 7A and 7C	Area (Square Feet)	4,282	4,422	5,443	+3	+23	+27
	Surface Width (Feet)	1,343	1,317	1,087	-2	-18	-19
North Channel Cross-Section 7A	Percent Total Area	56	36	40			
South Channel Cross-Section 7C	Percent Total Area	44	64	60			

NOTE: A water surface elevation of 423.9 feet was used as a basis for area and water surface width comparisons (see Figures 6.1 and 6.2).

SOURCE: CRREL letter report to Alaska District, Corps of Engineers, dated 12 October 1982.

Table 6.3. Areal erosion and areal erosion rates near the Floodway sill groin.

	Pre-Construction Period 2 Jul 1970 to 31 Oct 1979 (8.67 effective erosion years)			Post-Construction Period 1 May 1979 to 20 Oct 1981 (2.94 effective erosion years			
	Erosion Acres	%	Erosion Rate Acres/yr	Erosion Acres	%	Erosion Rate Acres/yr	Percent change From Pre-Construction Rate
North Bank	28	29	3.2	0	0	0	-100
Islands North Channel	32	33	3.7	12	40	4.1	+11
Islands-South Channel	18	18	2.1	9	30	3.1	+48
South Bank	19	20	2.2	9	30	3.1	+41
Total	97	100	11.2	30	100	10.3	-8

* For details see Appendix C (River reach considered 3.5 miles).

Table 6.4. Comparison of water surface width and cross-sectional area changes at cross section 4A in the Phase III construction area.

Date of Survey	Cross-Sectional Area Under Water Surface* Square Feet	Percent Change In Area Between Surveys %	Water Surface Width* Feet	Percent Change In W.S. Width Between Surveys %
28 Oct 80	6,016		660	
		-66		-49
6 Mar 81	2,024		323	
		+125		+50
29 May 81	4,557		511	
		+25		+16
8 Oct 81	4,677		595	
		+13		+14
5 Oct 82	6,398		679	

* A water surface elevation of 420.6 feet was used as a basis for area and water surface width comparisons (see Figure 6.4).

SOURCES: Appendix A and Chacho, et al. 1982.

The distribution of erosion rates across the channel after construction (Table 6.3) shows complete protection of the north bank and increased erosion rates along the islands and the south bank. The total areal erosion rate apparently decreased 8% in the groin area over the time frame compared. As observed in the North Pole Groin area, the northern channel nearest the Floodway Sill Groin is migrating to the north at the downstream end of the groin, as the river attempts to reestablish its pre-construction length. Post-construction erosion rates south of the groin ranged from 3.1 to 4.1 acres per year (as measured over a shorter post-construction time frame than for the North Pole Groin).

The north bank downstream of the Floodway Sill Groin encroaches on the specified 500-ft silt blanket zone along the levee just west of the mouth of Piledriver Slough and along the small channel downstream of the slough, but the bank in these two areas has not receded since 1970. Elsewhere, the north bank is from 100 to 1,100 ft outside the silt blanket zone. Using the highest historical bank recession rate for the groin area, 70 linear ft per year, it would take at least from 1 to 16 years for the river to erode into the silt zone, depending on locality. The area downstream of the groin should be monitored over the next few years as the river adjusts to its presence.

6.6 Phase III Levee and Groins

The Phase III Construction portion of the Chena River Lakes Projects extended the levee to a point near the mouth of the Chena River just south of the Fairbanks International Airport (Figure 5.3). Four L-head groins (Groins 0 through 3) were placed to protect the levee and to divert the main channel of the Tanana River southward. A pilot channel was excavated to allow for construction of the levee and groin system and to initiate the formation of a new channel along the curved alignment. The four groins were designed to maintain an active channel width after construction of approximately 1,500 ft. The previous minimum natural width in the area was about 1,600 ft, but the actual minimum pre-construction width was about 1,370 ft, between the DOT Groin and the south bank. The bend length through the new pilot channel alignment is 4,000 ft compared to a pre-construction bend length of 7,300 ft. The pilot channel was 300 ft wide at the invert, with 2 to 1 side slopes. Material excavated from the pilot channel was placed in a spoil pile adjacent to its north bank; see Figure 5.3.

Appendix A contains a detailed analysis of pre- and post-construction areal and volumetric erosion for Bends A, B, and C in the Phase II area (Figure 5.3). Table 5.3 consolidates information from Appendix A on areal and volumetric erosion rates for the bends. From 1970 to 1980, prior to Phase III Construction, the areal erosion rate in Bend A was 298,000 ft^2 per year. Areal erosion rates in Bends B and C were only about 20% of this rate. Erosion rates in Bend A were fairly consistent during the period, but increased during the high discharge year of 1975 and again following construction of the eastern Goose Island Causeway in late 1975; whether there is a causative connection in the latter case is uncertain. As would be expected, the erosion rates decreased when riprap was placed prior to Phase III Construction, although 1979 was a high water year. Areal erosion rates in Bends B and C were highly variable during the period of 1970 to 1980, but when added together they were much more consistent.

The Phase III Construction completely cut off the large former meander in Bend A. Figure 6.3 shows the post-construction channel configuration and areal erosion of material between the north bank of the initial pilot channel and the faces of the groins. In order to take the differences of bank height and spoil pile volumes into account, Appendix A utilizes a volumetric analysis to compare amounts of material eroded from Bend A. The immediate post-construction volumetric erosion rate for the new Bend A (pilot channel) was 598,000 cubic yards per year between March and October 1981, 27% greater than the maximum pre-construction rate. Post-construction volumetric erosion rates for Bends B and C were 41,000 and 55,000 cubic yards per year respectively, or 34% and 10% less than pre-construction rates. Material eroding from Bend A appeared to be depositing in near the right bank of Bend B. Appendix A showed that a considerable amount of material remained to be eroded in Bend A before the channel would reach the face of the groins, and that the development of a bar at the mouth of the Chena River would have to be closely monitored. After reviewing information presented in Appendix A, it was decided that the remaining portion of the spoil pile to the north of the pilot channel would be removed from the active river channel during the winter of 1982-83.

Figures 6.4 and 6.5 show cross-sectional changes at section 4A, which crosses the pilot channel, spoils pile, levee and old river channel in the Phase III area. A numerical comparison of water surface width and cross-sectional area changes is given in Table 6.4. The northward erosion of the pilot channel and spoil pile is clearly evident. The pilot channel has eroded to a water surface width and cross-sectional area which is comparable to the natural pre-construction channel and to other single-channel sections of the river. The pilot channel width has doubled and the cross-sectional area has tripled since the diversion into the channel on 6 March 1981. By 1982, the northward lateral erosion had slowed to about 80 ft per year (Figure 6.4).

Figure 6.6 shows cross-sectional changes at section X4, just downstream of the Chena River confluence. Bar development at the mouth of the Chena River is clearly visible in the 15 September 1981 cross section, but is not seen in the 5 October 1982 section*. Changes at this cross section are summarized in Table 6.5 for the last survey of each open-water season since 1978. The north bank of this cross section has remained relatively stable, but increase in width is occurring by erosion of the south bank, which receded about 150 ft in the period 1978-80 and a further 50 ft since Phase III Construction. The cross-sectional area increased during the high discharge years of 1979 and 1982, and decreased during the relatively low years of 1980 and 1981. During the period immediately following Phase III Construction (20 October 1980 to 15 September 1981), the cross-sectional area decreased by 17%, due to deposition of the bar shown in the 15 October 1981 cross section. The bar was closely monitored during the 1982 open-water season. Table 6.6 shows data from surveys conducted during 1981 and 1982 at cross section X4, and gives the location of the bar high point (refer to Figure 6.6) and the minimum water

* Evidence of the nucleus of this bar can be seen in cross sections from 1979, pre-dating Phase III Construction: see Figure 6.6 for example.

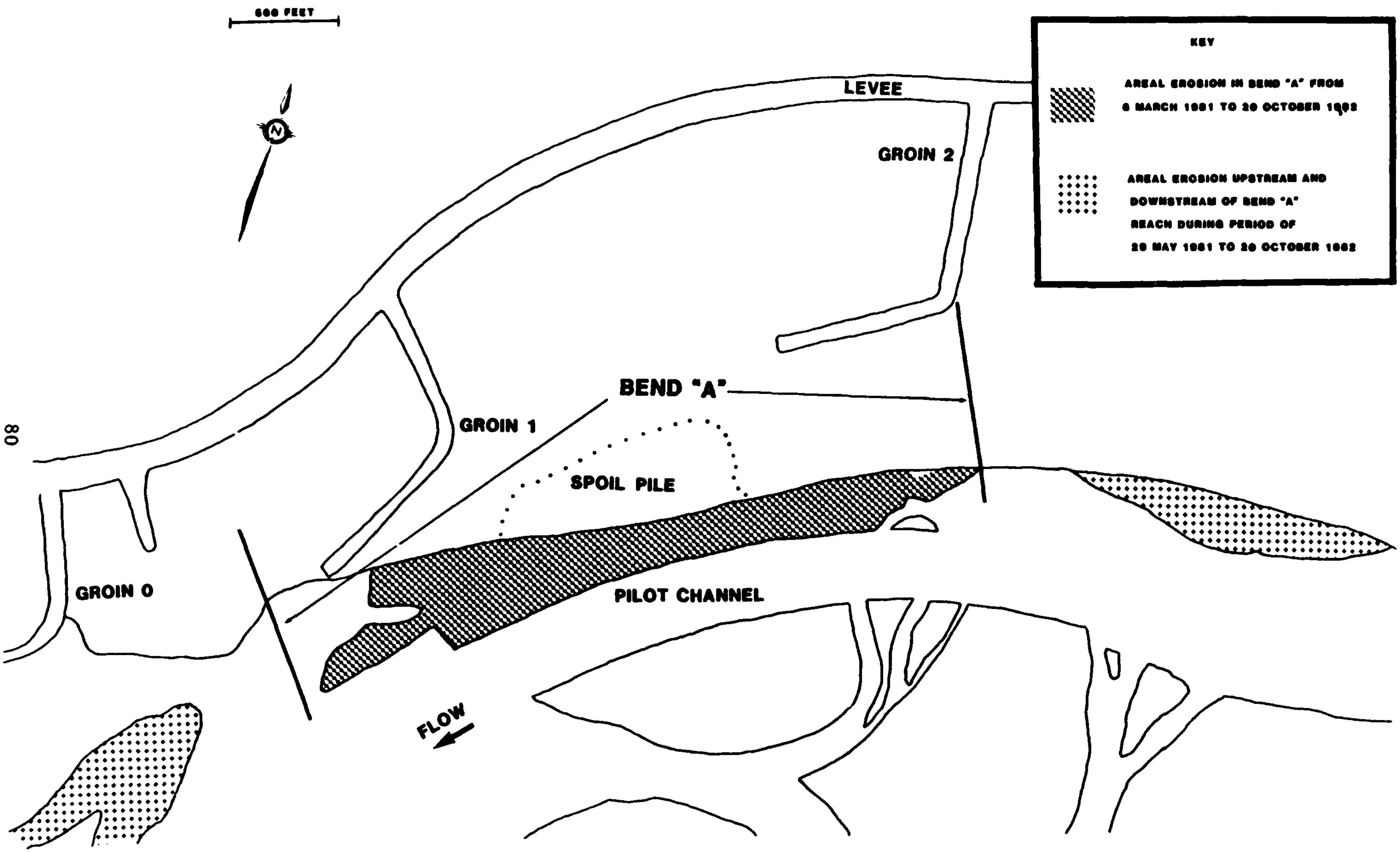

Figure 6.3. Bend A post-construction areal erosion.

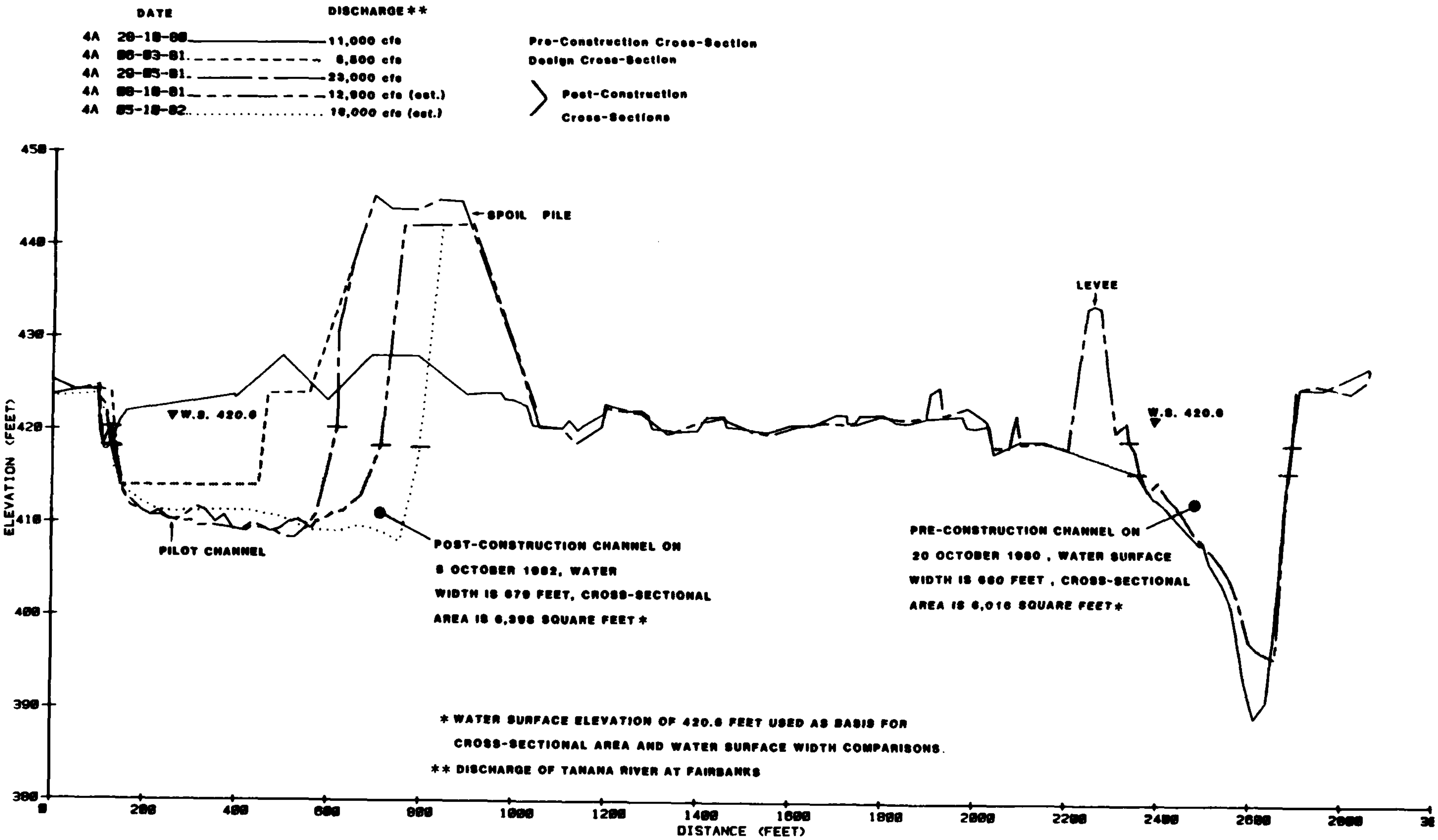

Figure 6.4. Comparison of cross-sectional changes at cross section 4A.

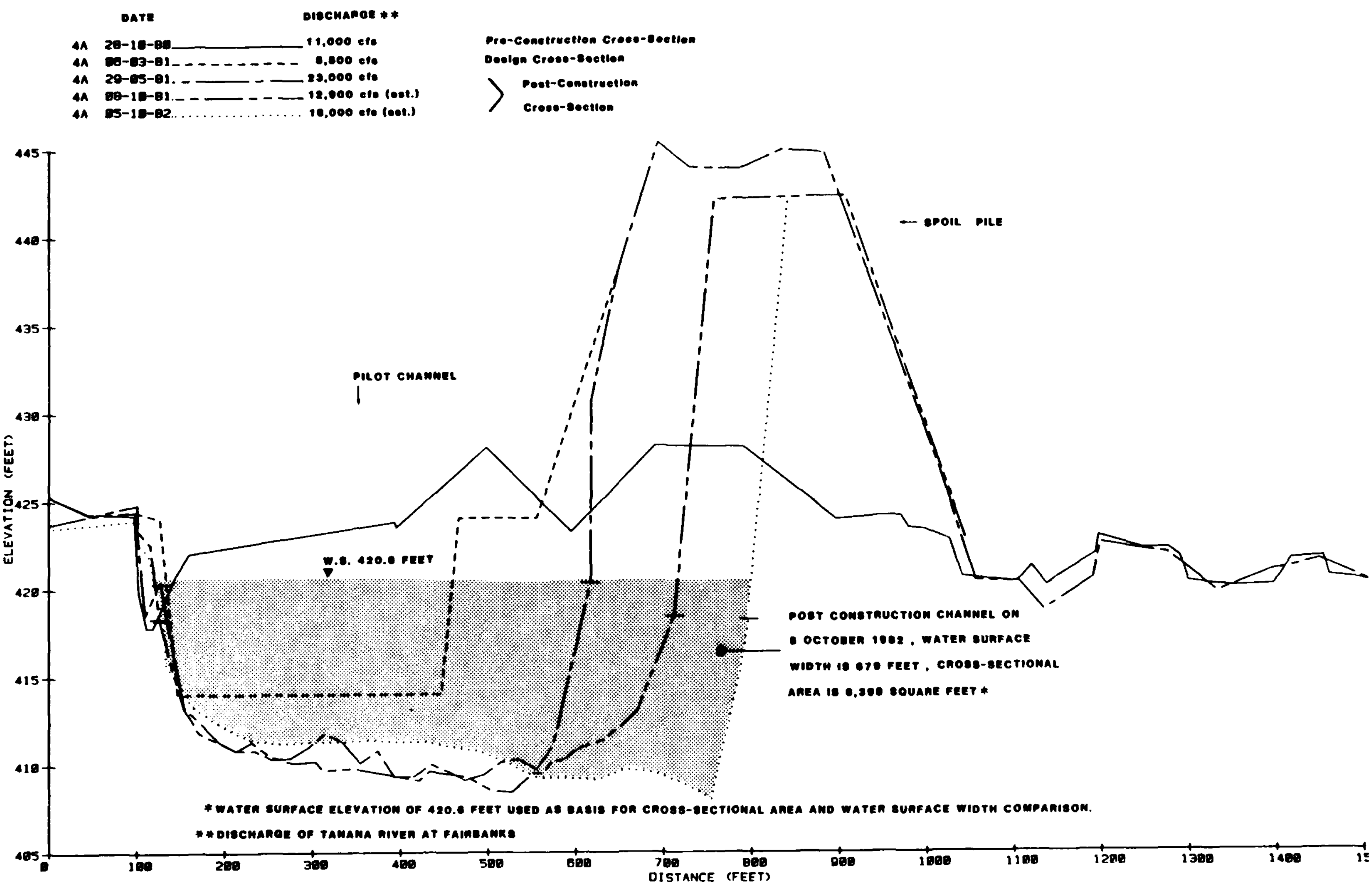

Figure 6.5. Detail of cross-sectional changes at Pilot Channel and spoil pile, cross section 4A.

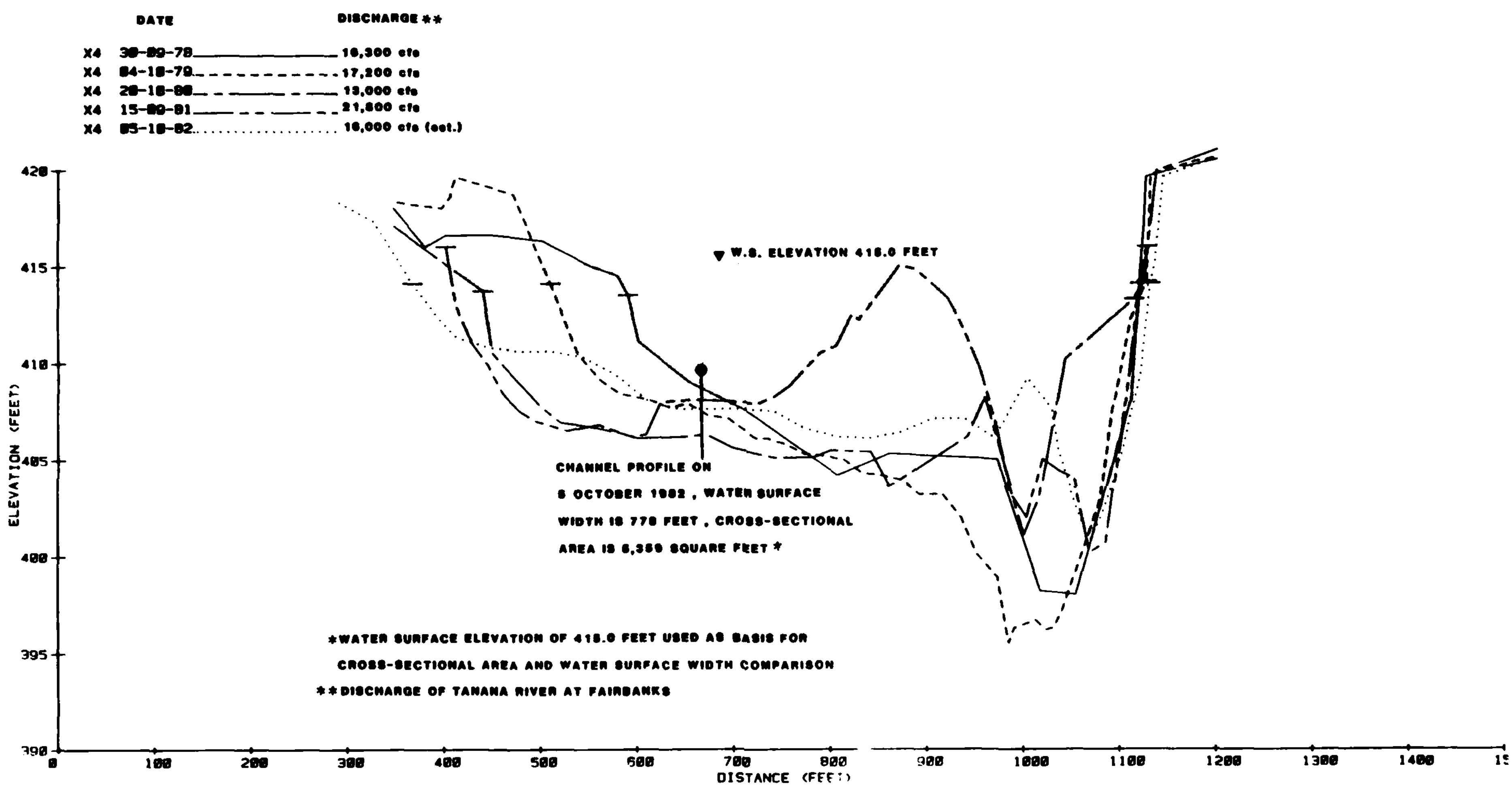

Figure 6.6. Comparison of cross-sectional changes at cross section X4, just downstream of the Chena River confluence.

Table 6.5. Comparison of water surface width and cross-sectional area changes at cross section X4 near the confluence of the Chena River.

Date of Survey	Cross-Sectional Area Under Water Surface* Square Feet	Percent Change In Area Between Surveys %	Water Surface Width* Feet	Percent Change In W.S. Width Between Surveys %
30 Sep 78	5,161		568	
		+21		+9
4 Oct 79	6,228		620	
		-9		+16
20 Oct 80	5,691		720	
		-17		0
15 Sep 81	4,737		721	
		+13		+8
5 Oct 82	5,359		778	

* A water surface elevation of 415.0 feet was used as a basis for area and water surface width comparisons (see Figure 6.6).

SOURCES: Appendix A and Chacho, et al. 1982.

Table 6.6. Compilation of data from surveys conducted during 1981 and 1982 at cross section X4 on the Tanana River just below the confluence of the Chena River.

Date of Survey	Bar Elevation (Feet)	Station Of Bar High Point (Feet)	Water Surface Elevation (Feet)	Depth Over Bar (Feet)
19 Aug 81	411.6	912	417.4	5.8
15 Sep 81	415.0	871	416.0	1.0
17 Mar 82	413.4	880	414.3	0.9
28 May 82	410.2	878	417.6	7.4
10 Jun 82	408.5	854	417.9	9.1
14 Jun 82	410.4	889	417.5	7.1
1 Jul 82	409.4	---	417.8	8.4
15 Jul 82	408.9	---	419.9	11.0
21 Jul 82	411.7	843	419.6	7.9
27 Jul 82	409.4	---	419.4	10.0
4 Aug 82	411.3	905	418.8	7.5
6 Aug 82	409.6	896	418.4	9.0
20 Aug 82	408.9	938	417.3	8.4
1 Sep 82	411.1	949	416.5	5.4
7 Sep 82	411.2	991	415.2	4.0
13 Sep 82	411.3	989	415.0	3.7
20 Sep 82	409.6	964	416.4	6.8
29 Sep 82	411.1	1017	414.9	3.8
5 Oct 82	409.2	1003	414.1	4.9

NOTE: The right bank station varies with water surface elevation between station 1140 and 1145 feet (see Figure 6.6).

SOURCE; Data from CRREL letter report to Alaska District, Corps of Engineers dated 19 October 1982.

depth over the bar. During 1982 the bar reduced in size, to an average height of about 3 ft over a 70-ft width, and moved northward about 130 ft. There appeared to be adequate freeboard for navigation at the time of the latest survey in October 1982. Cross section X6, just upstream of the Chena confluence, is being added to the monitoring program for 1983. Further photographic evidence of the growth of this bar following Phase III Construction is shown in Figures 6.7 and 6.8. At the time of writing it appears difficult to predict the future growth or decay of the bar upstream of the Chena mouth, especially considering the presence of the DOT Groin and associated gravel activities upstream. The DOT Groin is presently under attack by the river and its future is unclear.

6.7 Gravel Extraction

The most significant impact of gravel extraction with respect to the security of the levee has resulted from the method of gaining access to the extraction areas. The Goose Island Causeways and extensions caused severe constrictions of the active channel, which appear to have resulted in a short-term increase of erosion rates at distances of up to several miles downstream. Proposals for large-scale removal of gravel from islands, similar to that at Goose Island, should be assessed carefully with regard to their potential for uncontrolled channel changes, which are likely to result if dikes surrounding the extraction areas are left unprotected. Surface mining of point bars, similar to that done in Bend B during the period 1969 to 1976, may also have potential for internal channel changes detrimental to the security of the levee.

6.8 Summary

Key points in the foregoing review of river response to in-river construction and gravel extraction may be summarized as follows:

1. Blockages of secondary sloughs along the north bank of the Tanana River have resulted in local aggradation upstream of the blockages and may have accelerated main channel migration at points where the sloughs previously rejoined the river.
2. Structural constrictions of the active channel have caused local aggradation upstream of the constriction, increased downstream bank erosion, and scouring of the main channel in front of the constriction.
3. Pilot channels rapidly scour and erode laterally within the first year or two following diversion into the channel. Excess material from the construction of the pilot channel rapidly reenters the river system if spoiled in the immediate vicinity.
4. The method of obtaining access to gravel extraction sites and the way in which the gravel is removed could have an effect on the levee protection support. This point is discussed further in Part 7 following.
5. The Chena River has maintained a navigable opening into the Tanana River even though a bar has accumulated near the confluence. A close watch will be kept on bar development through 1983. In the Phase III Construction area upstream, the channel is approaching an equilibrium cross section. Downstream migration of the meander bend near the Chena mouth, causing

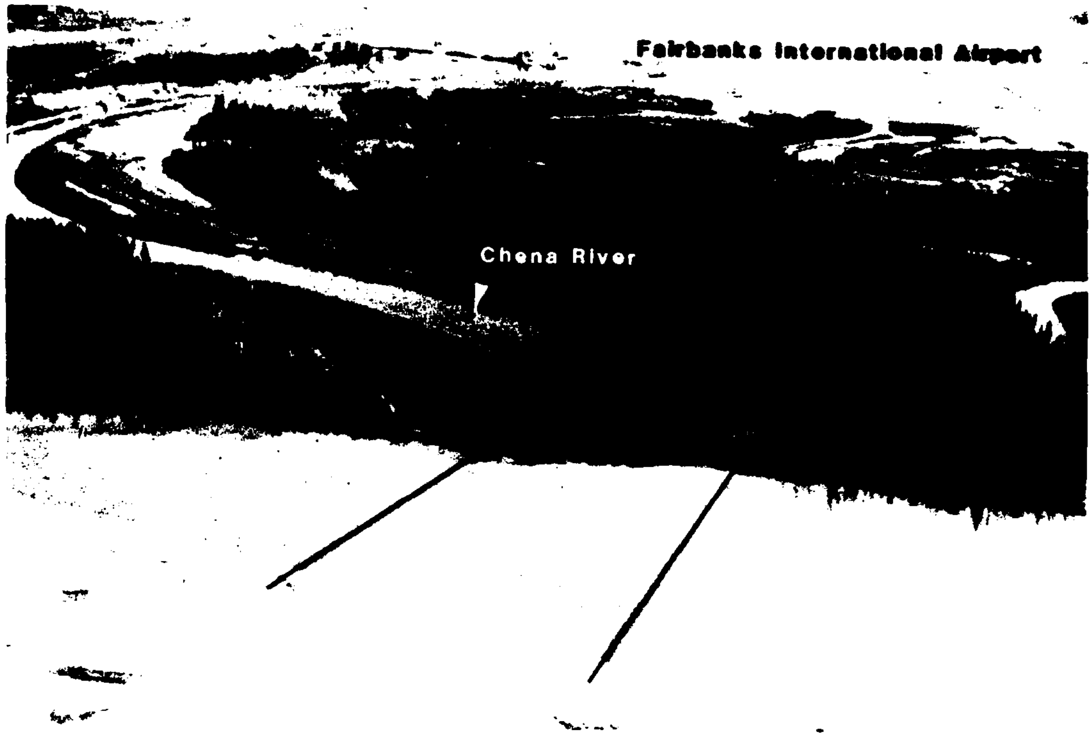

Figure 6.7. Chena-Tanana confluence on 9 May 1980.

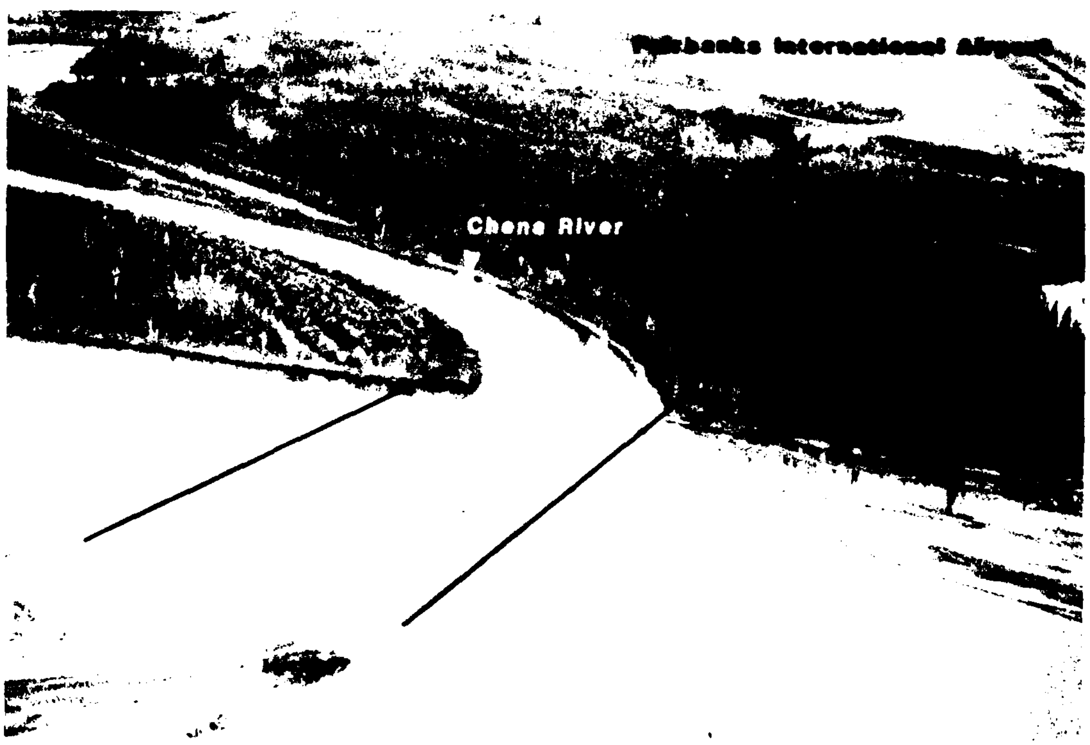

Figure 6.8. Chena-Tanana confluence on 6 October 1982.

erosion of the left bank upstream of Byers Island, may be expected to continue.

7. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary

Following is a brief summary of the principal points made in this overview report of the Tanana River Monitoring and Research Program, grouped according to the main parts of the report.

Physical setting and river history. Pre-historic build-up of a broad alluvial slope to the south of Fairbanks, derived from erosion products of the Alaska Range, has pushed the Tanana River to the north against the Yukon-Tanana Uplands. The river is mainly underlain by hundreds of feet of alluvial sediments. The river aggraded during two glacial periods and degraded after deglaciation, forming two terrace levels. There are some indications of slow aggradation over recent millennia.

In historic times the river has been affected by various forms of human activity, including stoppage of overflow to the Chena River by Moose Creek Dike (1945), the Fairbanks Flood Control Project including the Chena diversion floodway, levee and groins, and various gravel extraction activities with associated channel closures by causeways. Over the period 1969-81, 2 to 3 million cubic yards of gravel appear to have been removed from the channel, bars and islands of the river in the Fairbanks area, partly for construction of the flood control works.

Hydrology and hydraulics. The river's regime is characterized by relatively high flows from May through September and relatively low flows, mostly under ice, from October through April. Annual maxima normally occur in July or August, and minima in March. Over the record period of the Fairbanks gauge, 1973-82, year-to-year variations in flow pattern and volume have been relatively small. Relationships between discharge and water level at a given point on the river, however, are subject to substantial short-term changes due to channel shifting, erosion and deposition.

There is a remarkably close association between the gradient of the river, its planform, and its bed material. Upstream of Meridian Island, it is highly braided, with a multiplicity of channels, a gradient of about 0.1%, and a bed of mainly gravel. Downstream of Byers Island, it tends to a single or double winding channel, a gradient of about 0.03%, and a bed of mainly sand. The intervening 10-mile length exhibits a relatively abrupt transition in planform, gradient and bed-material composition.

The bed of the river is highly active under summer flow conditions, and many cross sections change substantially from month to month and from year to year. As flow rises in the river, the width of the occupied section increases rapidly. Because much of this width increase is in shallow areas, the average velocity of flow through the whole wetted section does not increase much. At specific locations where all of the flow is confined to a single channel, relationships between discharge, bed materials and cross-sectional dimensions are similar to those generally established for semi-stable alluvial rivers and canals. Some bed movement appears to take place under virtually all flow conditions.

Sediment. Bed material consists generally of a mixture of sand and gravel up to a maximum size of about 2 in., with almost no material in the coarse sand and fine gravel categories (0.5 to 5 mm approximately). Suspended sediment under summer high flow conditions consists mainly of silt, fine sand and clay, but in the spring and fall it consists mainly of sand and silt.

Consistent measurements of sediment quantities transported by the river are available for the period 1977-82. Average annual transport of material past Fairbanks as bed load amounts to about 360,000 tons or 260,000 cubic yards of sand and gravel. Average annual transport as suspended load amounts to about 28,000,000 tons of silt, clay and fine sand, nearly 80 times greater in tonnage than bed load, but much finer in grain size. It is the bed load that is mainly linked to the shifting of the river channels with associated deposition and erosion of bars, banks and islands.

Channel processes. Under the topic of channel processes, consideration is given to documented historical changes in river channel plan and location, in cross sections, and in volumes of material within given lengths and their relationship to quantities of sediment transported. Attention is confined mainly to changes that are apparently natural, or at least cannot be definitely ascribed to a specific artificial interference.

Changes in plan that can be documented from available mapping and photography take a wide variety of forms. Natural rates of river bank recession associated with channel migration appear to be typically about 20 ft per year, and local rates greater than 50 ft per year have been observed at certain points.

The nature of cross-sectional changes is highly dependent on the planform of the river at the section. Bend sections migrate outwards but generally retain their shape, whereas straight or cross-over sections are quite unstable. At certain sharp bends undergoing rapid migration, quantities of material eroded out of the bend length can more or less equal bed load transported into the bend, the incoming sediment being deposited on a growing point-bar and being replaced from outer bank erosion.

Response to In-River Construction and Gravel Extraction. Generally, response to in-river construction and gravel extraction follows quickly in the immediate vicinity and may have longer-term effects at considerable distances. Examination of repeated aerial photography and other information has enabled inferences to be drawn concerning the erosional and depositional effects of various historical interferences including Moose Creek Dike (1945), the DOT Groin and associated extractions (1970-76), the North Pole and Floodway Sill Groins (1975, 1979), the Goose Island Causeways and associated extractions (1977-81), and Phase III in-river levee and groin construction (1981).

Following Phase III Construction, the pilot channel south of the groins enlarged to more or less full river section within a period of about 18 months. Considerable quantities of bed material, including pilot channel excavation that had been piled on the north side of the pilot channel, were transported downstream and at least partly deposited in Bend B upstream of the Chena mouth. Substantial bar growth was recorded just below the Chena mouth in the fall of 1981, but by the fall of 1982 the depth of water at this location was more or less restored to pre-Phase III conditions.

7.2 Conclusions and Recommendations

It is useful at this point to reiterate the main objectives of the Monitoring and Research Program as stated in 1.2. These may be listed as follows:

- provide an understanding of the interaction between in-river construction and natural river processes;
- determine if adverse impacts are resulting from the levee and protective groin system and from permitted gravel extraction;
- if adverse impacts are resulting, make recommendations to lessen or alleviate them;
- provide data relating to timing, location and design of the deferred construction concept for levee protection.

Several conclusions and recommendations related to each of these objectives are given below:

Interaction between in-river construction and natural river processes. Natural river processes in this context include (i) growth, decay, abandonment and creation of individual channels within the braided or multi-channel system; (ii) downstream migration of meander bends in certain reaches; (iii) deposition and growth of bars and islands; (iv) erosion and removal of floodplain and island banks; (v) scour and fill at specific channel cross sections; (vi) transport of coarser sediment as bed load; (vii) transport of finer sediment as suspended load; and (viii) overall aggradation or degradation of the longitudinal profile. Some of these processes are mainly systematic in nature (for example, downstream migration of meader bends, and bed-load transport), but others are strongly influenced by specific flood events and flow sequences and by more or less random factors like blockages by debris and ice. Most of these processes are highly interrelated.

Given the complexity of this system, the highly active nature of many of the processes in the Tanana, and the shortage of long-term documentation, it is difficult in many cases to distinguish clearly the effects of in-river construction and other interferences from those resulting from natural processes. This is particularly true of effects that are far separated in time and distance from their sources. For example, it may be easy to identify the immediate local effects of a groin construction, but it is almost impossible to decide whether this construction was a partial cause of rapid bank erosion several miles downstream several years later.

What can be said with assurance is that any in-river construction, gravel extraction, etc. constitutes a disturbance of natural processes, and that subsequent developments, especially downstream, will differ, at least in the short term, from what would have occurred without the disturbance. Generally, the change will be most marked in the immediate vicinity in the period immediately following disturbance, but it is possible for effects to propagate downstream, and in certain cases upstream, for considerable distances over a period of years.

Impacts from levee and groin system. To date, the parts of the flood protection system that have impacted on the river are the North Pole and Floodway Sill Groins and the in-river construction of the Phase III levee and groin field near the International Airport. The North Pole and Floodway Sill Groins have both produced the desired effects of shifting the river locally to the south, with no apparent adverse effects of any significance.

The Phase III in-river levee and groin construction in early 1981 constituted a strong local disturbance of the river system, involving an abrupt cut-off, by pilot channel excavation, of a long meander bend in the main channel and the construction of the levee and three L-head groins across the former river bed. Local river slope was steepened abruptly and large quantities of bed material were put into transport from pilot channel enlargement and spoil pile erosion as the river occupied its new location in the summer of 1981. As of the end of 1982, the full or final effects of this disturbance were not clear. During the summer of 1981, development of a large bar accelerated near the right (north) side of the channel in Bend B just upstream of the Chena River mouth, its tail extending across the mouth of the Chena. But by the fall of 1982 it had diminished in height, at least at cross section X4 immediately downstream of the Chena mouth. The growth of this bar was probably accelerated by the excess quantities of material derived from pilot channel and spoil pile erosion, aided by redirection of flow. Another downstream process noticeable in 1981-82 was widening of cross section X4 by erosion of the bar on the left (south) side: this was probably a result of upstream bar deposition redistributing the flow approaching the section.

Impacts from gravel extraction and access causeways. In considering impacts from permitted gravel extraction, it is necessary to distinguish (i) gravel removal by bailing from the river itself; (ii) gravel extraction in the dry from more or less permanent bars and islands; and (iii) closure of channels by access causeways.

In considering the impact of bailing activities, the key information is the measured average river bed-load transport of approximately 360,000 tons per year, of which about 50% is gravel and 50% sand. A gravel extraction rate from a main river channel of up to about 180,000 tons per year will not exceed the incoming load, and the river immediately downstream will probably restore its normal bed load within a short distance. The detailed mechanics of how this is accomplished are complex. According to information compiled in Section 2.5 of this report, bailing activities have nowhere attained a rate of extraction comparable with available bed load.

It appears evident that continued long-term extraction of gravel at any point must result in a local reduction of bed levels, which by hydraulic adjustments tends to propagate upstream and downstream with respect to both bed and water levels. The effects of long-term extraction on the river slope profile are complicated by effects of lateral activity, so that the results of extraction from one or more points could be estimated only by a complex simulation procedure taking account of hydraulics, sediment transport, and bank erosion. Nevertheless, it appears likely that properly managed gravel extraction is beneficial from the standpoint of flood protection, because it must tend to reduce flood levels to a small degree.

The impact of gravel excavation from permanent bars or islands, as at Site 1 south of the International Airport or at Site 5 southwest of Goose Island (see Section 2.5, Figure 2.1 and Table 2.2), depends greatly on the previous history of the excavated area and on whether the river is allowed to occupy the excavated area after completion. If the material resulted from deposition in recent years and the area is made available for redeposition after excavation, then the material redeposited will be dropped from the river's bed load, and in some cases partly from its suspended load, and accelerated erosion will probably result downstream until normal loads are restored at some downstream point. Excavation of the large quantity of about 1,500,000 cubic yards at Site 1 in the period 1969-76 may have contributed to the rapid bank erosion immediately upstream in Bend A; however, a major upstream effect is considered unlikely. With regard to Site 5 southwest of Goose Island, reoccupation by the river in August 1981 is likely to have considerable effects on flow and erosional patterns for some distance downstream.

Blockage of the north channel at Goose Island by gravel extraction causeways in 1975 and later is believed to have had a major effect on channel patterns and bank erosion for several miles downstream. Closure of secondary channels upstream of the airport in 1969 is also believed to have had major effects.

Recommendations Regarding Alleviation of Impacts. The following recommendations are made regarding alleviation of perceived or potential impacts from future in-river construction and gravel extraction:

(i) Structural intrusions into the active channel of the river should be kept to a minimum consistent with needs for levee protection and access to gravel sites. Important channels of the river system should not be blocked off, unless reasons for doing so are compelling and full consideration is given to consequences.

(ii) Where pilot channel excavation is used to effect a shift of the river away from a construction area, spoiled material should be removed from the zone of immediate river erosion in order to reduce accumulation of deposits downstream.

(iii) Gravel extraction should continue to be permitted at a limited number of locations. Applications for gravel extraction should be reviewed by persons familiar with alluvial river processes in general and the Tanana River in particular, and quantities permitted should be decided in relation to bed-load transport, the possible impact of sudden occupation by the river of mined areas, and other hydraulic factors.

Recommendations Regarding Deferred Construction, Monitoring and Analysis.

(iv) In planning further levee protection groins under the deferred construction program, consideration should be given to closer spacing of short groins vs. a wider spacing of long groins. In evaluating the need for groins at specific locations, consideration should be given to the erosional impact of a single major flood.

(v) Further interpretive analysis of sediment transport data should consider the long-term sediment balance of the system in relation to the river geomorphology and longitudinal profile, and the effects of continued gravel extraction on bed and water surface profiles.

(vi) Water level data collected at the T-sites over a decade or more should be analyzed closely for possible evidence of river aggradation, which if indicated might have implications with regard to flood protection criteria and related matters.

(vii) In that the body of data accumulated on the Tanana River is a unique source of information on braided gravel rivers, every effort should be made to disseminate it among the scientific community, to promote understanding of braided river processes and to improve methods of predicting river behavior and response to disturbances.

(viii) Aerial photo coverage as done during the Tanana River Monitoring and Research Program should be maintained as a minimal future monitoring effort. A more desirable future monitoring effort would include approximately 12 river cross sections, throughout the 20-mile reach of river south of the levee, taken once a year during a high discharge period, and water surface elevations taken at the T-sites twice a year, during high and low discharge periods. The future monitoring efforts should be set up on a five-year basis, then reviewed for continuation for another five years. Continuity and reliability of the data collection efforts is best provided for by having those personnel who will interpret the data be responsible for their collection.

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GLOSSARY

Aggradation: continued rise in river bed and water levels over a long period of years due to net accumulation of sediments by geologic or man-made processes.

Anastomosing: A river channel pattern characterized by a single main channel with one or more secondary channels or 'sloughs' branching from and rejoining the main channel.

Bankfull: Condition of flow when a river is on the point of overflooding over a substantial length.

Bed-forms: Topographic features on a river bed, such as ripples, dunes and bars.

Bed load: Sediment transported by rolling or sliding along the river bed under the action of hydraulic traction or shear.

Bed-material transport: Total transport of sediment in sizes found on the bed, both as bed load and as suspended load.

Bimodal (grain-size distribution): Characterized by peaks in two separate size classes, with a deficiency in intermediate sizes.

Braided: A river channel pattern consisting of a considerable number of interlacing channels separated by more or less transient bars.

Coefficient of variation (statistics): Standard deviation divided by mean.

Flood frequency curve: Cumulative distribution curve of annual maximum discharges.

Gauging station: Point on a river at which water levels are recorded and discharges measured or calculated.

Groin: River training or bank protection structure aligned more or less obliquely to the river course.

Hydrograph: Graph showing river flow (discharge) plotted versus time.

Levee: Flood protection dike aligned more or less parallel to the river course.

Mean velocity: Discharge divided by cross-sectional area of flow.

Pilot channel: Relatively small channel excavated to direct a river into a new course and designed to be enlarged by river erosion.

Revetment: Continuous erosion protection along and parallel to a river bank.

Saltating load: Sediment traveling near the bed by an alternation of jumps and rests.

Silt blanket: Area of ground in front of a dike or dam, covered naturally or artificially with material of low permeability to control seepage flow beneath the structure.

Spoil pile: Deposit of surplus material from an excavation.

Stage: Water level referred to a specified datum.

Suspended load: Sediment transported within the flow, sustained by the action of turbulence.

Thalweg: Trace of the deepest points along the course of a river channel.

APPENDIX A

THE EFFECTS OF PHASE III CONSTRUCTION OF THE CHENA FLOOD CONTROL PROJECT ON THE TANANA RIVER NEAR FAIRBANKS, ALASKA—A PRELIMINARY ANALYSIS

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ABSTRACT

The Alaska District, Corps of Engineers initiated a program called the Tanana River Monitoring and Research Program to determine if any adverse impacts are occurring or may occur as a result of Phase III construction of the Chena Flood Control Project. The results of the monitoring efforts and a preliminary analysis of the effects of the Phase III construction are presented in this report.

Aerial photograhy and river cross-sections were used to document historical changes from 1961 to 1981. Riverbank erosion and channel changes before and after the Phase III construction are evaluated to determine the effects of the construction on the natural river process.

The Tanana River was diverted into a pilot channel on 6 March 1981, as part of the Phase III construction. Post-construction erosion magnitudes and rates in the pilot channel are representative of the river trying to re-establish a natural cross-section in the area. Riverbank erosion magnitudes and rates downstream of the Phase III construction area are within the year to year variability measured prior to construction.

PREFACE

This report was prepared by James S. Buska, Steven A. Barrett, Edward F. Chacho, Charles M. Collins and Steven A. Young of the U.S. Army Cold Regions Research and Engineering Laboratory. Funding for this report was provided by the Alaska District, Corps of Engineers.

This report was reviewed at a meeting of the Tanana River Monitoring and Research Program participants in April 1982. Subsequent to the April review comments and suggestions from the following reviewers were particularly helpful in the preparation of this version of the report: Charles R. Neill, Northwest Hydraulic Consultants, Ltd., George Ashton and Larry Gatto, Cold Regions Research and Engineering Laboratory.

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INTRODUCTION

This report is a preliminary analysis of the effects of Phase III construction, of the Chena Flood Control Project, on the Tanana River near Fairbanks, Alaska. The analysis is being done as part of the Tanana River Monitoring and Research Program to determine if any adverse impacts are occurring or may occur due to the Corps' construction of the levee and protective groin system of the Chena Flood Control Project.

BACKGROUND

The Tanana River levee and protective groin system, as part of the Chena Flood Control Project, is designed to protect the city of Fairbanks, Alaska against flooding from the Tanana River. The Phase III construction portion of the project extended the levee to a point near the mouth of the Chena River just south of the Fairbanks International Airport (Fig. 1). Four L-head groins (Fig. 1) were placed to protect the levee and to direct the main channel of the Tanana River southward. A pilot channel was excavated (Fig. 1) to allow for the construction of the levee and groin system and to encourage the formation of a new channel along the curved alignment.

The Phase III portion of the Chena Flood Control Project was constructed during the period of January to June 1981 with the Tanana River diverted into the pilot channel on 6 March 1981. River events prior to 6 March are considered pre-construction and events after 6 March are post-construction.

A summary hydrograph and exceedance frequency curves based on the period-of-record of 1973 to 1980 for the Tanana River at Fairbanks are shown in Figure 2.

AREAL EROSION AND LATERAL CHANNEL CHANGES

Study Area

The overall area of interest (Fig. 1) was studied for changes in riverbank, sandbar and channel locations, while only riverbank erosion on the outside of the Bends A, B and C was measured. Figures 3 and 4 show the overall sutdy area prior to the Phase III construction on 12 May 1970 and 7 May 1980, respectively. Figures 5 and 6 show the area after the Phase III construction on 29 May 1981 and 20 October 1981, respectively. Figures 7 through 9 are oblique views, looking upstream, of the Phase III construction area on 20 June 1980, 23 June 1981 and 6 August 1981 respectively.

Aerial Photographic Data

Riverbank, bar and channel changes were measured using historical aerial photography. The dates of the photography and the corresponding river discharges are shown in Table 1. Earlier sets of aerial photography were available but were not used in these studies due to lack of adequate coverage or high river discharges. Pre-construction data consists of 11 sets of aerial photography. Post-construction data consists of 2 sets of aerial photography.

Figure 10 shows the dates of the aerial photo data acquisition with respect to the daily mean discharge of the Tanana River for the years 1973 to 1981.

Methods

The 7 May 1980 aerial photography was selected as a photo mapping base, to which all other aerial photography was compared. The overall area of interest (Fig. 1) was shown on frame 16-3. This frame was photographically enlarged to a scale approximately 1:4700 (1 inch = 392 feet) for use as the photo mapping base.

A horizontal stage zoom transfer scope was used to transfer main channel banklines, important subsidiary channels and sloughs, islands and large bars, and pertinent cultural features from the historical photography to a sheet of mylar overlaying the photo base. The accuracy of the transfers is approximately ± 30 ft. The mylar overlays were registered to the photo base during the analysis and the overlays and base recombined photographically for presentation.

Three composites (Fig. 11 through 13) of the overall area of interest were prepared for the periods shown below.

Time Period	Years Between Dates	Figure
1 May 1961 to 12 May 1970	9.03	11
12 May 1970 to 7 May 1980	9.99	12
29 May 1981 to 20 October 1981	0.39	13

Figures 11 and 12 show pre-construction riverbank erosion and channel migration over 9 and 10 year periods respectively. Figure 13 shows post-construction riverbank erosion and channel changes over a 0.39 year period. The cross-hatching on the figures denotes wetted surface areas corresponding to the dates of the aerial photography compared in each figure. Double cross-hatching indicates that wetted water surface areas are shown on both sets of aerial photography. Areas within the earlier riverbanks that have no cross-hatching are bars and islands that apparently have not changed. Single cross-hatching is an indicator of planimetric change.

Erosion is indicated by the single cross-hatching of the latest wetted water surface area in Figures 11 through 13. Erosion of the earlier riverbank is indicated whenever the single cross-hatching of the latest wetted water surface area extends beyond the riverbank. In-channel erosion is indicated if the single cross-hatching of the latest wetted water surface area lies within the earlier riverbanks. Eroded areas in the later case may be exaggerated if the river discharge was higher in the latest set of aerial photography used to map the wetted water surface area.

Deposition is indicated by the single cross-hatching of the earlier wetted water surface area in Figures 11 through 13. Depositional areas are likely to be exaggerated if the river discharge is lower in the latest set of aerial photography and under defined if the discharge is higher.

Composites of the bankline positions along Bends A, B and C (Fig. 13 through 15) were assembled from the mylars drawn from the aerial photography. The area between the banklines shows the areal extent of land surface eroded along the outside of a bend during a given time interval. The areas were measured using a digitizer and the time intervals considered are shown on the figures.

Time period 1 was divided into two time periods, 1a and 1b, for Bends A and C. Time period 8 was divided into a pre-construction (8a) and post-construction (8b) time period for Bend A.

The effective erosion season on the Tanana River is normally about 6 months per year (May through October, Fig. 2 and 10). Riverbank erosion during the rest of the year is assumed to be negligible. Effective periods between aerial photography dates and rates of erosion are derived on the basis of an effective erosion season of May through October (183 days). Figure 10 shows the dates of aerial photography and the actual time interval between the dates. The effective erosion season is indicated by the shaded areas under the discharge curve. Figure 10 and Table 2 give the effective days and years in each time period. The effective years are calculated by dividing the number of effective days by 183 days per erosion year.

Areal erosion rates are given as a function of erosion per effective year. The rates given in Table 2 are valid over the time periods considered (i.e., 270,000 ft^2/yr for time period 1a, acting on Bend A for 3.25 effective years).

Results

Figures 11 and 12 show a history of pre-construction erosion on the outside of Bends A, B and C. Considerable channel migration occurred in Bend A during the period of 12 May 1970 to 7 May 1980. Figure 13 shows a small amount of riverbank erosion on the outside of the bends during the post-construction period. Figure 13 also indicates a widening to the north of the pilot channel in Bend A, deposition of the mid-channel area of Bend B and deposition near the mouth of the Chena River. The deposition areas are likely to be over exaggerated due to the lower river discharge of the later aerial photo set. The depositional changes can also be seen by comparing Figures 5 and 6.

Banklines for Bend A are shown in Figure 14 over the reach shown in Figures 12 and 13. The numbers between the banklines indicate time periods as referenced in Table 2 and on the figures. Historic riverbank erosion in

Bend A is 4 to 5 times greater than that for Bends B and C (Table 2). Prior to Phase III construction, the maximum rate of areal erosion was 423,000 ft^2/yr during period 2. The minimum rate of 38,000 ft^2/yr occurred during period 8a. A riprap revetment was placed in Bend A, as shown in Figure 4, during 13 July to 31 August 1979 which contributed to the lower erosion rates during periods 7 and 8a. The long-term pre-construction areal erosion rate over the 9.98 effective year period, of 12 May 1970 to 7 May 1980, is 298,000 ft^2/yr.

The 6 March 1981, post-construction bankline for Bend A was derived from the design drawings for the Phase III construction and the 8 September 1980 banklines. The first post-construction time period, 8b, began on 6 March 1981 and ended on 29 May 1981, the date of the next set of aerial photography. Figures 17 and 18 are oblique views, looking downstream of the pilot channel and spoils pile in the Phase III construction area on 1 May 1981 and 6 June 1981, respectively. During the excavation of the pilot channel 300,000 yd^3 of material was spoiled to the north of the pilot channel as shown in Figure 14.

Forty percent of the 748,000 ft^2 of areal erosion measured during the post-construction period of 8b and 9 occurred during period 8b at a rate of 1,993,000 ft^2/yr. The remaining 449,000 ft^2 eroded during period 9 at a rate of 568,000 ft^2/yr. The post-construction areal erosion rate for Bend A, 796,000 ft^2/yr during the period 8b and 9 is 2.7 times the long-term pre-construction rate and 1.9 times the maximum pre-construction rate.

The value given in Table 2 for the areal erosion at Bend A during period 9, does not include the shaded areas at the upstream and downstream ends of the pilot channel (Fig. 14). These areas were eroded during period 9 and could be considered as part of a redefined Bend A which would increase the erosion magnitude and rates during period 9. The erosion of the upstream area could have been due to a major channel change in the Goose Island area upstream of the Phase III construction.

Banklines for Bend B are shown in Figure 15. The maximum pre-construction rate of areal erosion, 105,000 ft^2/yr (Table 2), occurred during period 1. The minimum rate of 16,000 ft^2/yr occurred during period 4. The long-term pre-construction areal erosion rate (period 1 through 7) is 67,000 ft^2/yr.

Post-construction areal erosion rates for periods 8 and 9 in Bend B are within the range of variability previously measured for the bend. The post-construction areal erosion rate for Bend B of 45,000 ft^2/yr, during period 8 and 9, is 0.7 times the long-term pre-construction rate and 0.4 times the maximum pre-construction rate.

Banklines for Bend C are shown in Figure 16. The maximum pre-construction rate of areal erosion, 279,000 ft^2/yr (Table 2), occurred during period 3. The minimum rate of 15,000 ft^2/yr occurred during time period 1a. The long-term pre-construction areal erosion rate (period 1 through 7) is 57,000 ft^2/yr.

Post-construction areal erosion rates for periods 8 and 9 in Bend C are also within the range of variability previously measured for the bend. The post-construction areal erosion rate for Bend C of 51,000 ft^2/yr, during period 8 and 9, is 0.9 times the long-term pre-construction rate and 0.2 times maximum pre-construction rate.

Long-term erosion rates in Bend B and C are approximately 20 percent of the rate for Bend A. The variation of the areal erosion rates, for periods 1 to 7, from the long-term rate (period 1 through 7) is much less in Bend A than in Bends B and C.

RIVER CROSS-SECTION CHANGES

Cross-Section Data

Historical data (1977-1981) from fourteen river cross-sections shown on Figure 5 and 11 through 13 were reviewed for this report: 5A, 5B, 4A, 4B, 3A, N1, N2, 2A, 2B, X5, X4, X3A, X3B and X2 (X2 is downstream of Figure 5 coverage). The remaining cross-sections in Figure 5, 6A and GSX1 are sediment sampling sites maintained by the U.S. Geological Survey. The cross-sections were obtained by the Alaska District, Corps of Engineers, U.S. Geological Survey and CRREL.

Methods and Results

Historical data for each cross-section were plotted for comparative analysis (Fig. 19 through 32). Observations and measurements of bank erosion, thalweg migration and channel development are listed in Table 3 along with a general summary of significant changes measured at each cross-section.

VOLUMETRIC EROSION

Methods

Average thalweg depth near the eroding bends were calculated from the river cross-section data for Bends A, B and C. The values obtained were 30 ft (time periods 1 through 8a) and 16.5 ft (time periods 8b and 9) for Bend

A, 25 ft (time periods 1 through 9) for Bend B and 29 ft (time periods 1 through 9) for Bend C. The values obtained above were multiplied times the total areal erosion values in Table 2 to estimate total volumetric erosion at each bend for the time periods studied. Aerial photography intervals, effective time periods, estimated volumetric erosion and volumetric erosion rates are given in Table 4 for Bends A, B and C. The volumetric erosion analysis also took into account the erosion volumes of the spoils pile shown in Figures 17 and 18 north of the pilot channel. River cross-section, 4A, the Phase III design drawings, and the post-construction aerial photography for Bend A were used to estimate the spoils pile erosion volumes given in Table 4.

Results

The discussion of the volumetric erosion history of the bends will parallel the areal erosion discussion because of the constant depth multipliers used for each bend. Additional comparisons can be made of pre and post-construction changes in Bend A and in the differences between bends.

Post-construction volumetric erosion values for Bend A given in Table 4 include the following spoils pile erosion volumes: 15,000 yd^3 during time period 8b, 90,000 yd^3 during time period 9, and 105,000 yd^3 during time period 8b and 9. Thirty-five percent of the 300,000 yd^3 contained in the spoils pile had eroded by 20 October 1981.

Thirty-five percent of the total estimated 562,000 yd^3 of volumetric erosion occurred during period 8b at a rate of 1,320,000 yd^3/yr. The remaining 364,000 yd^3 eroded during period 9 at a rate of 461,000 yd^3/yr. The post-construction volumetric erosion rate of 598,000 yd^3/yr during period 8b and 9 is 1.8 times the long-term pre-construction volumetric erosion rate for Bend A. A rough estimate of the volume of material between the right bank of the pilot channel and the face of Groins 1 and 2 is 887,000 yd^3 (including the reamining portion of the spoils pile). The post-construction volumetric erosion rates in Bend A could be expected to gradually decrease to a value near the long-term pre-construction rate as the river re-establishes a natural cross-sectional area in the Bend A. Assuming the pilot channel was to simply erode to the north through the spoils pile until it was up against Groins 1 and 2, it would take 2 to 3 years to get to that point.

The long-term pre-construction volumetric erosion rates (period 1 through 7, Table 4) for Bend B and C are within the pre-construction variability previously estimated for the bends. Post-construction rates for Bends B and C (period 8 and 9) are 34 and 10 percent less than the long-term pre-construction averge, respectively.

RELATED STUDY

Bend A was studied in a attempt to determine if the distribution of bank sediments, permafrost and vegetation are related to the locations of bankline recession. The preliminary analysis found inconclusive relationships.

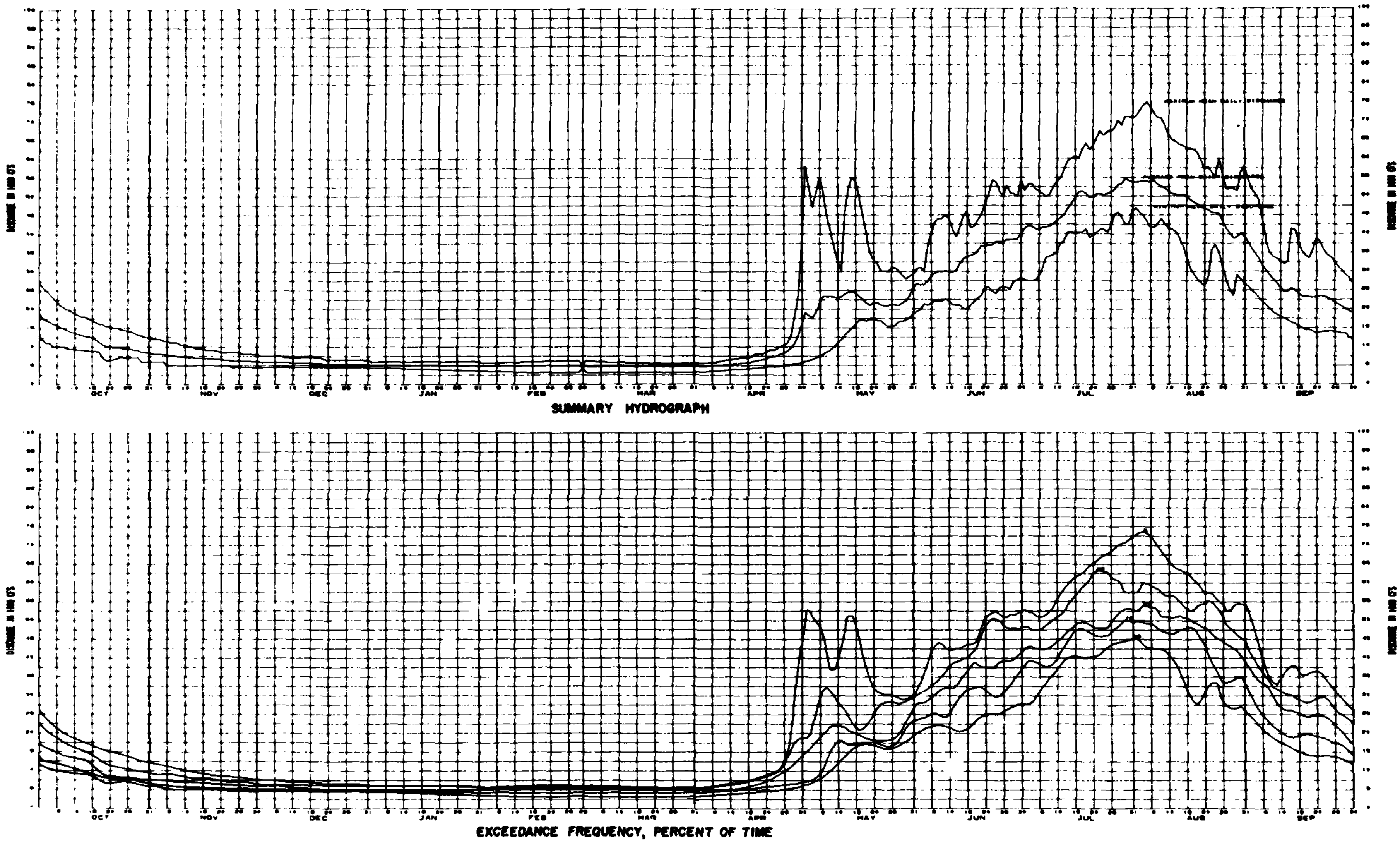
SUMMARY

Approximately 1,473,000 yd^3 of material lay between the north bank of the pilot channel and the face of Groins 1 and 2 after construction of the levee, groins and pilot channel. An estimated 38 percent of that material eroded into the river system during the period of 6 March to 20 October 1981. The lateral erosion in Bend A is clearly visible in Figures 13 and 14. Post-construction erosion magnitudes and rates (Tables 2 and 4) are representative of the river trying to re-establish a natural cross-sectional area in the bend, not totally provided for by the pilot channel. Material eroding from Bend A appears to be depositing in Bend B as shown in Figures 13 and 24 through 26. The trend of erosion in Bend A and deposition in Bend B will likely continue until Bend A establishes a natural cross-section.

There is no indication of a cut off occurring south of Byers Island, Wenrich Island or south of the pilot channel (Fig. 13, 20, 22, 27 and 31). There is a trend towards channel enlargement of the right (north) side channel in Bend B (Fig. 24 through 26). Riverbank erosion at Bend B and C have not increased and are within the normal variability previously measured at the bends.

The formation of the bar at the mouth of the Chena River may be a potential navigation problem if the Chena River flow is unable to maintain a navigable opening into the Tanana River. There is an indication that recent scour of the bar and navigation channel (not included in Fig. 29) may alleviate any potential problems. The development of the bar at the mouth of the Chena River will be closely monitored.

There do not appear to be any adverse effects occuring as a result of the Phase III construction of the Chena Flood Project, as this time.



TANANA RIVER AT FAIRBANKS

Figure 2. Summary hydrograph and exceedance frequency curves.

Figure 3. Study area on 12 May 1970.

Figure 4. Study area on 7 May 1980.

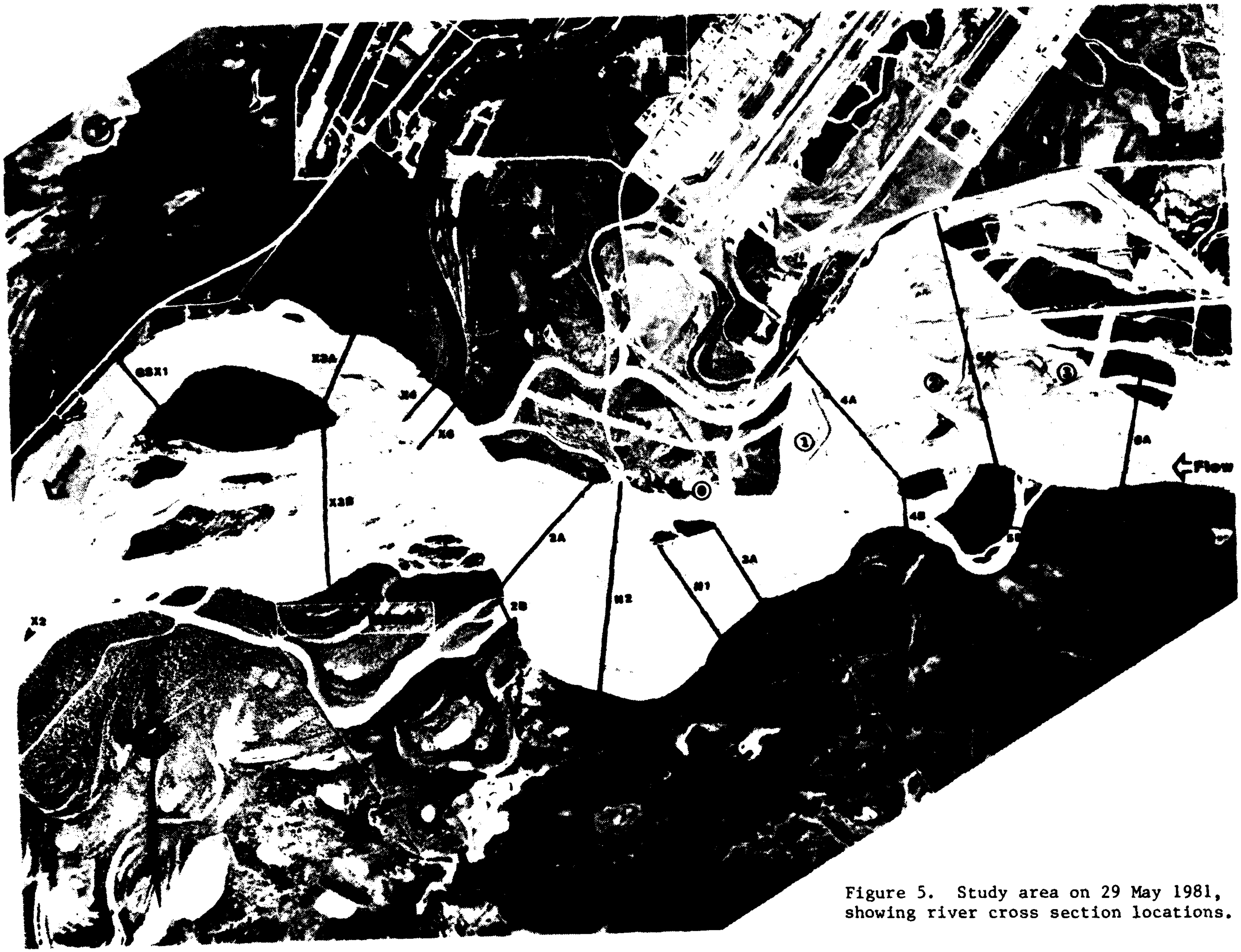


Figure 5. Study area on 29 May 1981, showing river cross section locations.

Figure 6. Study area on 20 October 1981.

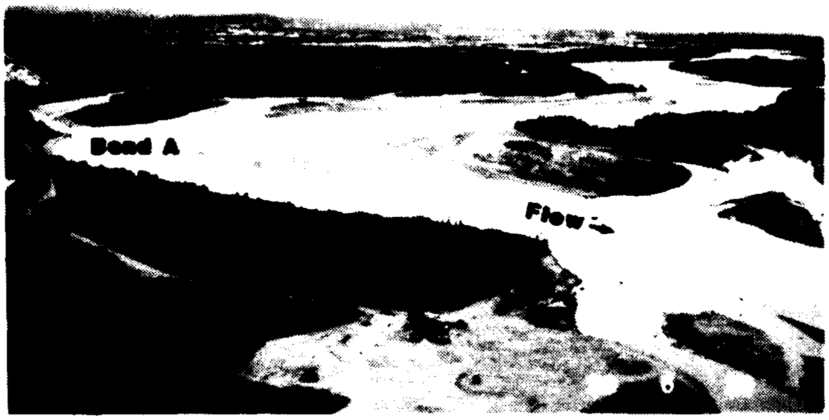
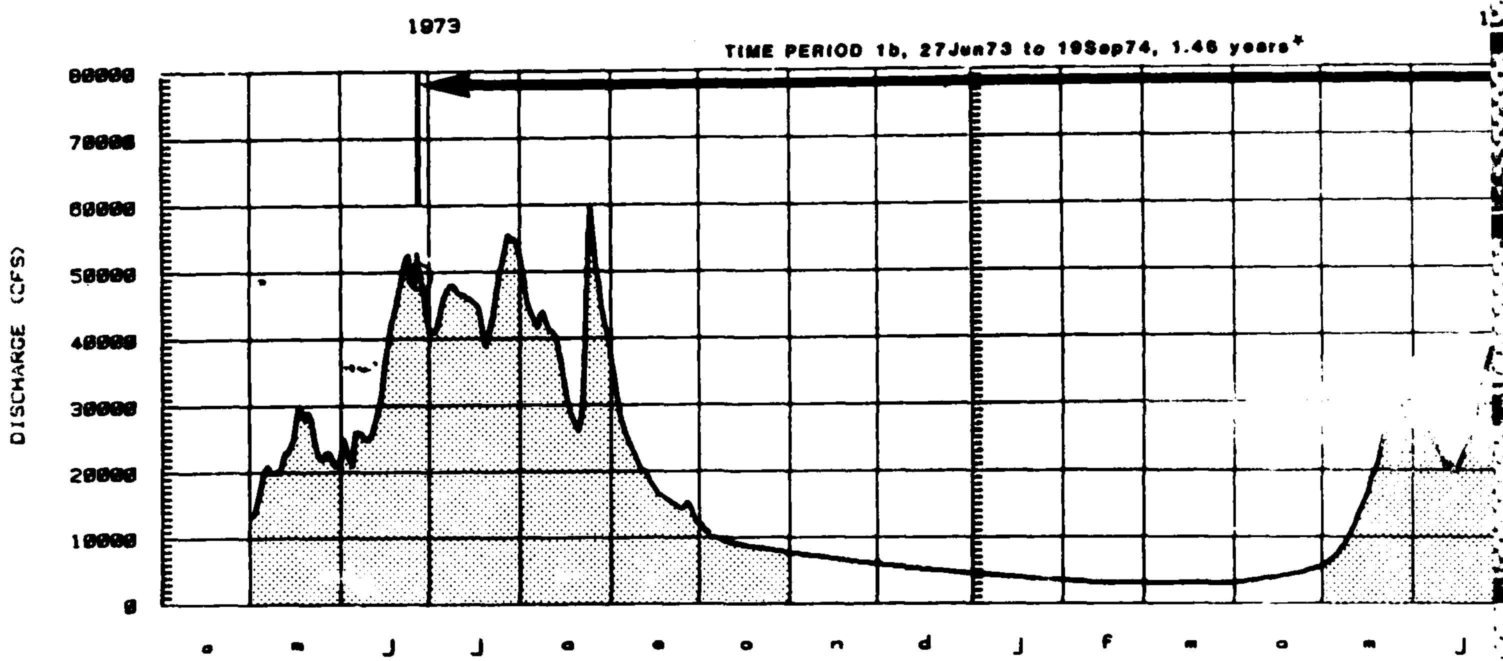
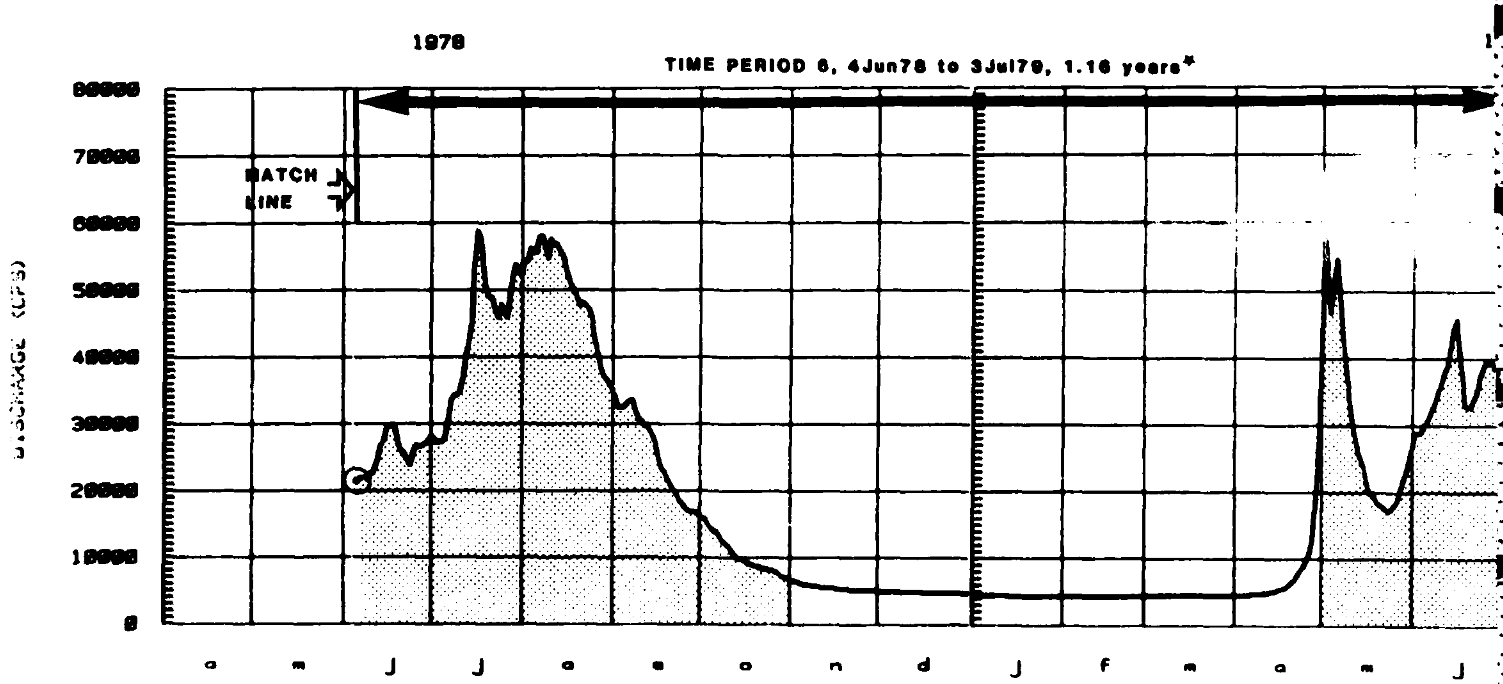


Figure 7. Phase III construction area on 20 June 1980.

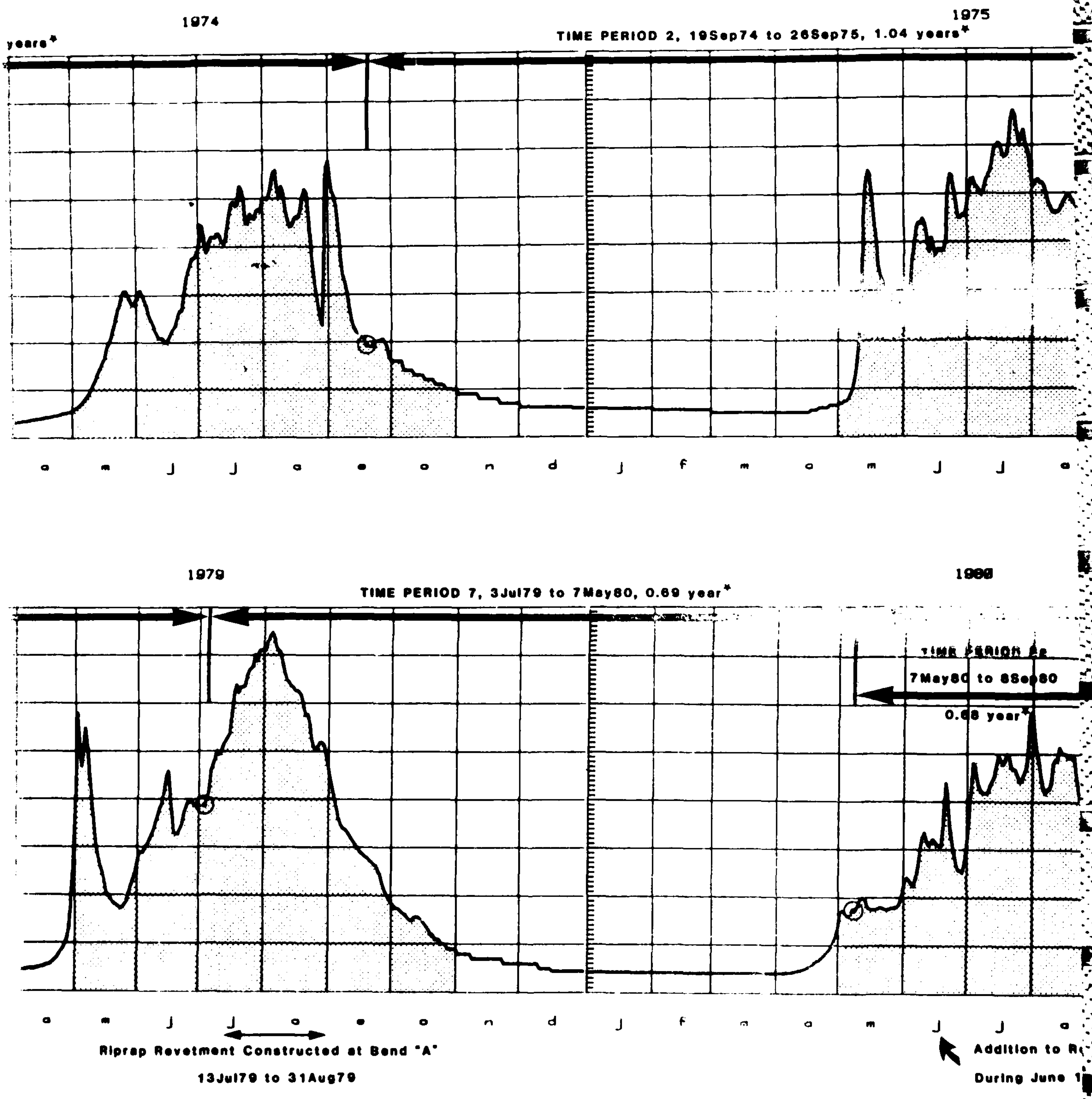
Figure 8. Phase III construction area on 23 June 1981.

Figure 9. Phase III construction area on 6 August 1981.

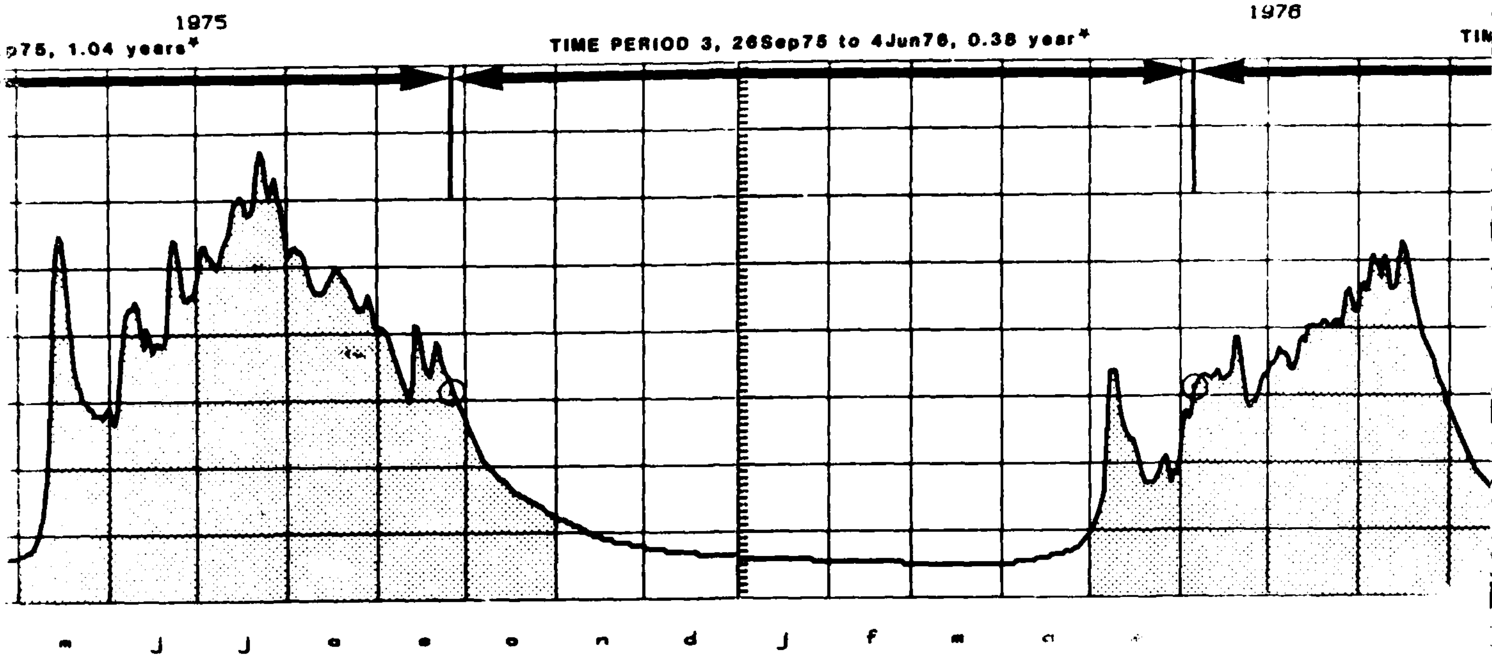


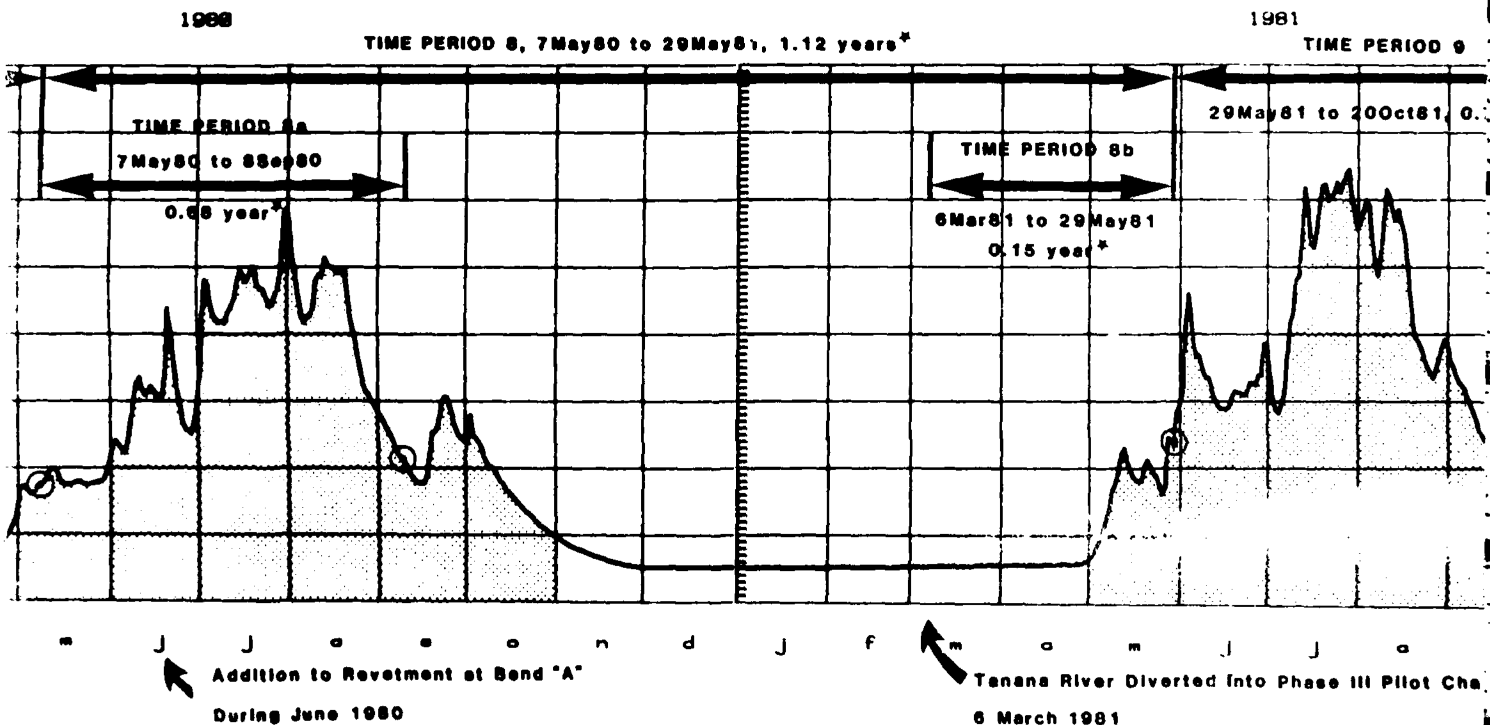


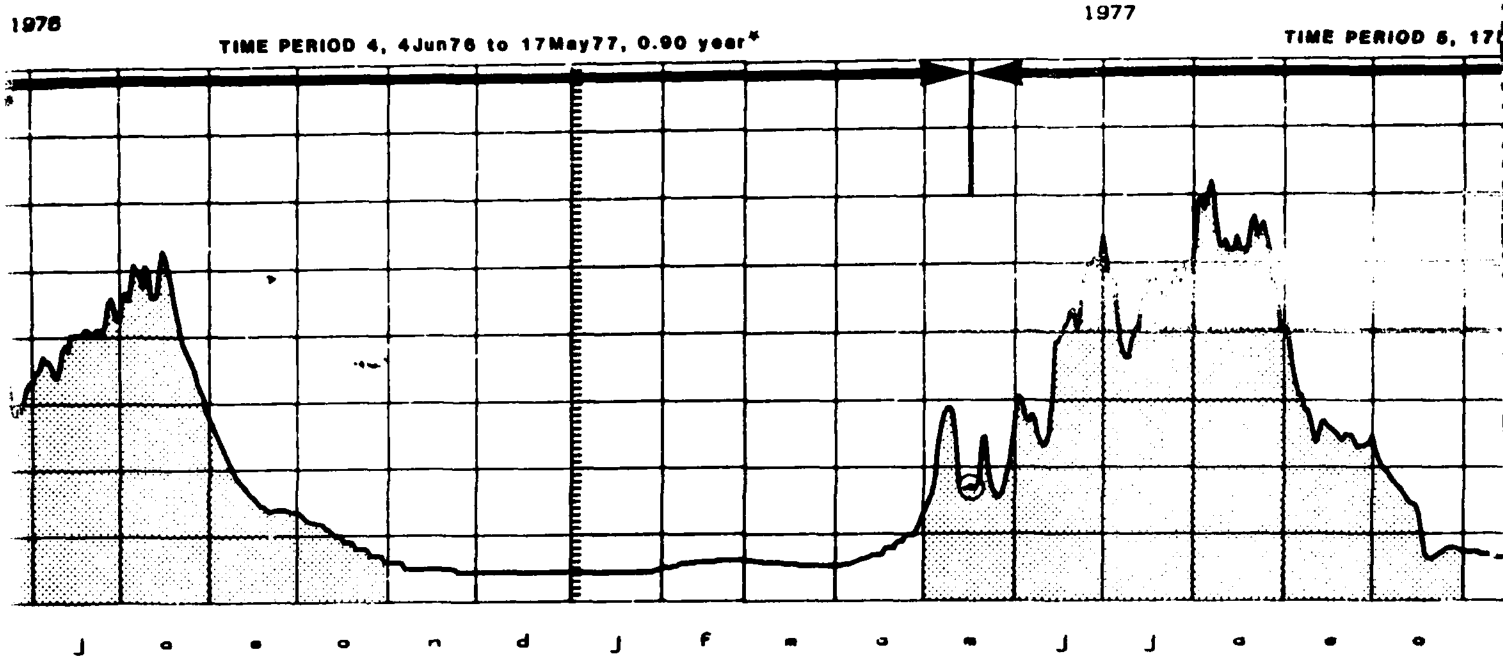
Riprap Revet

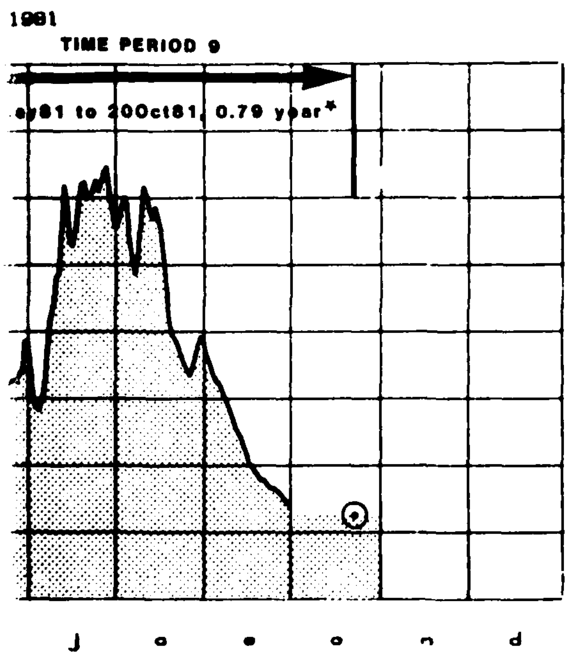


1974
1975
years*
TIME PERIOD 2, 19Sep74 to 26Sep75, 1.04 years*
a m j j a s o n d j f m a m j j a
1979
1980
TIME PERIOD 7, 3Jul79 to 7May80, 0.69 year*
7May80 to 8Sep80
a m j j a s o n d j f m a m j j a
Riprap Revetment Constructed at Bend "A"
13Jul79 to 31Aug79
During June 1


1975
p75, 1.04 years*
TIME PERIOD 3, 26Sep75 to 4Jun76, 0.38 year*
1976
m
j
j
a
s
o
n
d
j
f
m


TIME PERIOD 8, 7May80 to 29May8, 1.12 years*
1981
TIME PERIOD 9
29May81 to 20Oct81, 0.
TIME PERIOD 8b
6Mar81 to 29May81
year*
m
j
j
a
s
o
n
d
j
f
a
m
j
j
a
Addition to Revetment at Bend "A"
During June 1980
Tanana River Diverted Into Phase III Pilot Cha
6 March 1981



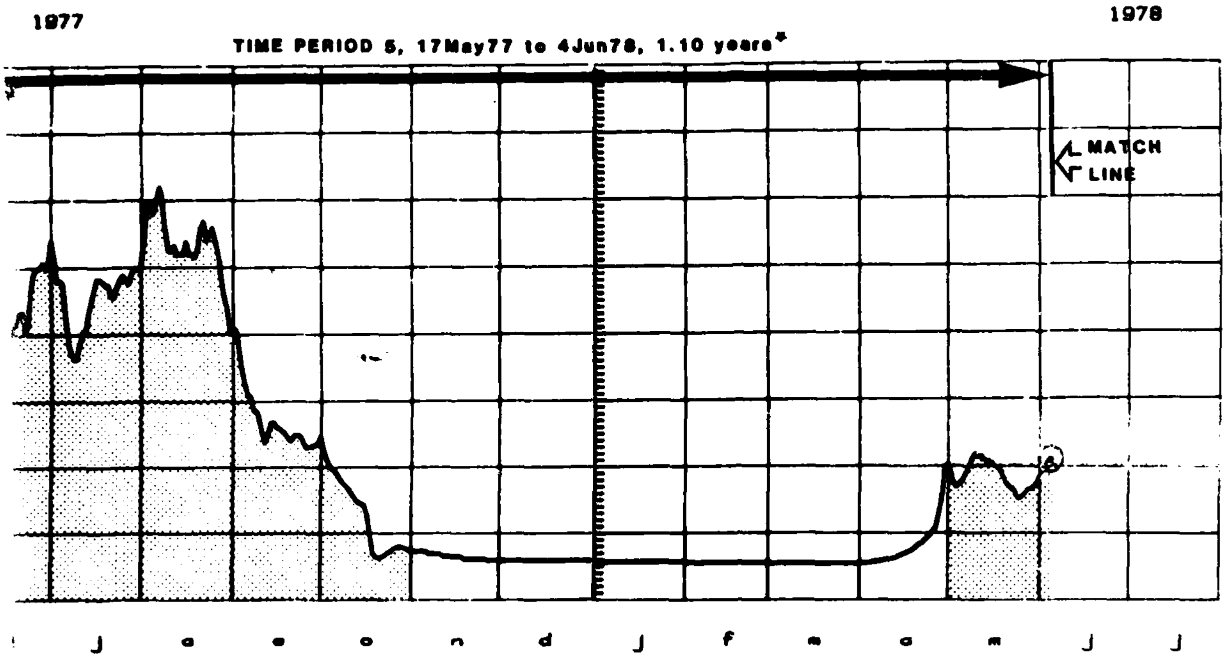


te Phase III Pilot Channel

KEY

⊙ AERIAL PHOTOGRAPHY TAKEN

* EFFECTIVE TIME PERIODS BASED ON SIX MONTH EFFECTIVE EROSION YEAR OF MAY THROUGH OCTOBER (Indicated As Shaded Areas Under Discharge Curve)



KEN

BASED ON

OSION

CTOBER

as Under

FIGURE 10

DATES OF AERIAL PHOTOGAPHY AND TIME PERIODS WITH RESPECT TO THE TANANA RIVER DISCHARGE, 1973 TO 1981

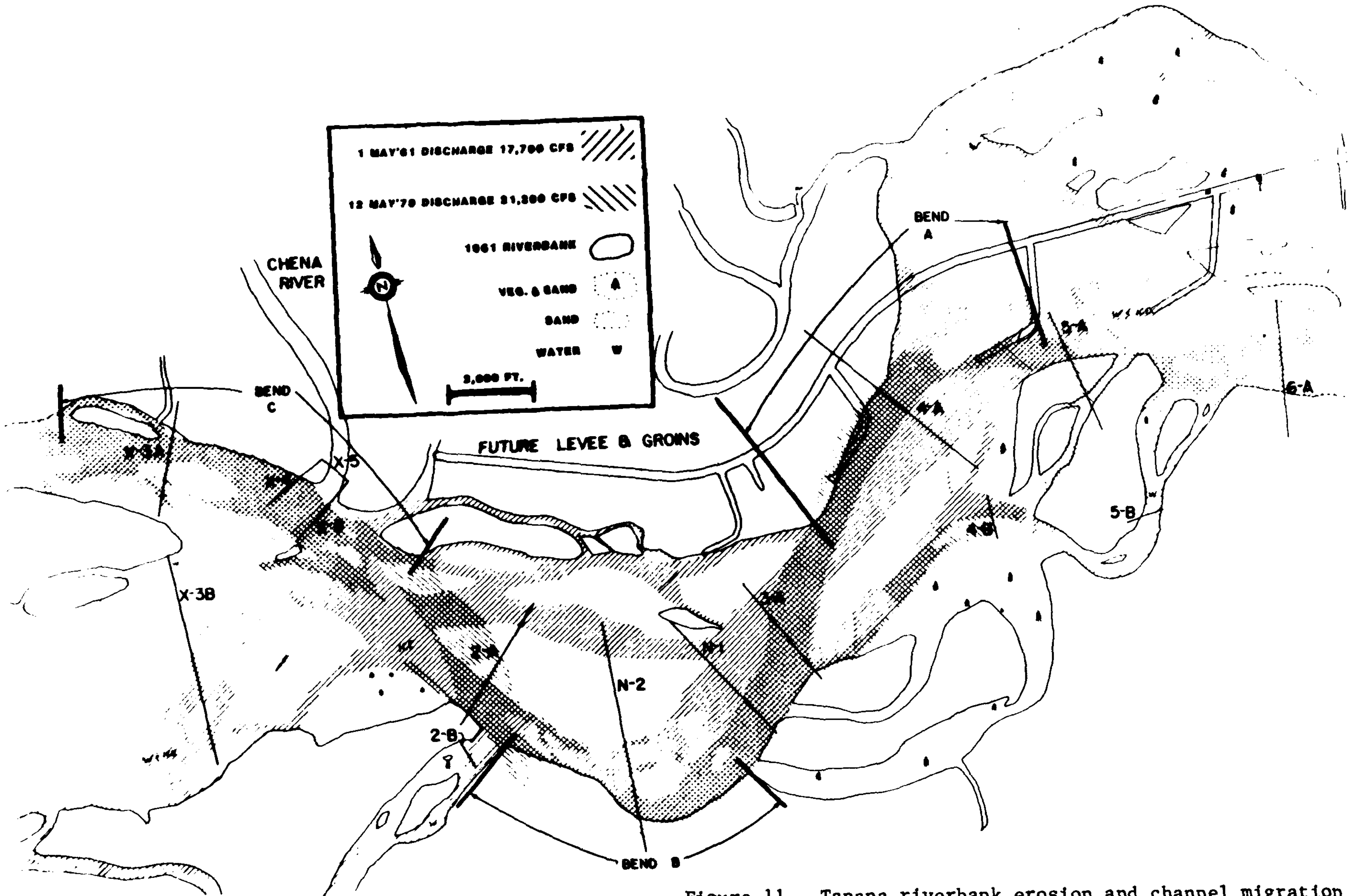


Figure 11. Tanana riverbank erosion and channel migration from 29 May 1981 to 20 October 1981.

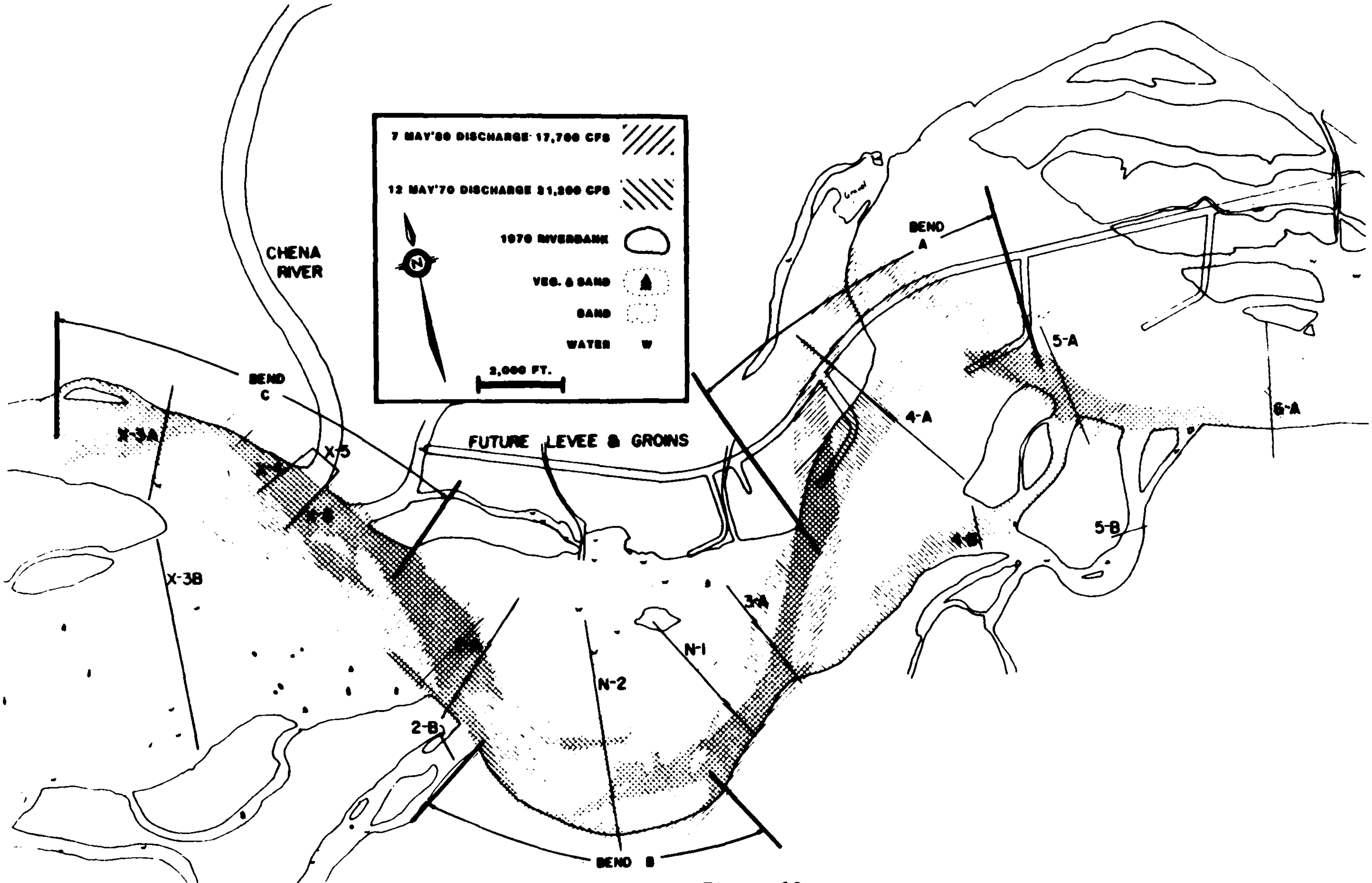


Figure 12. Tanana riverbank erosion and channel migration from 29 May 1981 to 20 October 1981.

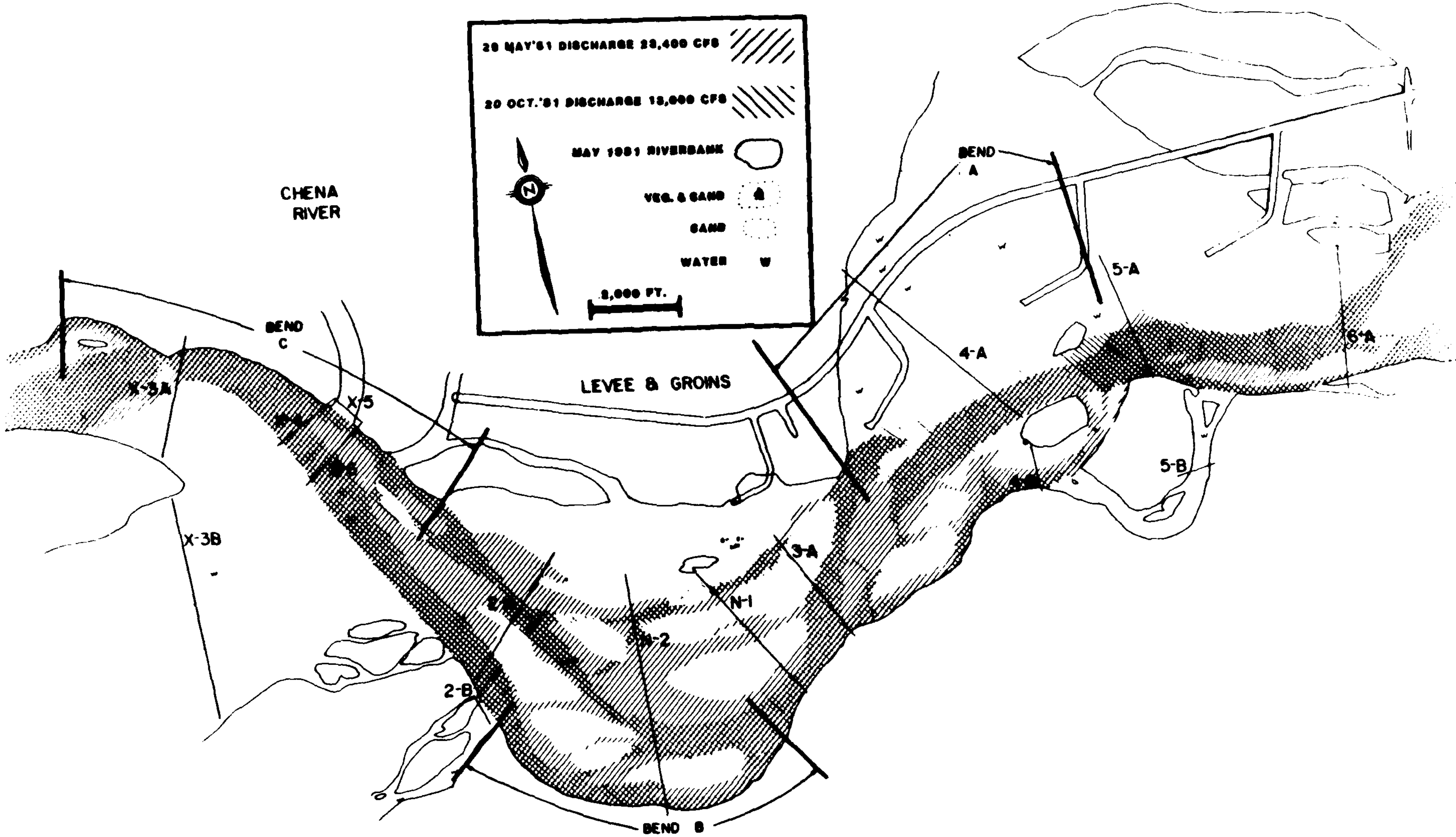
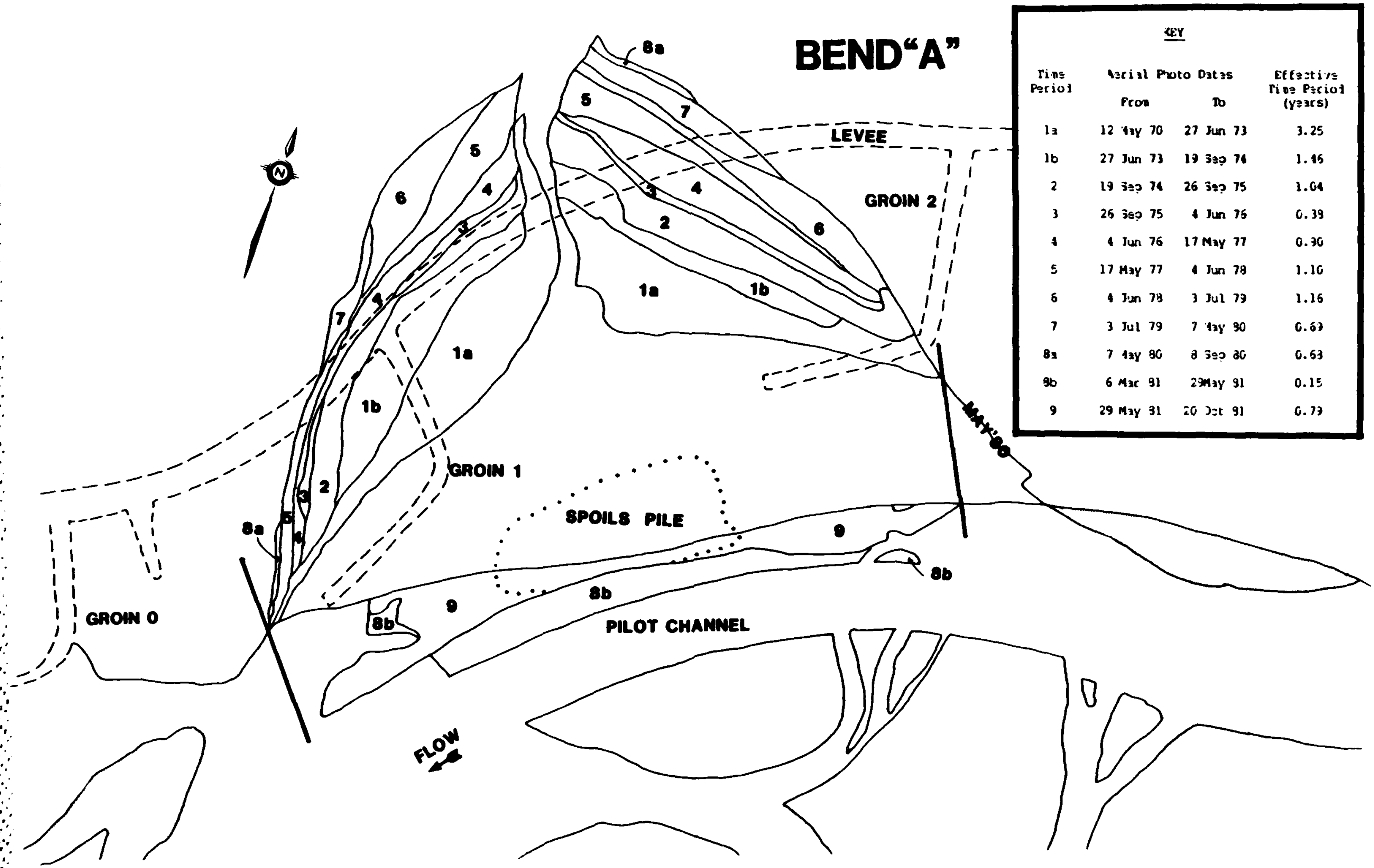


Figure 13. Tanana riverbank erosion and channel migration from 29 May 1981 to 20 October 1981.



KEY

Time Period	Aerial Photo Dates From	Aerial Photo Dates To	Effective Time Period (years)
1a	12 May 70	27 Jun 73	3.25
1b	27 Jun 73	19 Sep 74	1.46
2	19 Sep 74	26 Sep 75	1.04
3	26 Sep 75	4 Jun 76	0.39
4	4 Jun 76	17 May 77	0.30
5	17 May 77	4 Jun 78	1.10
6	4 Jun 78	3 Jul 79	1.16
7	3 Jul 79	7 May 80	0.69
8a	7 May 80	8 Sep 80	0.63
8b	6 Mar 81	29May 81	0.15
9	29 May 81	20 Oct 81	0.79

Figure 14. Riverbank erosion detail, Bend A, 12 May 1970 to 20 October 1981.

KEY

Time Period	Aerial Photo Dates From	Aerial Photo Dates To	Effective Time Period (years)
1	12 May 70	19 Sep 74	4.71
2	19 Sep 74	26 Sep 75	1.04
3	26 Sep 75	4 Jun 76	0.38
4	4 Jun 76	17 May 77	0.90
5	17 May 77	4 Jun 78	1.10
6	4 Jun 78	3 Jul 79	1.16
7	3 Jul 79	7 May 80	0.69
8	7 May 80	29 May 81	1.12
9	29 May 81	20 Oct 81	0.79

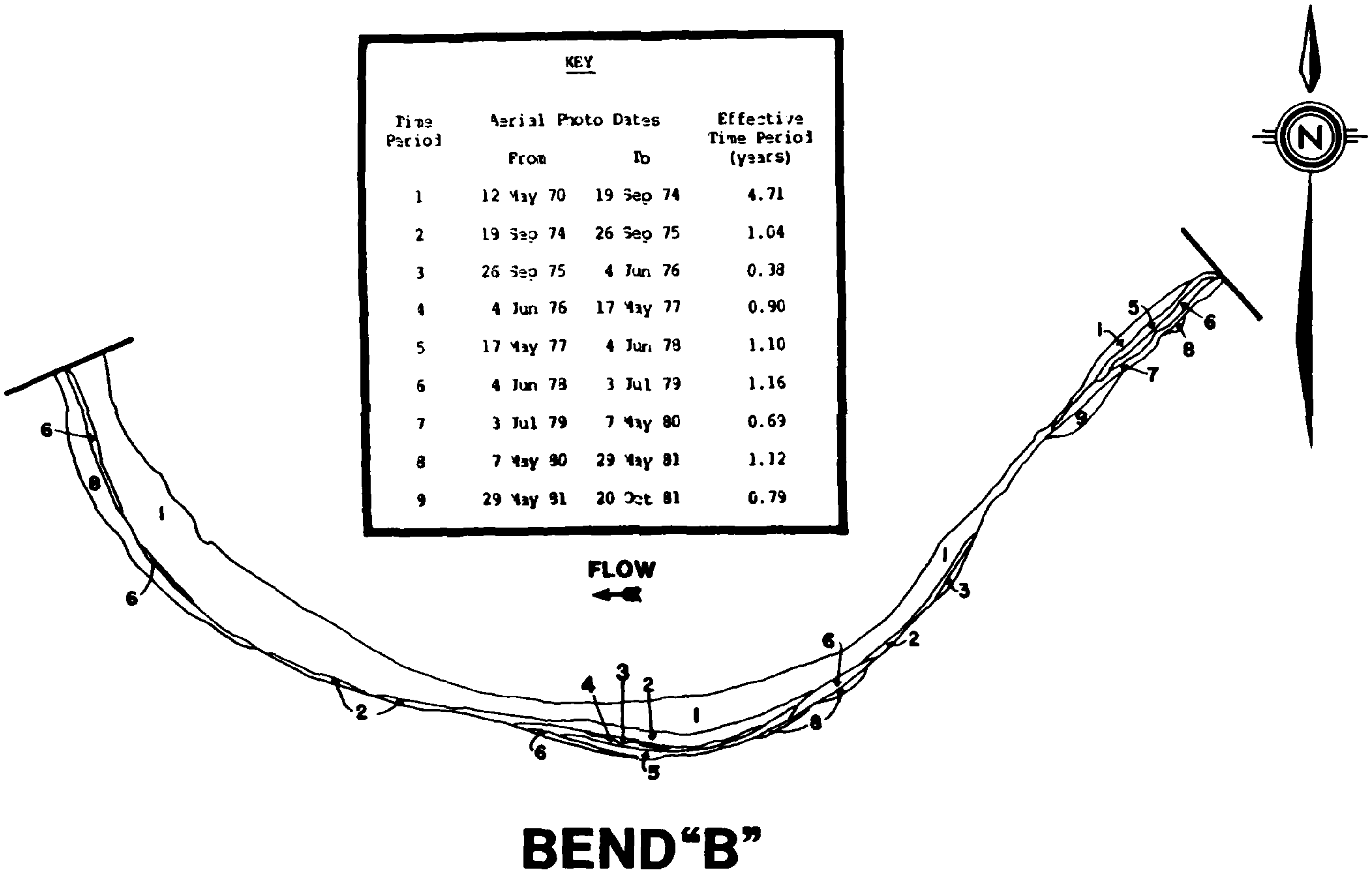
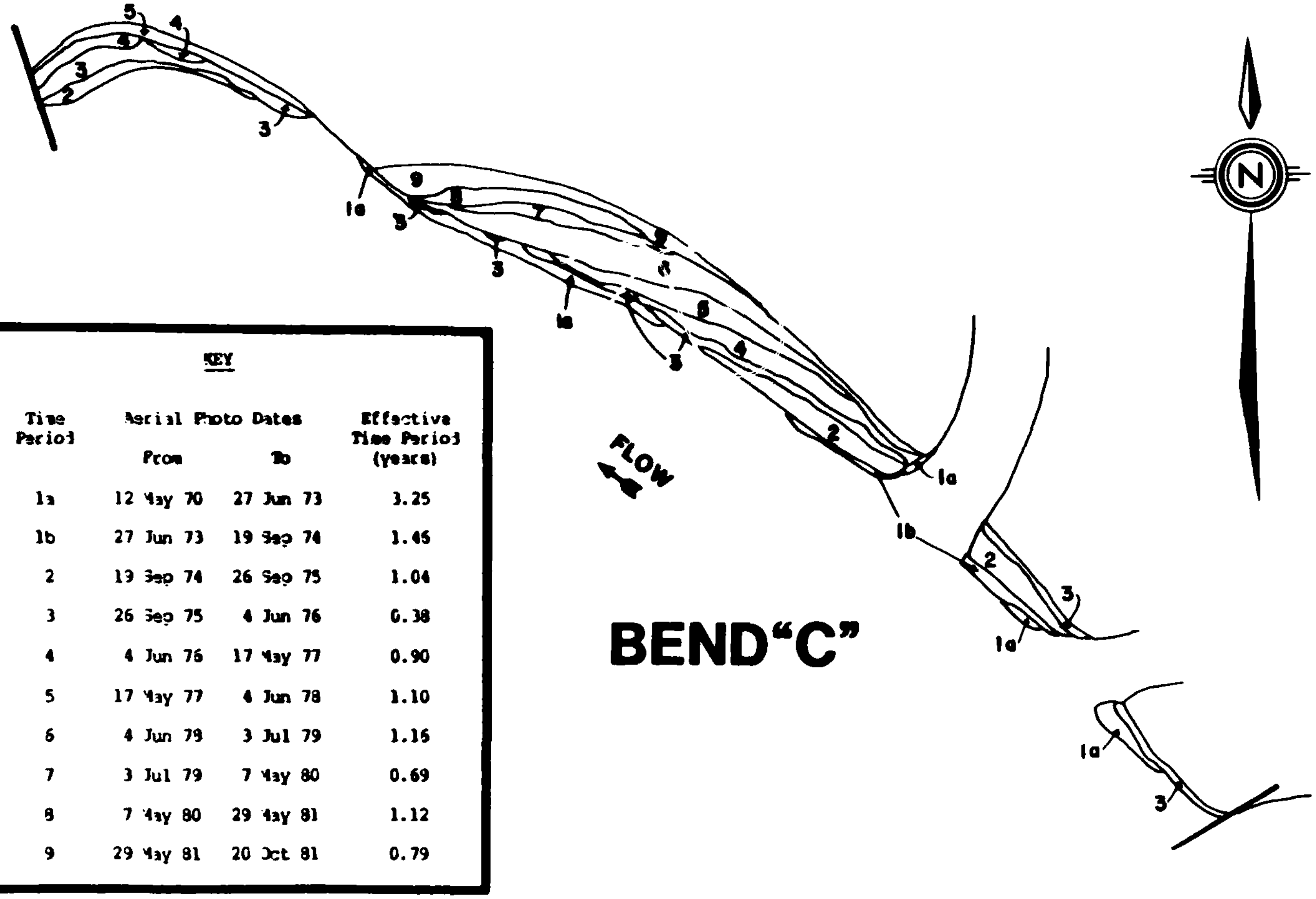


Figure 15. Riverbank erosion detail, Bend B, 12 May 1970 to 20 October 1981.



KEY

Time Period	Aerial Photo Dates From	Aerial Photo Dates To	Effective Time Period (years)
1a	12 May 70	27 Jun 73	3.25
1b	27 Jun 73	19 Sep 74	1.45
2	19 Sep 74	26 Sep 75	1.04
3	26 Sep 75	4 Jun 76	0.38
4	4 Jun 76	17 May 77	0.90
5	17 May 77	4 Jun 78	1.10
6	4 Jun 79	3 Jul 79	1.16
7	3 Jul 79	7 May 80	0.69
8	7 May 80	29 May 81	1.12
9	29 May 81	20 Oct 81	0.79

Figure 16. Riverbank erosion detail, Bend C, 12 May 1970 to 20 October 1981.

Figure 17. Pilot channel and spoils pile on 1 May 1981.

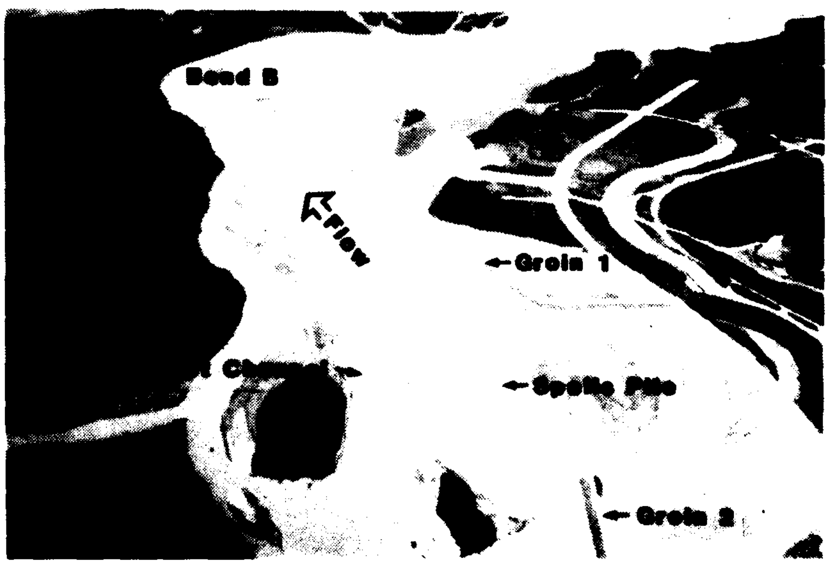


Figure 18. Pilot channel and spoils pile on 6 June 1981.

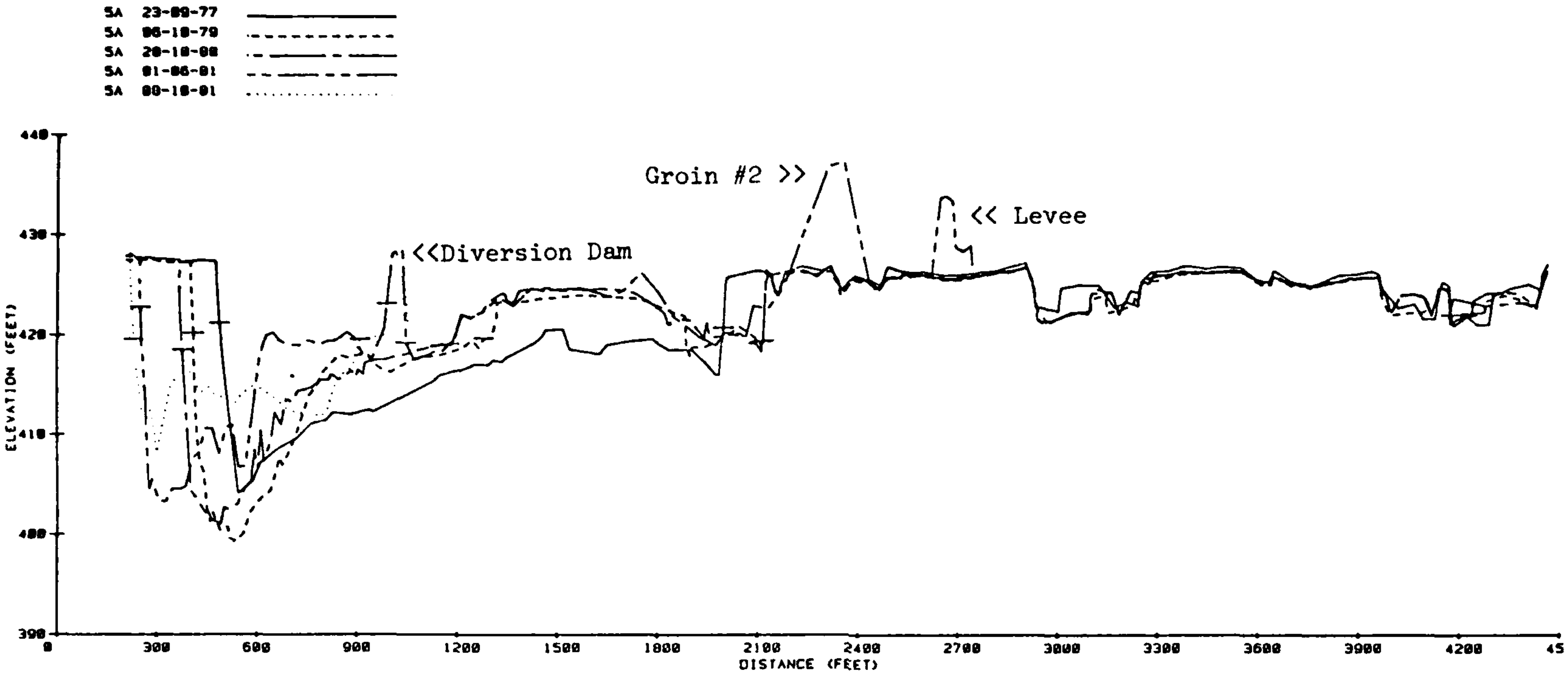


Figure 19. Tanana River cross section 5A, 1977-1981.

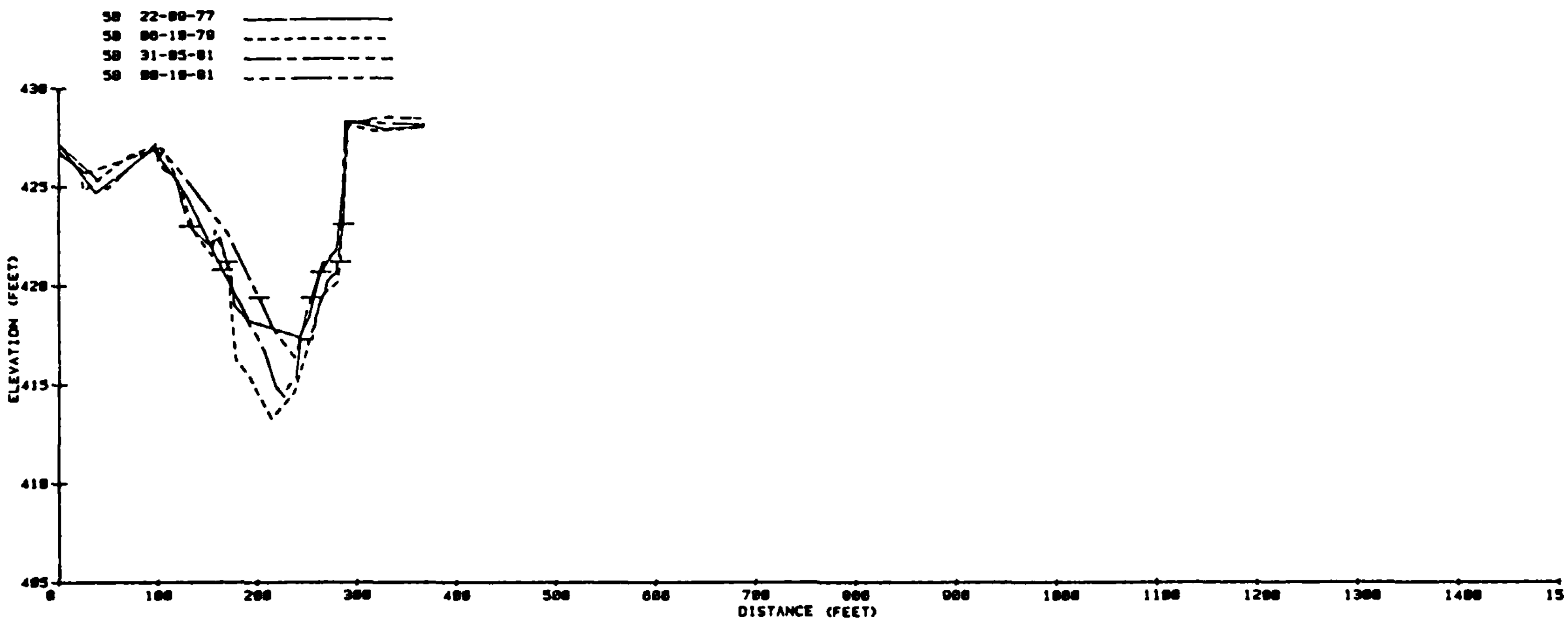


Figure 20. Tanana River cross-section 5B, 1977-1981.

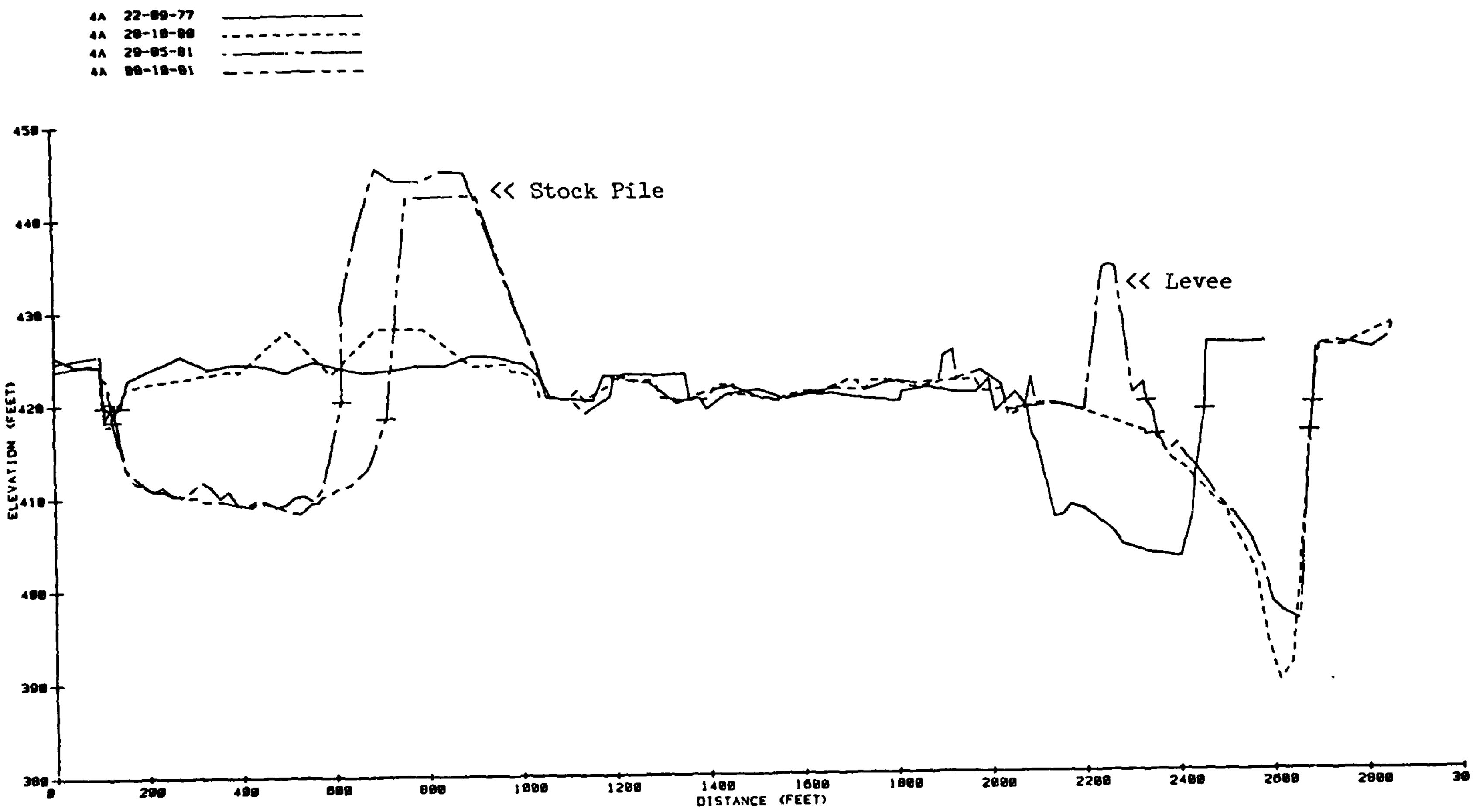


Figure 21. Tanana River cross section 4A, 1977-1981.

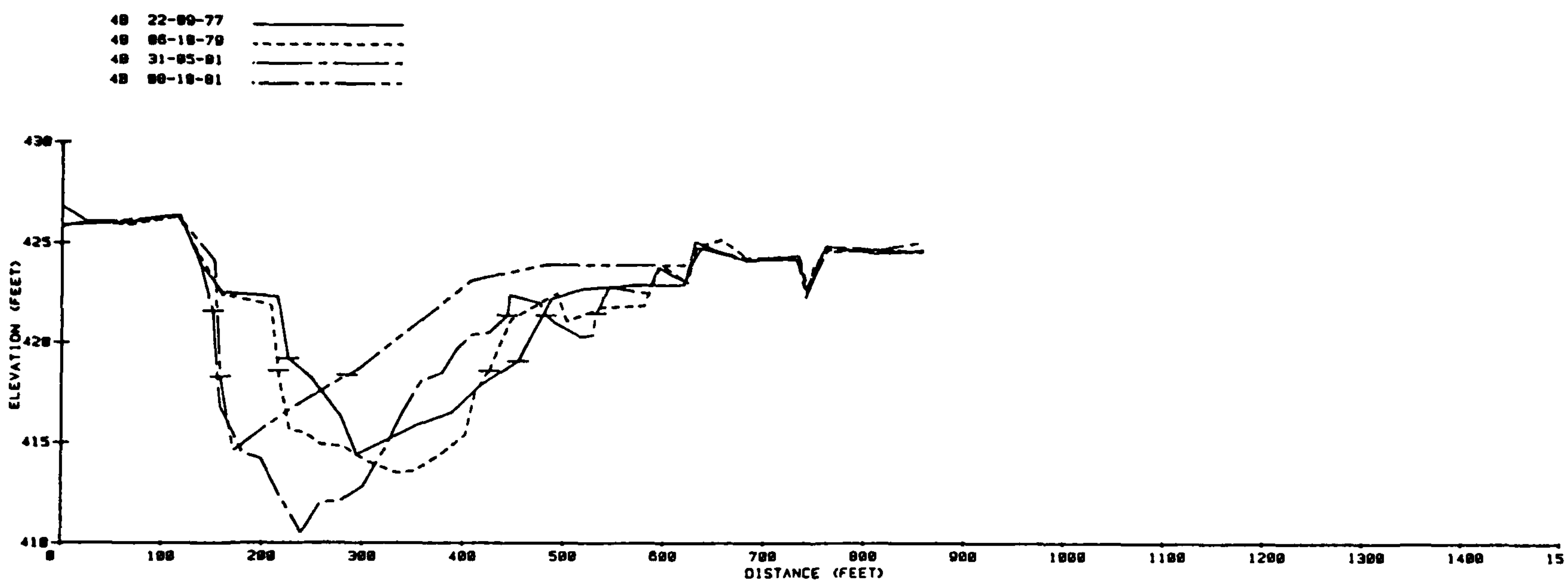


Figure 22. Tanana River cross section 4B, 1977-1981.

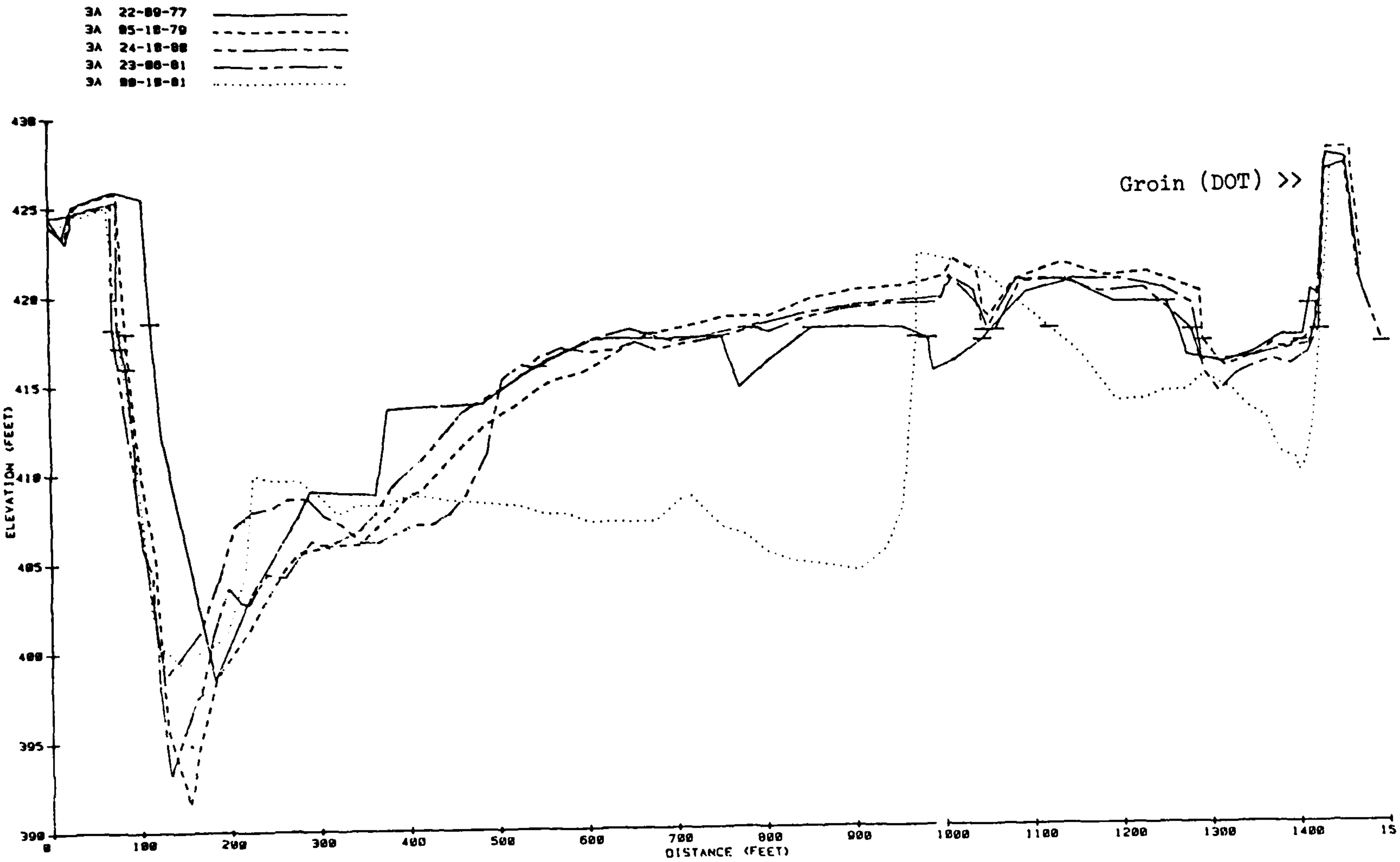


Figure 23. Tanana River cross section 3A, 1977-1981.

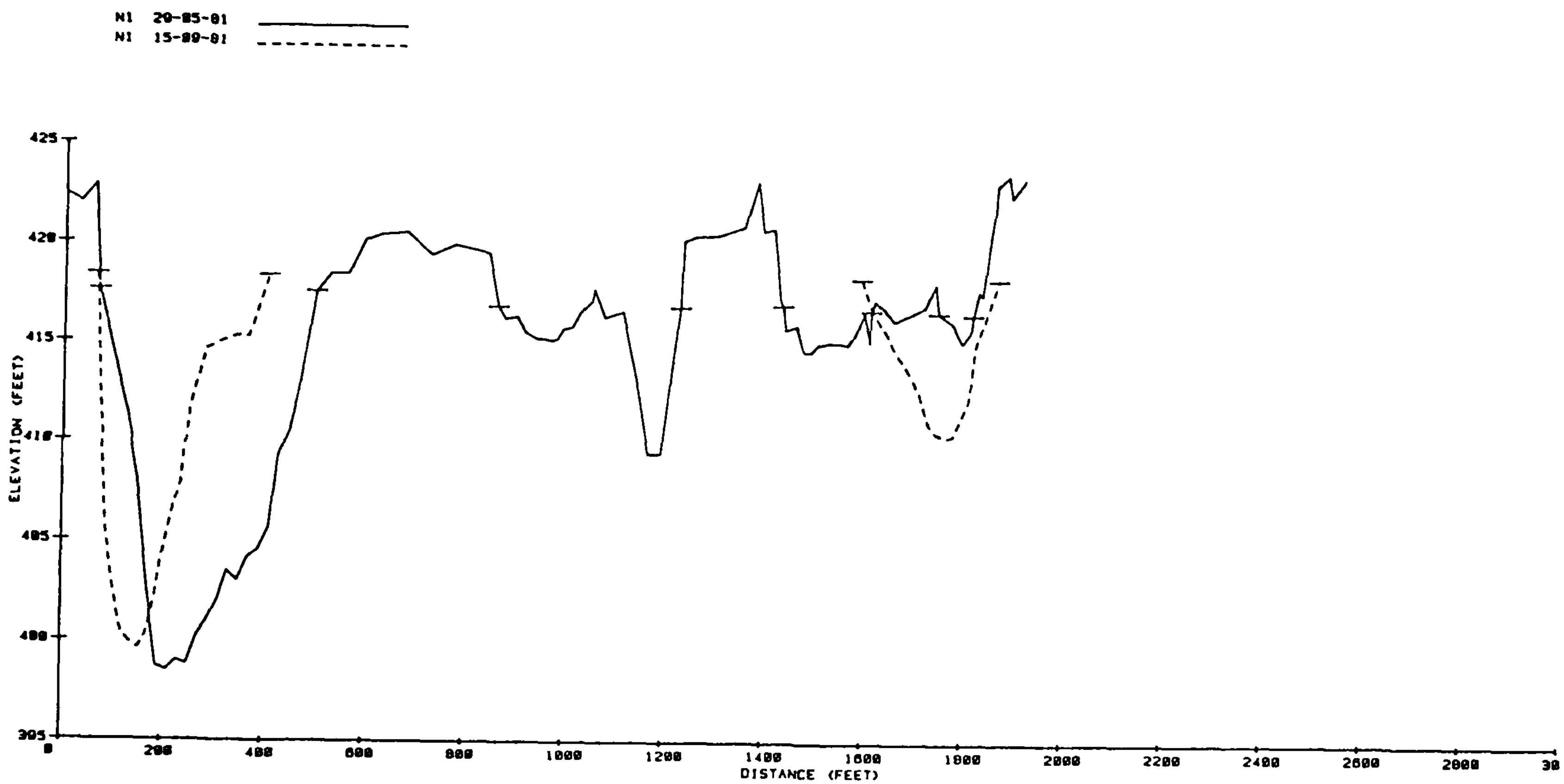


Figure 24. Tanana River cross-section N1, 1981.

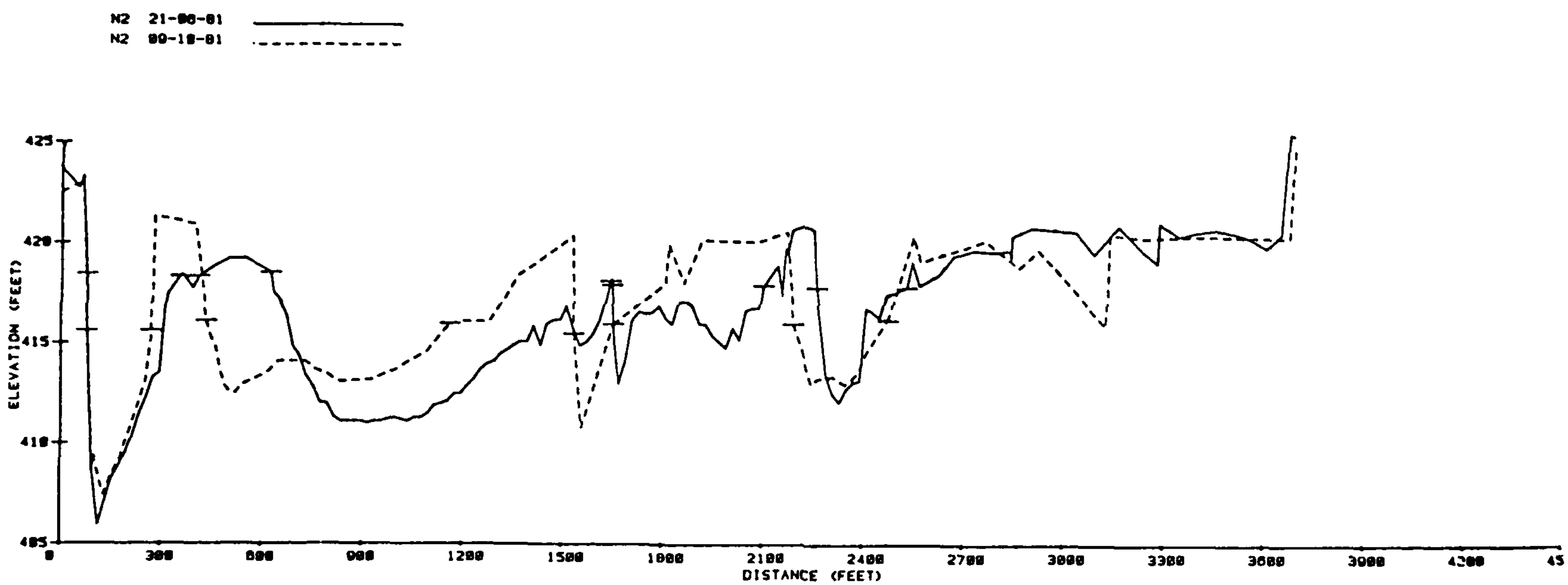


Figure 25. Tanana River cross section N2, 1981.

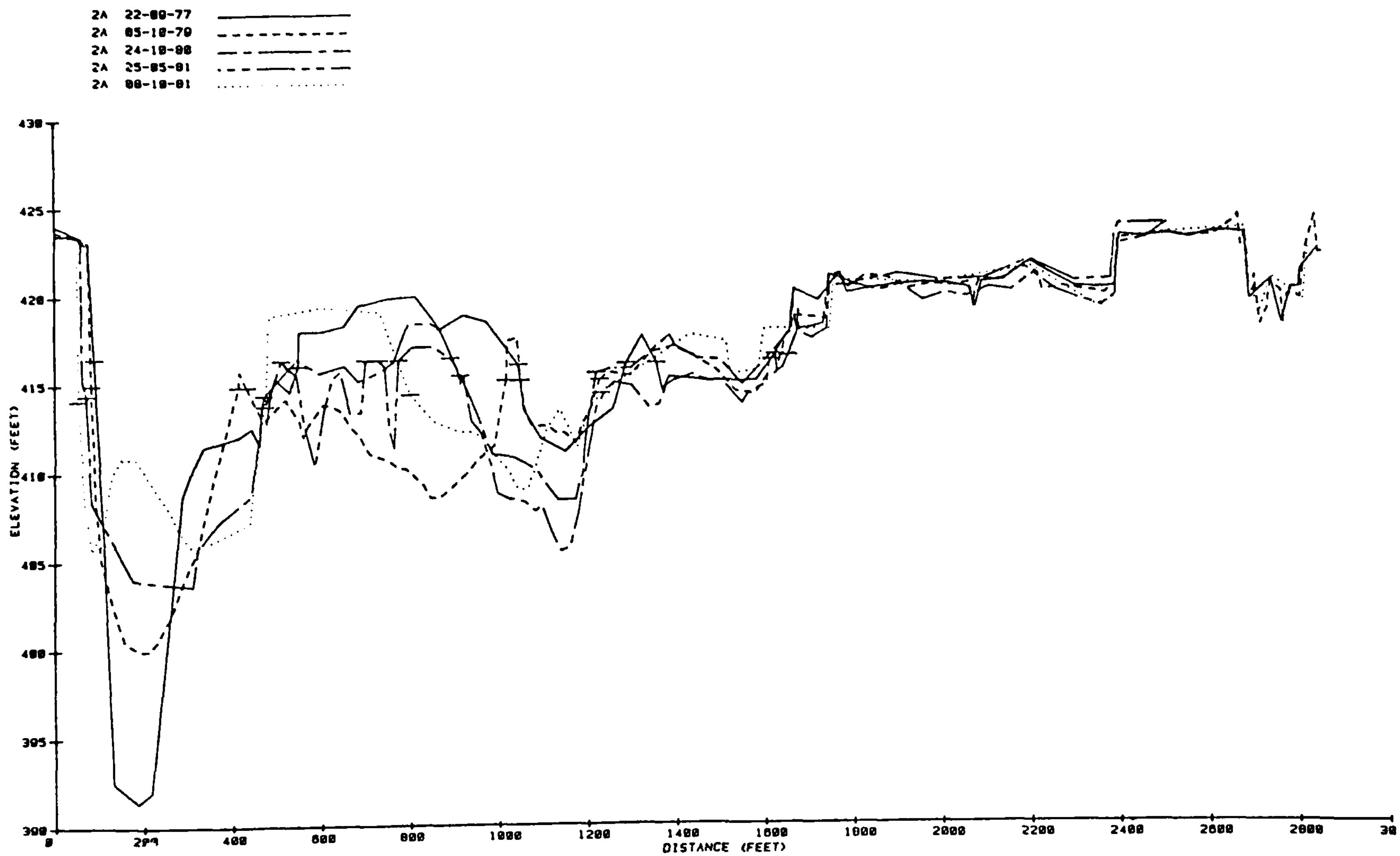


Figure 26. Tanana River cross section 2A, 1977-1981.

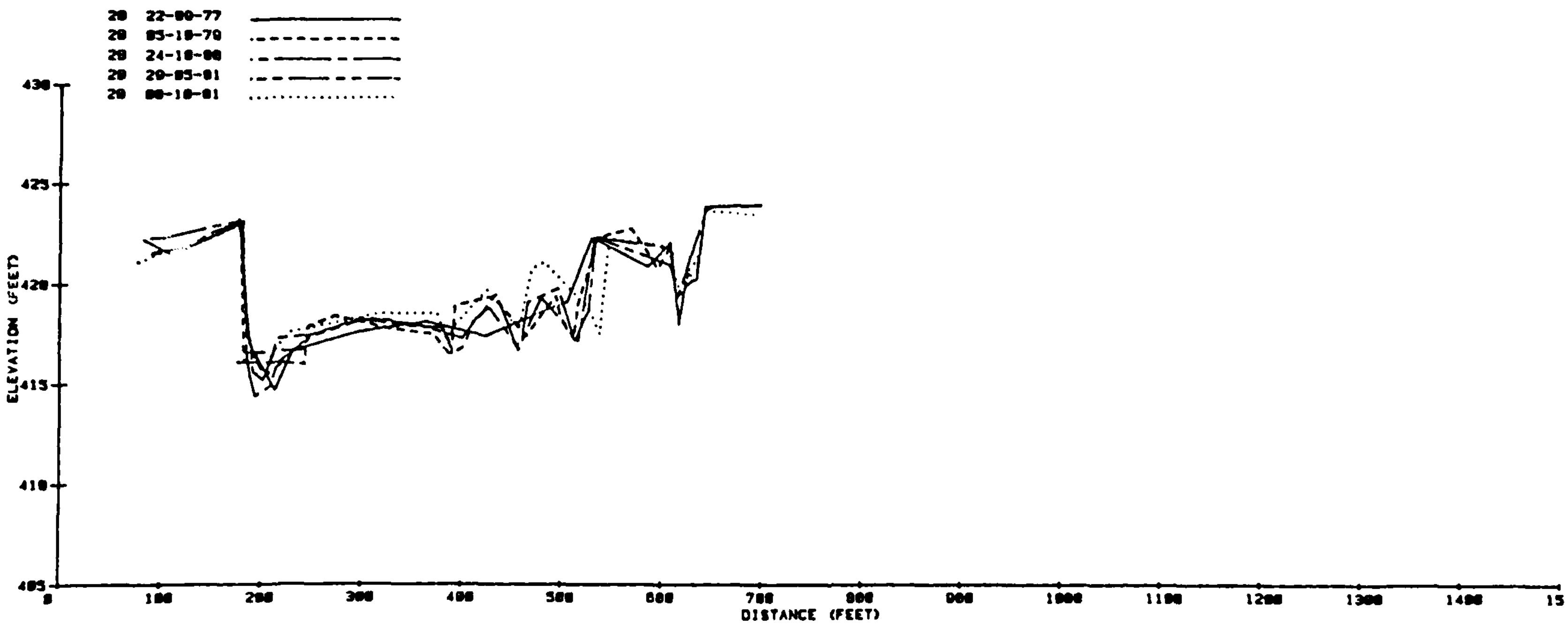


Figure 27. Tanana River cross section 2B, 1977–1981.

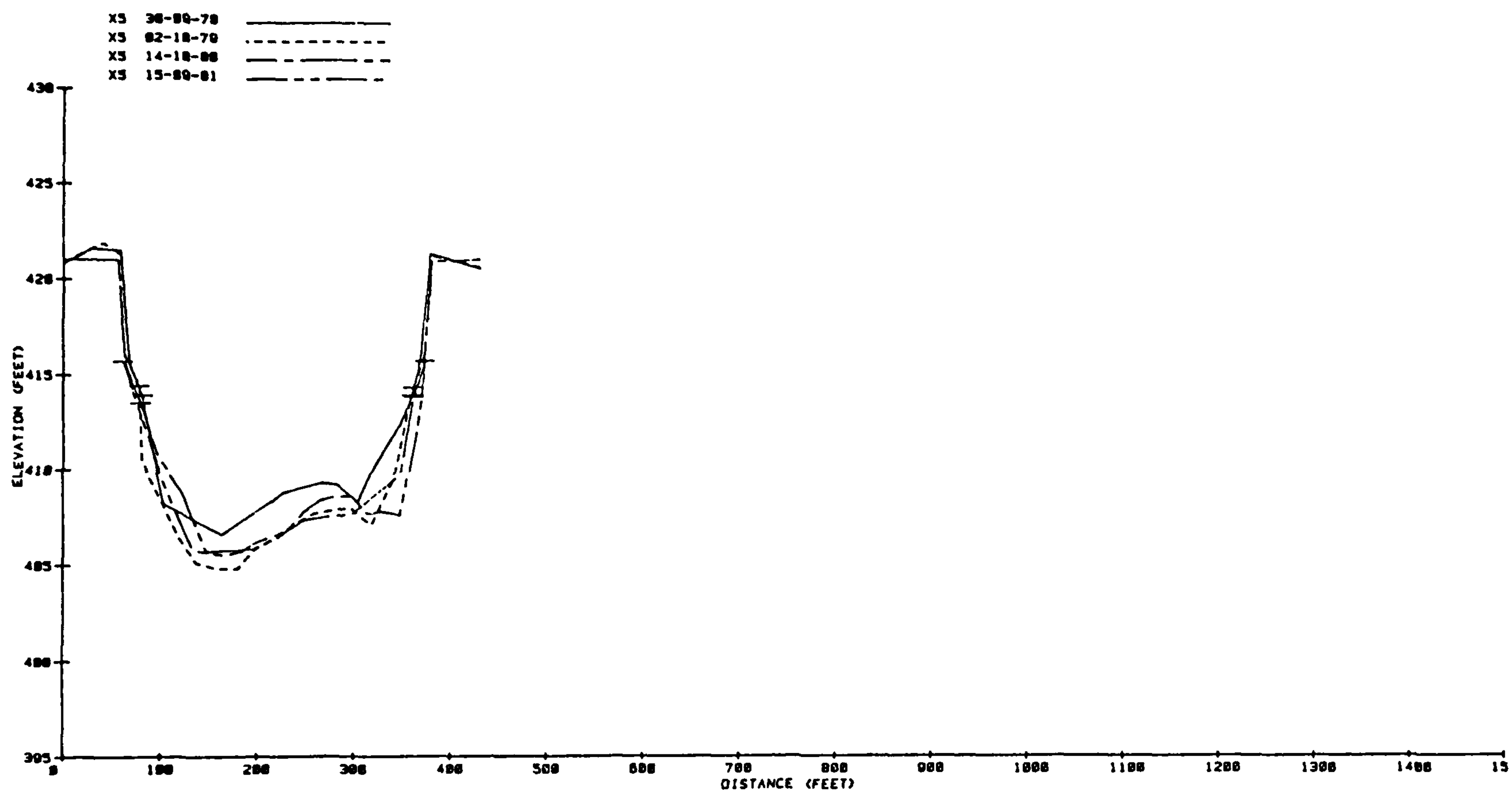


Figure 28. Chena River cross section X5, 1978-1981.

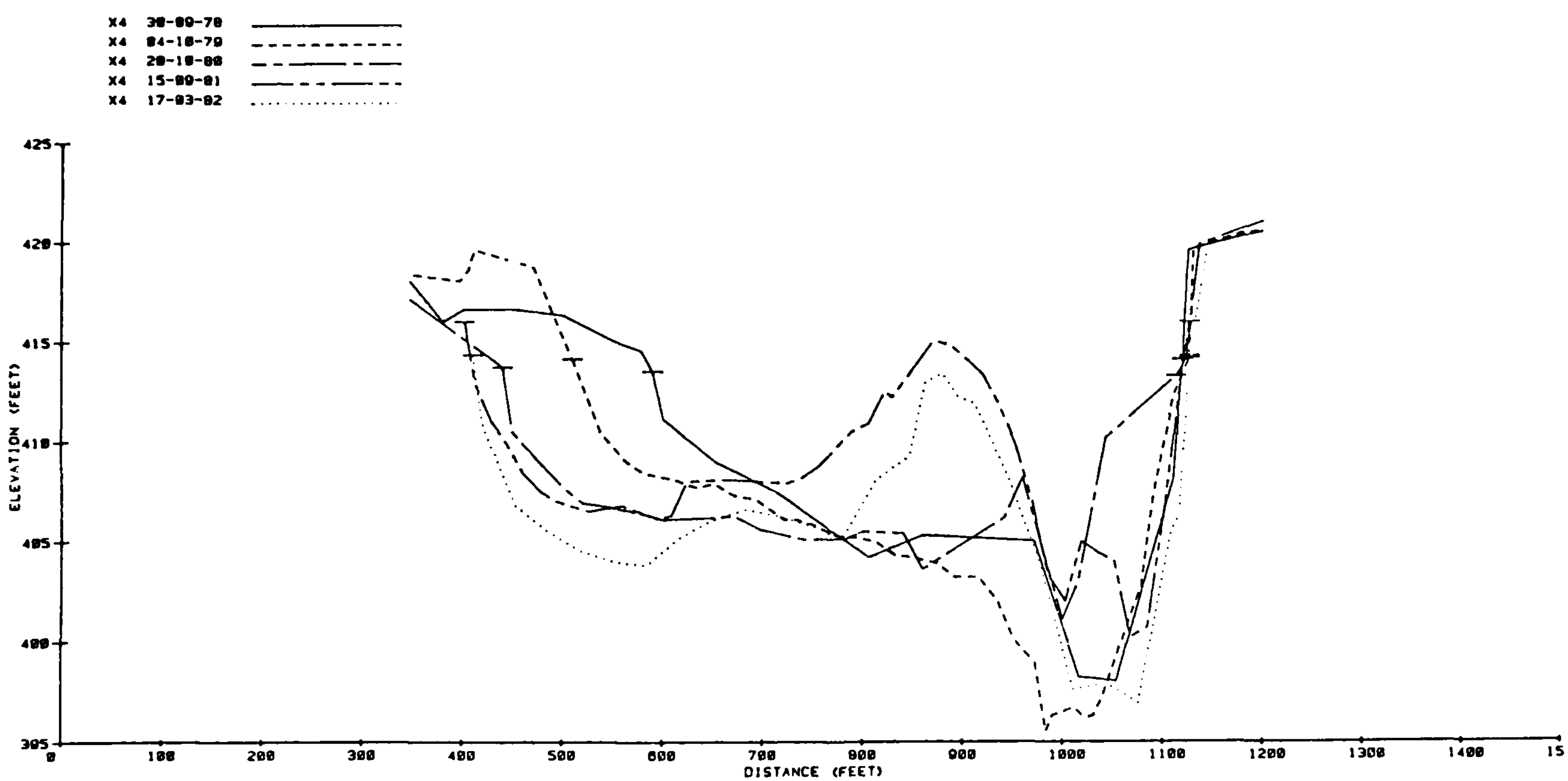


Figure 29. Tanana River cross section X4, 1978-1981.

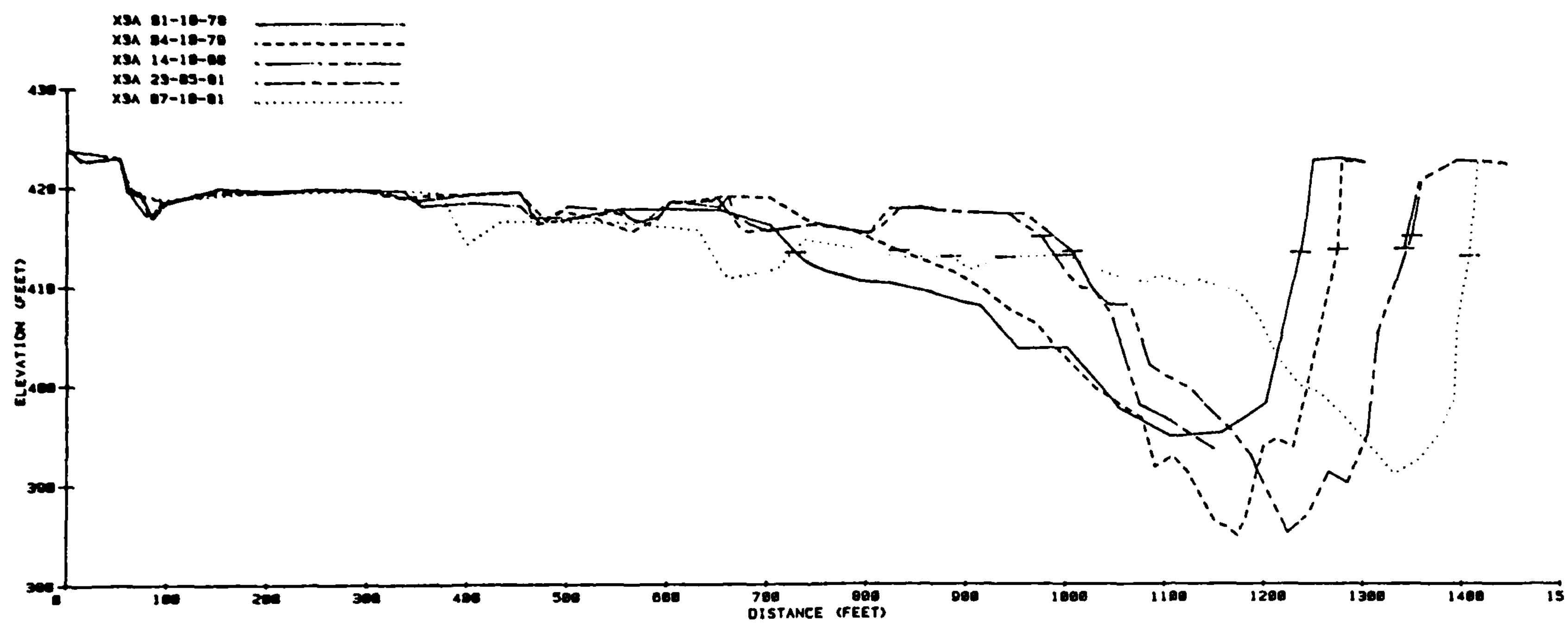


Figure 30. Tanana River cross section X3A, 1978-1981.

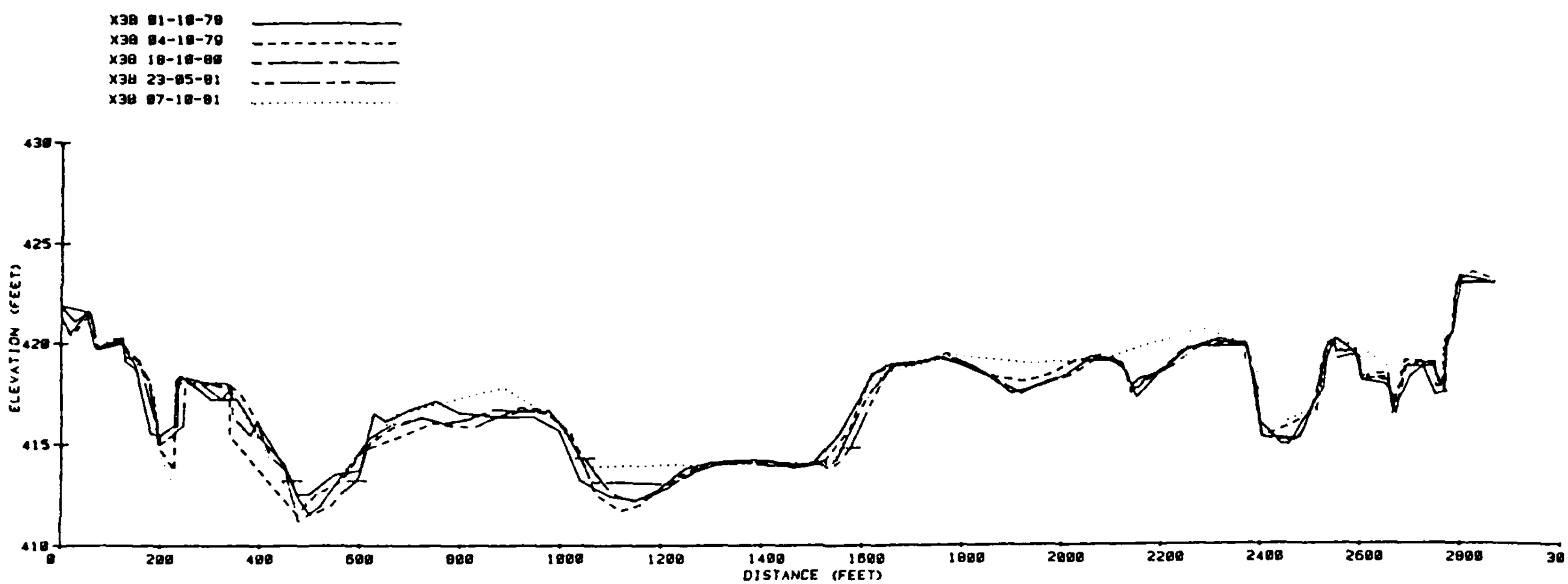


Figure 31. Tanana River cross section X3B, 1978-1981.

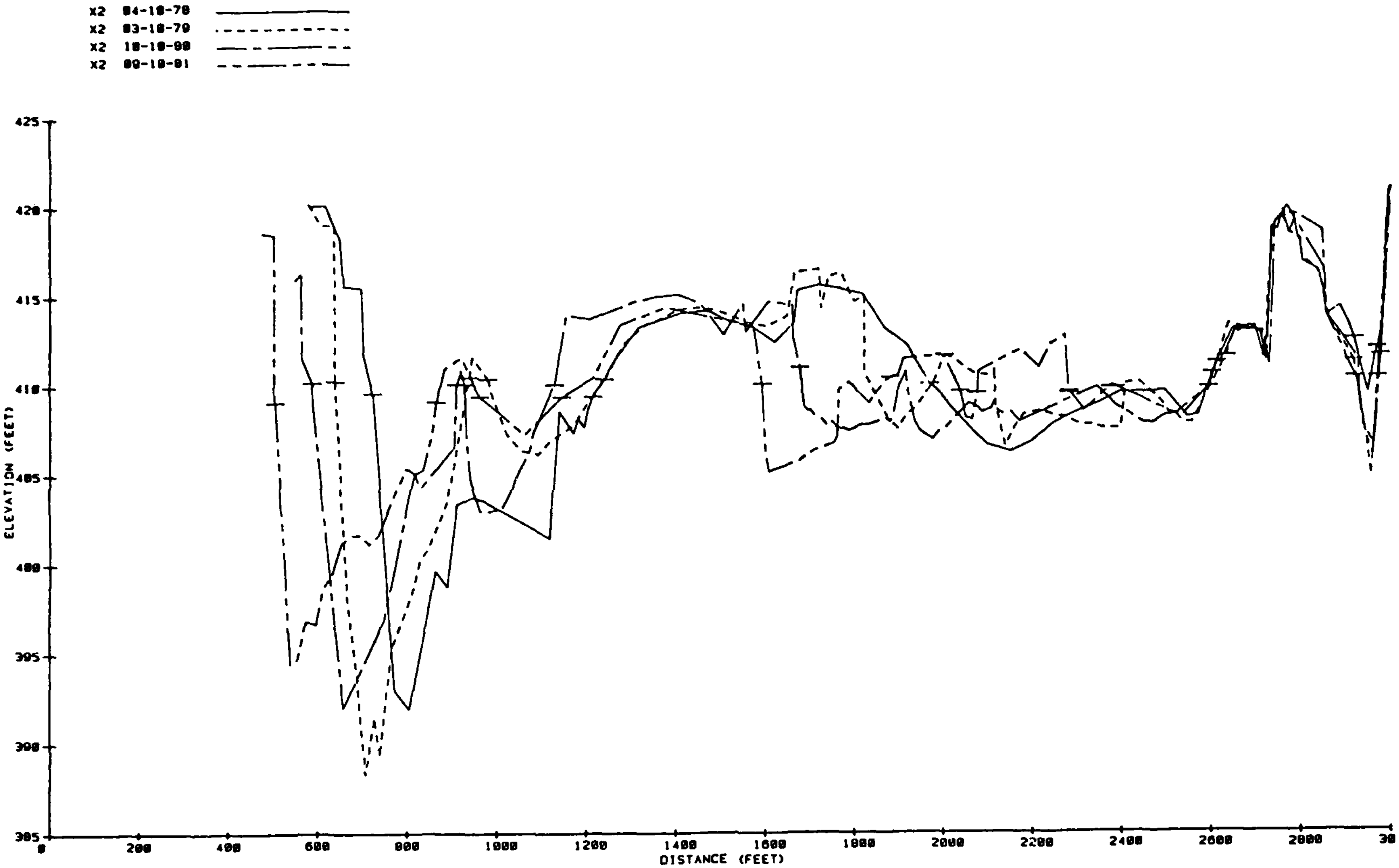


Figure 32. Tanana River cross section X2, 1978-1981.

Table 1. Aerial photography used in studies.

Pre-Construction Aerial Photography

Date	Tanana River Discharge (CFS)
1 May 1961	17,700 (estimated)
12 May 1970	21,200 (estimated)
27 June 1973	49,200
19 September 1974	19,100
26 September 1975	31,300
4 June 1976	31,200
17 May 1977	17,100
4 June 1978	21,600
3 July 1979	39,100
7 May 1980	17,700
8 September 1980	21,300

Post-Construction Aerial Photography

Date	Tanana River Discharge (CFS)
29 May 1981	23,400 (estimated)
20 October 1981	13,000 (estimated)

Table 2. Areal erosion, Bends A, B and C.

	Time Period	Aerial Photo Dates		Effective Time Period [1]		Areal Erosion (square feet)			Areal Erosion Rate (square feet/year) [1]		
		From	To	Days	Years	Bend A	Bend B	Bend C	Bend A	Bend B	Bend C
Pre-construction Time Periods	1a	12 May 70	27 Jun 73	595	3.25	877,000	-	49,000	270,000	-	15,000
	1b	27 Jun 73	19 Sep 74	267	1.46	434,000	-	23,000	297,000	-	16,000
	1	12 May 70	19 Sep 74	862	4.71	1,311,000	493,000	72,000	278,000	105,000	15,000
	2	19 Sep 74	26 Sep 75	190	1.04	440,000	64,000	92,000	423,000	62,000	88,000
	3	26 Sep 75	4 Jun 76	69	0.38	114,000	7,000	106,000	300,000	18,000	279,000
	4	4 Jun 76	17 May 77	165	0.90	340,000	14,000	75,000	378,000	16,000	83,000
	5	17 May 77	4 Jun 78	201	1.10	335,000	31,000	84,000	305,000	28,000	76,000
	6	4 Jun 78	3 Jul 79	212	1.16	298,000	43,000	116,000	257,000	37,000	100,000
	7	3 Jul 79	7 May 80	126	0.69	133,000	19,000	24,000	193,000	28,000	35,000
	1 - 7	12 May 70	7 May 80	1825	9.98	2,971,000	671,000	569,000	298,000	67,000	57,000
	8a	7 May 80	8 Sep 80	124	0.68	26,000	-	-	38,000	-	-
Post-construction	8b	6 Mar 81	29May 81	28	0.15	299,000	-	-	1,993,000	-	-
	8	7 May 80	29 May 81	205	1.12	-	72,000	34,000	-	64,000	30,000
	9	29 May 81	20 Oct 81	144	0.79	449,000	13,000	64,000	568,000	16,000	81,000
	8b & 9	6 Mar 81	20 Oct 81	172	0.94	748,000	-	-	796,000	-	-
	8 & 9	7 May 80	20 Oct 81	349	1.91	-	85,000	98,000	-	45,000	51,000

[1] Time periods and rates are based on a six month effective erosion year (May through October, 183 days).

Table 3. Summary of cross section changes.

Cross-section	Date	South Bank	North Bank	Channel	Remarks
5A (Fig 19)	23/09/77-06/10/79	80 ft erosion	120 ft erosion	deposition of 7-10 ft on north side of main channel	located at upstream end of meander bend
				thalweg scour of 5 ft	skewed to flow contained in main channel
	06/10/79-28/10/80	30 ft erosion	stable	minor deposition on north side of main channel	
	28/10/80-01/06/81	130 ft erosion	controlled by diversion dam	thalweg migration 130 ft southward in conjunction with bank erosion	located at upstream end of pilot channel at diversion dam
					change of river flow direction
					restricted flow area
					deposition on north side of channel due to dam construction
	01/06/81-08/10/81	20 ft erosion	controlled by diversion dam	deposition of 5-15 ft on south side of main channel	shape changed to nearly uniform channel
				scour of 5-10 ft on north side of main channel	

Summary: *Construction of pilot channel and diversion dam has changed flow direction and restricted flow area resulting in major channel changes.* A trend of south bank erosion is continuing into the post-construction time period.

Cross-section	Date	South Bank	North Bank	Channel	Remarks
5B (Fig 20)	22/09/77-06/10/79	stable	stable	5 ft scour of channel bottom	scour probably due to 1979 high runoff
	06/10/79-08/10/81	stable	stable	deposition to near 1977 cross-section	

Summary: Channel has remained relatively stable with no indication of enlargement and therefore no reason to suspect a shift in flow to this south channel.

Table 3 (cont'd).

Cross-section	Date	South Bank	North Bank	Channel	Remarks
4A (Fig 21)	22/09/77-28/10/81	stable	220 ft erosion	thalweg migration and scour in reponse to north bank erosion	
	28/10/80-29/05/81	stable	stable		pilot channel and spoil pile construction has cut off original channel
	29/05/81-08/10/81	stable	100 ft erosion	stable	
Summary: Construction of the pilot channel has cut off original channel. Pilot channel has enlarged by erosion of north bank (and spoil pile) only.					
4B (Fig 22)	22/09/77-06/10/79	stable	stable	minor scour	
	06/10/79-31/05/81	stable	stable	10 ft scour on south side of main channel	due to timing of surveys the changes cannot be distinguished from affects of pilot channel construction
	31/05/81-08/10/81	stable	stable	3-5 ft of deposition across entire main channel	deposition appears to be result of sediment entering channel around the island rather than upstream erosion in this south channel
Summary: Since construction of the pilot channel it appears the channel is being filled in and may be by-passed altogether in the future.					
3A (Fig 23)	22/09/77-05/10/79	30 ft erosion	stable con-trolled by groin	thalweg migration to south and scour of 7 ft deposition up to 5 ft on large bar on north side of floodplain	
	05/10/79-24/10/80	stable	stable (groin)	relatively stable	

Table 3 (cont'd).

Cross-section	Date	South Bank	North Bank	Channel	Remarks
	24/10/81-23/06/81	stable	stable (groin)	deposition at thalweg and lower portion of north side of main channel	located downstream of pilot channel
				scour of bar adjacent to main channel beginning to occur	
	23/06/81-08/10/81	stable	stable (groin)	bar in center of floodplain eroded 470 ft to the north and to depth of 15 ft	redirection of flow due to construction of the pilot channel resulting in main channel skewed to cross-section
				secondary channel on north side of floodplain enlarged by scour to the south of mid-channel bar and deepening of channel	

Summary: Construction of pilot channel has resulted in major changes, partially due to changes in flow direction and skewed cross-section. Significantly the flow appears shifted to north both by scour of the main channel and enlargement of the secondary channel.

Cross-section	Date	South Bank	North Bank	Channel	Remarks
N1 (Fig 24)	30/06/81-15/09/81	stable	30 ft erosion	migration of thalweg to the south, with narrowing of main channel due to deposition on the north side	new cross-section started in 1981 located on upstream end of large meander bend
				apparently deposition occurred in the mid-floodplain channel as no survey was done	15/09/81 survey included flowing channels only
				the north channel was enlarged by scour of the banks and river bottom	

Summary: Since this is a new cross-section it is impossible to determine if the relatively large changes in the floodplain are greater than those which typically occur in one run off season. These surveys provide baseline data to determine future channel changes.

Table 3 (cont'd).

Cross-section	Date	South Bank	North Bank	Channel	Remarks
N2 (Fig 25)	21/06/81-09/10/81	stable	30 ft erosion	large areas of scour and deposition across entire floodplain	new cross-section established in 1981 at widest point on large meander bend
				enlargement of north secondary channel	

Summary: Since this is a new cross-section it is impossible to determine if the relatively large changes in the flood plain are greater than those which typically occur in one run-off season. These surveys provide baseline data to determine future channel changes.

Cross-section	Date	South Bank	North Bank	Channel	Remarks
2A (Fig 26)	22/09/77-05/10/79	stable	stable	large bar located near the center of the flood-plain scoured up to 10 ft across a 250 ft width	bar erosion is typical of cross-sections during *this time period* (5A, 4A, 3A) but thalweg deposition not found at upstream locations
				deposition at the main channel (thalweg) of up to 9 ft	
	05/10/79-24/10/80	20 ft erosion	stable	additional deposition in the main channel	
				rebuilding of mid flood-plain bar	
				channel on north side of floodplain enlarged to twice its previous size	
	24/10/80-25/05/81	missing	stable	minor changes across floodplain and right channel	main channel survey missing
					changes possibly due to ice scour and break-up affects
	25/05/81-08/10/81	10 ft erosion	stable	north secondary channel slightly enlarged	
				deposition in main channel (at thalweg) of 5 ft depth and 220 ft width	shape of deposit appears to be of a transverse section of a bar or possibly of a single large dune

Table 3 (cont'd).

Cross-section	Date	South Bank	North Channel	Channel	Remarks
Summary: Significant changes in bar location have taken place since 1977. The pre-construction trend of main channel deposition has continued with a large deposit forming in 1981.					
2B (Fig 27)	22/09/77-08/10/81	stable	stable	relatively stable	cross-section located on channel south of Wenrich Island
Summary: The channel has remained stable since 1977, therefore there is no reason to suspect a shift of flow into this channel south of Wenrich Island.					
X5 (Fig 28)	30/09/78-02/10/79	stable	stable	relatively uniform scour of 2 ft across entire channel	located on Chena River scour probably resulting from 1979 high flows
	02/10/79-14/10/80	stable	stable	minor deposition at thalweg	
	14/10/80-15/09/81	stable	stable	minor scour and deposition across channel	changes probably fall within typical year to year variations however some trend toward scour on the right side of the channel is *indicated*
Summary: This channel located at the mouth of the Chena River has remained fairly stable since 1977 with no reason to suspect future channel changes.					
X4 (Fig 29)	30/09/78-04/10/79	70 ft erosion	stable	scour at thalweg of 2 ft over a 200 ft width	located just downstream of Chena River confluence
	04/10/79-20/10/80	70 ft erosion	stable	deposition at thalweg of up to 6 ft	
				deposition on north side of channel	this depositon appears suspect, possibly survey error
	20/10/80-15/09/81	30 ft erosion	stable	north bank deposit no longer present	disappearance indicates there was a 1980 survey error
				dune-like deposit of up to 5 ft depth at previous thalweg	
				large bar formation of up to 10 ft depth and 200 ft width near mid-channel	deposit becomes exposed at later date with lower discharge

Table 3 (cont'd).

Cross-section	Date	South Bank	North Bank	Channel	Remarks
	15/09/81-17/03/82	10 ft erosion	stable	scour along entire channel width with significant scour on south side of bar and at thalweg where dune-like deposit has disappeared	through the ice survey

Summary: All surveys show a trend of erosion of the south bank since 1978. The significant channel changes has been the formation of the large mid-channel bar. Further surveys are required to determine the permanence of the bar.

Cross-section	Date	South Bank	North Bank	Channel	Remarks
X3A (Fig 30)	01/10/78-04/10/79	stable	30 ft erosion	scour at the thalweg of 10 ft	
				deposition of up to 5 ft on south side of main channel	
	04/10/79-14/10/80	stable	75 ft erosion	deposition on south side of main channel extending bank northward about 200 ft	survey of main channel missing in 1980
	14/10/80-23/05/81	stable	stable	thalweg depth and shape similar to last survey in 1979 but migrated to north	main channel included in 1981 similar to 1979 survey
	23/05/81-07/10/81	stable	60 ft erosion	migration of thalweg in conjunction with north bank erosion but depth reduced 5 ft	
				scour on south bank of main channel of 10-15 ft depth and 400 ft width	scour of mid-floodplain channel

Summary: There has been a trend of north bank erosion throughout the survey history ranging from 30-75 ft per runoff season. The October 1981 survey shows a change in channel cross-section shape from previous years due to scour of the middle of the floodplain and a smaller thalweg depth.

Table 3 (cont'd).

Cross-section	Date	South Bank	North Bank	Channel	Remarks
X3B (Fig 31)	01/10/78-07/10/81	stable	stable	stable	located on channel south of Byers Island
Summary: The stability of this channel to the south of Byers Island indicates there has been no shift in flow to the south through the 1981 runoff season.					
X2 (Fig 32)	04/10/78-03/10/79	80 ft erosion	stable	deepening at thalweg and migration in conjunction with south bank erosion	located downstream of Byers Island and probably out of reach of Phase III construction affects
				deposition on north side of main channel	
	03/10/79-10/10/80	60 ft erosion	stable	slight fill at thalweg and migration to south	
				deposition on north side of main channel	
				migration of north secondary channel to the south of 150 ft	
	10/10/80-09/10/81	80 ft erosion	stable	migration of thalweg to the south	
				deposition on north side of main channel	
				migration of north secondary channel to the south of 100 ft	

Summary: This cross-section is located downstream of Phase III construction and is assumed unaffected by the construction. Changes are therefore thought to be within the normal annual variations. The trend is toward southward migration of all channel formations except the apparently stable north bank.

Table 4. Volumetric erosion, Bends A, B and C.

	Time Period	Aerial Photo Dates		Effective Time Period [1]		Volumetric Erosion (cubic yards) [2]			Volumetric Erosion Rate (cubic yards/year) [1]		
		From	To	Days	Years	Bend A	Bend B	Bend C	Bend A	Bend B	Bend C
Pre-construction Time Periods	1a	12 May 70	27 Jun 73	595	3.25	974,000	-	52,000	300,000	-	16,000
	1b	27 Jun 73	19 Sep 74	267	1.46	482,000	-	25,000	330,000	-	17,000
	1	12 May 70	19 Sep 74	862	4.71	1,456,000	456,000	77,000	309,000	97,000	16,000
	2	19 Sep 74	26 Sep 75	190	1.04	489,000	59,000	99,000	470,000	57,000	95,000
	3	26 Sep 75	4 Jun 76	69	0.38	127,000	6,000	114,000	334,000	16,000	300,000
	4	4 Jun 76	17 May 77	165	0.90	378,000	13,000	80,000	420,000	14,000	89,000
	5	17 May 77	4 Jun 78	201	1.10	372,000	29,000	90,000	338,000	26,000	82,000
	6	4 Jun 78	3 Jul 79	212	1.16	331,000	40,000	125,000	285,000	34,000	108,000
	7	3 Jul 79	7 May 80	126	0.69	148,000	18,000	26,000	214,000	26,000	38,000
	1 - 7	12 May 70	7 May 80	1825	9.98	3,301,000	621,000	611,000	331,000	62,000	61,000
	8a	7 May 80	8 Sep 80	124	0.68	29,000	-	-	43,000	-	-
Post-construction	8b	6 Mar 81	29 May 81	28	0.15	198,000	-	-	1,320,000	-	-
	8	7 May 80	29 May 81	205	1.12	-	67,000	36,000	-	60,000	32,000
	9	29 May 81	20 Oct 81	144	0.79	364,000	12,000	69,000	461,000	15,000	87,000
	8b & 9	6 Mar 81	20 Oct 81	172	0.94	562,000	-	-	598,000	-	-
	8 & 9	7 May 80	20 Oct 81	349	1.91	-	79,000	105,000	-	41,000	55,000

[1] Time periods and rates are based on a six month effective erosion year (May through October, 183 days).

[2] Volumetric erosion estimated using average thalweg depths of 30 feet (time periods 1 thru 8a) and 16.5 feet (time periods 8b thru 9) for Bend A, 25 feet (time periods 1 thru 9) for Bend B, and 29 feet (time periods 1 thru 9) for Bend C. Post-construction values for Bend A include the following spoils pile erosion volumes: 15,000 cubic yards during time period 8b, 90,000 cubic yards during time period 9, and 105,000 cubic yards during time period 8 & 9.

APPENDIX B

RELATIONSHIPS AMONG BANK RECESSION, VEGETATION, SOILS, SEDIMENTS AND PERMAFROST ON THE TANANA RIVER NEAR FAIRBANKS, ALASKA

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Tanana River Monitoring and Research Program

ABSTRACT

The objective of this analysis was to determine if available data are useful in identifying the characteristics that contribute to erodibility of the banks along two reaches of the Tanana River. Existing data on bank vegetation, soils, sediments and permafrost were used. Because these data were general and not collected for the purpose of site-specific analysis, my analytical approach was simple and did not include any statistical tests. The data were visually compared to the locations and estimated amounts of historical recession to evaluate if any relationships were obvious.

The results of this analysis showed no useful relationships. Vegetation was similar in eroded and uneroded areas and its distribution did not show any obvious relationship to the locations of bank recession. Surface sediments and soils in the eroded areas had little, if any, effect on bank erodibility because the river erodes the bank over its entire depth, which is well below this surface zone. The subsurface sediment from eroded and uneroded wells and along transects with high and low measured recession was similar. Permafrost occurrences are about equal in eroded and uneroded sites, although it appears that recession can be higher where permafrost is common than where it is absent. In most cases the existing data are either too general or not properly located to be useful in anticipating future locations of bank erosion. In order to predict future erosion, a field project should be initiated to evaluate the influences of bank characteristics and hydraulic forces on bank erosion rates.

PREFACE

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RELATIONSHIPS AMONG BANK RECESSION, VEGETATION, SOILS, SEDIMENTS AND PERMAFROST ON THE TANANA RIVER NEAR FAIRBANKS, ALASKA

by

Lawrence W. Gatto

INTRODUCTION

The Corps of Engineers, Alaska District, is responsible for the planning and construction of groins along the flood control levee between Fairbanks and the Tanana River (Fig. 1). The groins will be placed to divert the river southward from the north bank so as to stop bank erosion and bankline recession. The Corps plans to build additional groins as required to protect the levee from being undermined by bank erosion and to maintain 500 ft of land between the levee and the river. Any information on where future north bank erosion will likely occur would be useful to the Corps in planning the requirements for groin construction.

OBJECTIVES

This analysis was done to determine if the selected banks have characteristics that make them erodible and if these characteristics are identifiable from available data on bank vegetation, soils, sediments and permafrost. If the existing data could be related to historical bank recession, then these data could be used to anticipate where future bank erosion and recession would occur.

The available data, compiled from maps and well logs, were, however, not intended for a site-specific, comparative analysis such as this. Because these general data were not collected at locations proper for this type of study, detailed statistical analyses were neither warranted nor applicable. Consequently the comparative analyses were intentionally simple.

BACKGROUND

The roles of vegetation, soils, sediments and permafrost in influencing river bank erodibility are not firmly established, although it is agreed that they influence the rates of bank erosion and recession. In Alaska, the effect of permafrost on erodibility is perhaps the factor about which there is most debate. This disagreement is apparent in the papers reviewed by Scott (1979).

In general terms, the Fairbanks area is in the discontinuous permafrost zone (Ferrians 1965, Ferrians et al. 1969), as it is underlain by areas of moderately thick to thin permafrost in fine-grained deposits and by isolated masses of permafrost in coarse-grained deposits. Some investigators report that ice-rich permafrost increases bank recession beyond what would occur if ground ice were absent, because thermal erosion of the ground ice adds to the volumes of bank material eroded by river water abrasion alone (Lewellen 1972, Shamanova 1971). The higher the ice content in a bank, the faster the bank erosion (Are 1977, Shamanova 1971, Miles 1977).

In addition, thermal erosion (and consequently bank recession) may be more rapid when water is in contact with the frozen bank zone (Jahn 1975, Are 1977) and when either the temperature of the ice-rich permafrost is near 0°C or the water temperature is warm (Are 1977, Cooper and Hollingshead 1973, Jahn 1975).

Other investigators conclude that frozen sediments are harder to erode by fluvial action than unfrozen sediments (Outhet 1974) and permafrost tends to stabilize material that, if unfrozen, would be inherently unstable (Cooper and Hollingshead 1973). Consequently, permafrost may slow bank erosion and recession. Scott (1978) concluded that the frozen material has no direct effect on the rate of erosion if the bank erosion rate is lower than the thaw rate of bank permafrost; conversely, the frozen bank will retard erosion if the erosion rate is greater.

The question of the effects of permafrost on the erodibility of a bank is complicated by many factors: bank sediment texture and properties, ice structure of the permafrost, vegetation, river stage, bank aspect, current velocity, water temperature and angle of attack (severity of erosive attack) (Are 1977, Cooper and Hollingshead 1973, Jahn 1975, Miles 1977, Ritchie and Walker 1974, Scott 1978, and Smith 1976).

My purpose is not to try to resolve the disagreements regarding the effect that permafrost has on bank erosion. This would require a detailed, site-specific field study of selected river bank reaches. I mention this ongoing debate simply to point out a few of the factors that influence erosion and to emphasize the potential effects of permafrost on bank erosion along the Tanana River.

APPROACH

The Corps of Engineers, Alaska District, and CRREL personnel selected reaches 1 (Figs. 1 and 2) and 2 (Fig. 3) for analysis. It was understood that reaches 3 and 4 (Fig. 1) might be analyzed later if the results of this initial analysis showed that existing data could be useful for anticipating where future erosion may occur.

DATA SOURCES

The vegetation and soils information were obtained from available maps that show unit distributions throughout the Fairbanks area. As with all general maps, characteristics at a particular site may vary from the regional descriptions. Although these maps may be of debatable utility, no site-specific vegetation or soils data were available.

A broader range of data was available on sediments and permafrost. General information was taken from maps, and site-specific data were obtained from the logs of wells drilled by the Corps of Engineers. The well log data were collected for pre-construction analysis of the subsurface conditions along the planned route of the flood control levee. Consequently, the wells were drilled along or near this route, which runs approximately parallel to the bank, but not near the riverbank at most locations (Fig. 1).

The Corps classified the sediments from the wells according to the Unified Soil Classification System (Tables A1-A3). For comparison, Table A4 shows sediment sizes expressed in different scales. Descriptions of specific engineering characteristics of the sediments and nature of the permafrost are not included in the well logs, although information on the following are usually provided: color, presence or absence of organics and ice crystals, depth of seasonal frost and water table, ground water flow rate, percentage of silt, sand and gravel at sampled depths, layering within a given sediment type, penetration rate during drilling, and whether the sediment was frozen or wet.

ANALYTICAL METHODS

Initially, I transferred the Corps' well locations from maps onto base photographs (Fig. 4) and superimposed historical bankline positions onto the vegetation, soils and general sediment maps using a zoom transfer scope. The process of transferring and superimposing with a zoom transfer scope is, however, somewhat inaccurate.

I then plotted the sediment logs and categorized them in 5-ft depth intervals from the bank surface to the approximate depths that could be eroded by the river. These depths were obtained from available river cross sections. I had to assume for this analysis that the sediments and permafrost in a local area were similar to those in the closest well. Clearly this assumption may be invalid, but it was necessary in order to use the well log data. Two methods were used for evaluating the correlation between vegetation, soils, sediment and permafrost and riverbank erosion.

Method 1

The first method was to visually compare the vegetation, soils, sediments and permafrost data to detect any difference at eroded and uneroded well sites. There were two problems with this approach. First, the inaccurate positioning of the well sites with the zoom transfer scope influenced whether or not a well was positioned in the eroded or uneroded part of the bank (Fig. 4). This was a special problem where the wells were originally drilled near an old riverbank or where the wells are now near the bank due to bankline recession.

Second, it was not possible to determine whether a particular well location was eroded because of its vegetation, soil, sediment or permafrost characteristics or simply because it was drilled nearer the bank than an uneroded well. To adequately evaluate if bank erosion could be related to the available data, I eliminated this uncertainty by the second method.

Method 2

This second approach gave a measure of erodibility of the bank as a function of estimated bank recession and not well location. This approach used the well logs only to give profiles of bank sediments and permafrost. I had to assume for this method that the bank sediment and permafrost profile for a well was the same along an entire transect drawn through the well. The actual ground locations of the wells relative to the bankline were not important in this approach.

Transects were drawn perpendicularly to the historical banklines through the well sites, and the amount of bank recession for the historical periods was measured along these transects. Then I compared the bank characteristics to differences in measured recession. Although possible correlations can be more reliably evaluated with this second method, results from both methods are discussed for comparison so that inferences gained from either approach will not be overlooked.

RESULTS

VEGETATION

Vegetation information was available from maps and descriptions by Graham (1975) and Rieger et al. (1963). Information from the latter source was based on photointerpretation of 1951 photography. Haugen[1] suggested that the more recent information would likely be more reliable because fires in the Tanana River lowlands frequently alter the natural succession of trees. In addition, the Graham map contained more vegetation units for reach 2, which allowed a better evaluation of erosion differences between the units.

The Graham (1975) vegetation units (Fig. 5) are so general that only four tree types make up the four units. The vegetation in unit 9 was not given but it is probably similar to the others. Paper birch is in three units, while white spruce and balsam poplar are in two. This overlap complicates trying to infer if vegetation has affected erosion along these reaches.

Unit 2 is dominated by white spruce stands with secondary paper birch. The age of the white spruce trees could vary from 80 to 300 years (Table 1). Usually the elevation of the area with white spruce above the

[1] R. Haugen, CRREL, pers. comm. 1982.

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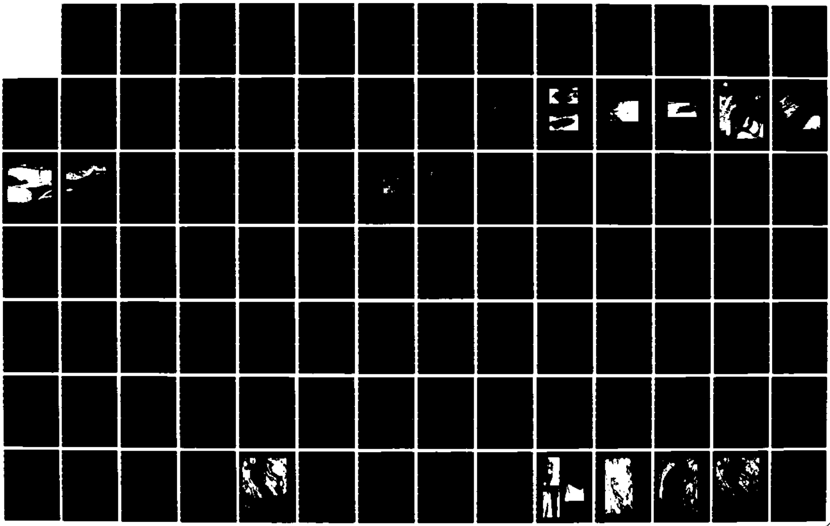

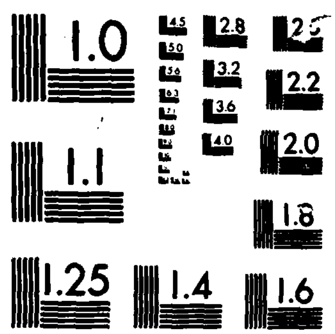

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river is higher than with other trees. Consequently, the frequency of floods, fluvial effects, and the percentage of shrub cover decrease with age.

Balsam poplar dominates in units 4 and 15. Generally the age would vary between 20 and 175 years. The elevation of the terrain would be lower than that with white spruce and would tend to be affected more by flooding and other fluvial actions. Also the shrub cover is more extensive (10% to 100%).

Paper birch dominates unit 5, which is usually a wetland. Frequently, paper birch succeeds after white spruce has been burned, so that the area where paper birch predominates is similar to that where white spruce is found.

Reach 1

White spruce/paper birch (unit 2) and paper birch/black spruce (unit 5) covered most of the land area along reach 1 that was eroded between 1948 and 1980 (Fig. 5). The north part of the reach was predominantly water and cultural features (unit 9). Three well sites are in unit 9 (Table 2), six in unit 2 and nine in unit 5.

Using the first analytical method, I estimated that one of the three wells in unit 9, all six in unit 2, and one of the nine in unit 5 were eroded between 1948 and 1980. From these figures, it can be inferred that the section with unit 2 vegetation is most erodible and that the sections with units 9 and 5 follow in decreasing order (Table 3).

Wuebben[2] pointed out that the amount of historical recession adjacent to the eroded well locations and the uneroded locations is nearly equal (Fig. 4). The recession for these two groups has occurred during different times as the river migrated and eroded different parts of the bank. The uneroded well locations (Fig. 4) are simply farther back from the 1980 bankline.

Following the second (or transect) method, the highest cumulative (1010 ft) and average (940 ft) recession occurred in unit 2 (Table 2), followed by unit 5 with 970 ft and 700 ft, respectively, and unit 9 with

[2] J. Wuebben, CRREL, pers. comm. 1982.

560 ft and 460 ft, respectively. However, unit 5 also had the lowest cumulative recession, 260 ft. These cumulative figures suggest that unit 2 is most erodible, followed by either units 5 or 9. However, the amounts of bankline recession along a transect change between the time intervals (Fig. 6) so that the effects of vegetation do not always influence bank erosion in the same way and the same bank erodes at variable rates.

From 1948 to 1961 most recession (Fig. 6; Table 4) occurred where unit 5 vegetation predominates and the least recession occurred in unit 2 vegetation. From 1961 to 1970, most recession occurred in unit 9 and 2 vegetation and less recession occurred in units 5 and 2. From 1970 to 1975, most recession occurred in unit 5 vegetation and there was no recession in units 9, 2 and 5. From 1975 to 1980 more of the bank with unit 2 vegetation receded faster than the portion with units 5 and 9, respectively (Table 4).

Reach 2

Most of reach 2 (Fig. 5) is covered by balsam poplar/white spruce (unit 15), followed by balsam poplar/paper birch (unit 4) and white spruce/paper birch (unit 2). Less unit 2 vegetation appears to be within the eroded area of reach 2 than within that of reach 1. "Water and cultural features" (unit 9) cover only a small part of the reach on the eastern end. The vegetation at well site 653 was not mapped (Table 5). One well was in units 2 and 9, three wells were in unit 4, and seven wells were in unit 15.

With the first method, it would be inferred that unit 15 vegetation is the most erodible along reach 2 because the only eroded well was in unit 15. The other units would be equally less erodible (Table 3). With the transect method, the highest cumulative recession (660 ft) occurred in unit 2 (Fig. 7; Table 5). The average recession in unit 4 was 390 ft (the high being 620 ft, the low, 0 ft) and the average in unit 15 was 240 ft (the high being 520 ft, the low 80 ft). No bank recession occurred in unit 9. This finding suggests that the bank with unit 2 vegetation is most erodible, followed by the banks with units 4, 15 or 9 in decreasing order.

With minor exceptions, the trends in the bankline recession have not changed drastically during any of the intervals (Fig. 7). The western end of the reach (Fig. 4) receded faster in each interval than the middle or eastern portions. However, interval recession varied drastically (Table 6) adjacent to particular wells and within the same vegetation unit.

From 1961 to 1970, high recession occurred in units 15, 4 and 2 while most of the recession was in unit 15. From 1970 to 1975, most recession occurred in unit 15 and less in units 2 and 4. From 1975 to 1980, most recession occurred in units 4 and 2 vegetation, while units 15, 9 and 4 showed no recession.

Discussion.

Although the amounts and the time of recession for a particular vegetation unit vary greatly, the cumulative recession data along both reaches suggest that banks with unit 2 vegetation receded the most and those with unit 9 vegetation receded the least (Table 3). This is contrary to what is frequently assumed. Investigators report that vegetation reinforces bank sediments (Smith 1976) and contributes to bank resistance (Mackin 1956). The binding from the vegetation root mat can retard slumping of undercut banks but is unimportant in limiting bank erosion along large streams (Scott 1978). One would expect less erosion along banks with extensive tree root systems (unit 2) than where man's activities (unit 9) may have adversely affected a forest cover and consequently reduced any potential bank reinforcement caused by the forest roots. The river, however, has eroded the bank to a depth well below that where roots are found. Along reach 1, this depth can be 32 ft below the ground surface, and 8 to 15 ft below along reach 2 (Fig. 8).

I suggest that falling trees may actually contribute to bankline recession. Once the supporting sediment below the tree root zone is eroded, the unsupported trees would lean and collapse into the river, carrying with them large amounts of bank sediment. Since the white spruce/paper birch trees in unit 2 may be older (Table 1) and have a more developed root system than the trees in the other units, they may remove more bank sediment when they collapse into the river. However, Wuebben[3] points out that bank erosion caused by collapsing trees may only be a

[3] J. Wuebben, CRREL, pers. comm. 1982.

local, temporary aberration. Since the bank was probably receding anyway, collapsing trees would remove soils only from the top of a bank and would dislodge a minor amount of extra soil. Along a forested bank, more significant bank soil removal and bankline recession might occur where many trees are collapsing frequently.

Chacho[4] agrees that the amount of bank sediment dislodged when trees fall would probably be insignificant. He suggests that the collapsed trees may protect the bank because they can frequently remain attached to the bank and lie against its submerged portion. As long as the trees remain attached, whether on the water surface or submerged, it could be argued that the bank is protected from river erosion because the currents are diverted from the bank and the current velocity near the bank is reduced. The protection offered by slumped vegetation has also been discussed by others (Scott 1978, Klimek 1975, Smith 1976, Miles 1977).

The comparisons between the measured recession and vegetation in the intervals gave inconsistent results. The bank along reach 1 with unit 5 vegetation receded the most during two intervals, and the least during two. Banks with unit 9 receded most during one interval and the least during two. Banks with unit 2 receded most during one interval and the least during three.

Along reach 2, banks with unit 15 vegetation receded the most during two intervals and the least during three. Banks with unit 4 receded most during one interval and the least during three. Banks with unit 2 receded most during one and the least during one.

In light of the inconclusive evidence from this analysis and the speculations on the effects that trees may have on bank stability, it is impossible to adequately infer where future bank erosion will occur from the distribution of vegetation types available on the existing maps. From my experience, I think this type of simple correlation is not valid without additional data. The influences of vegetation on bank erosion are neither simple nor consistent and many other factors may affect the amount of erosion that occurs at a location.

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[4] E. Chacho, CRREL, pers. comm. 1982.

The results suggest that either the vegetation has little effect on the erodibility of the bank or the existing data on vegetation are not detailed enough to be useful in determining possible vegetative effects. In my opinion vegetation is not an important factor influencing bank erosion along the Tanana River.

SOILS

The regional soil association along both reaches is loamy, consisting of nearly level histic pergelic cryaquepts[5] and typic cryofluvents[6] (Rieger et al. 1979). Along the lower parts of the floodplain, soils are poorly drained with permafrost. Soils on natural levees are well drained, with permafrost deep or absent. Due to extensive channel shifting, abandoned channels are numerous but not always conspicuous. Most areas of this association are flooded occasionally.

The histic pergelic cryaquepts occur in poorly drained, low areas such as meander scars. They have thick surface organic horizons and are usually saturated above a shallow permafrost table. These soils are usually stratified and range from silt to sandy loam. The typic cryofluvents occur on natural levees and are well-drained, having thin organic seams throughout and permafrost at 5 ft or more. Usually, they consist of stratified silt loam and fine sands, but some have uniform textures.

Three soil series were present along the two reaches, Salchaket (Sc), Bradway (Br) and Tanana (Ta) (Fig. 9). Characteristics of these soils are summarized in Table 7 and an idealized distribution of soils across the Tanana River floodplain is shown in Figure 10.

The differences between sediment textures and some of the characteristics of the three soil series (Table 7) are insignificant. One would not

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[5] Typic cryofluvents: mostly gray soils with alternating layers of sand and silt loam, usually underlain by thick very gravelly sand; some irregular black and brown streaks from buried organics; free of permafrost or only at great depth; usually occupy natural levees.

[6] Histic pergelic cryaquepts: soils with texture ranging from gravelly sand to clay, color from gray to olive grey, thick organic matter on surface; permafrost is shallow and active layer is saturated when thawed; textural soil layers are disrupted by freeze-thaw and frost processes; occur in lowlands and hilly areas.

expect a substantial difference in their erodibility. The Salchaket and Tanana soils form in similar locations and all three have sands and silts of variable thicknesses over gravels. Their profiles are similar: organics over silt loam over fine sand. The Salchaket soil typically has gravels beneath 2 ft. Drainage in the Salchaket is good, but poor in the Bradway and Tanana. The wetter Bradway and Tanana soils may be slightly more erodible due to their more persistent wetness. Permafrost is usually absent in the Salchaket above the gravels, but the Bradway and Tanana have permafrost at 3-4 ft and at about 30 in., respectively.

Reach 1

Ten wells are located in the Tanana soil and eight in the Bradway (Table 2). Three of the eight eroded sites were in Tanana soil and five were in Bradway. Seven of the 10 uneroded sites were in Tanana soil and three of 10 were in Bradway (Table 8). This trend suggests that the Bradway soil is more erodible. But as previously stated, this first method of simply comparing soils at eroded and uneroded well sites may not a reliable way to evaluate the erodibility of a bank with a particular soil. This is especially true when the soil distribution between the 1951 and 1980 banklines is as complex as it was along reach 1 (Fig. 9a). Clearly, different soils were being eroded during the intervals.

The following observations were made from the second method. The Bradway soil was the most frequently eroded (Table 9) along six of the eight transects where the cumulative recession was greater than 800 ft, while Tanana soil predominated along two of the eight (Table 4). Where 600 to 800 ft of cumulative recession was found, Bradway predominated along three of five transects and Tanana along two. Along the five transects with less than 600 ft cumulative recession, Tanana predominated along four and Bradway along one. Within these three recession ranges Bradway soil predominated along nine of 13 transects with more than 600 ft recession and Tanana predominated along four of 13. This suggests that banks with Bradway soil are more erodible.

When soils and recession within each historical interval are analyzed, a more complex and inconsistent picture results. From 1951 to 1961, average recession was 130 ft and Bradway soil predominated along 11 transects, Tanana along five and Salchaket along two (Table 9), yet the lowest recession occurred in Bradway soil and the highest in Tanana and Bradway soils. From 1961 to 1970, average recession was 160 ft (Table 9) and Bradway soil predominated along nine transects and Tanana along seven, yet the highest and lowest recession also occurred in Bradway soil. From 1970 to 1975, average recession was 250 ft and Bradway soil predominated along eight transects, and Tanana along three. The highest recession occurred in Bradway soil and no recession occurred along seven transects while Tanana soil predominated. From 1975 to 1980, average recession was 210 ft (Table 9) and Tanana soil predominated along nine transects, and Bradway along six. The highest recession occurred in Bradway soil and no recession occurred along three transects with Tanana soil.

Reach 2

The soil distribution along reach 2 (Fig. 9b) in the zone eroded between 1951 and 1980 is not as complex as it was along reach 1 (Fig. 9a). The Salchaket soil covered most of this zone, although Tanana soil covered a small central area. Nine wells were drilled in Salchaket soil (Table 5) and three in Tanana. None of the well sites in Tanana soil was eroded, while only one of nine sites (well 124) in the Salchaket soil was eroded. These results from the first method suggest that neither soil is appreciably more erodible than the other.

The following observations were made from the second method. Salchaket soil was eroded along the two transects where the cumulative recession was greater than 600 ft (Table 5). At areas with between 400 and 600 ft of cumulative recession, Tanana soil was eroded along one of two transects and Salchaket along one of two. Along the eight transects with less than 400 ft of recession, Salchaket occurred along six and Tanana along two. Since Salchaket soil occurs along seven of the 10 eroded transects (Table 5), both high and low cumulative recession occur in Salchaket soil only because it is more common along reach 2. Recession during the four intervals also shows inconclusive results.

From 1951 to 1961, average recession was 60 ft (Table 6) and most of the recession occurred in Salchaket soil (Tables 5 and 6) while five transects with Salchaket soil had no recession. The highest recession occurred in Tanana soil. From 1961 to 1970, average recession was 80 ft and the most recession for this time period and the highest recession occurred in Salchaket soil, while five transects in Salchaket soil had no recession. From 1970 to 1975, average recession was 110 ft and Salchaket soil occurred where the most and the highest recession occurred. Salchaket soil also occurred where there was no recession. From 1975 to 1980, average recession was 30 ft. The highest recession and those transects with no recession were in Salchaket soil.

Discussion

Most recession along reach 2 occurred in Salchaket soil, but recession along reach 1 was primarily in Bradway. Bank recession was lowest along reach 1 where Salchaket soil occurred and along reach 2 where Tanana occurred. The average recession along reach 1 per interval was much higher than along reach 2, which suggests that the Bradway and Tanana soils along reach 1 are more erodible than the Salchaket and Tanana soils along reach 2. However, this apparent relationship is not straightforward.

The main portion of river flow shifts (Figs. 4 and 9) and different soils were eroded at different rates during the intervals. There does not appear to be a preferential trend controlled by soil distribution. It may be that the soil most eroded along a reach is simply that which is most common in the area. Clearly the Bradway (reach 1) and Salchaket soils (reach 2) are most common.

Most of the eroded wells and the highest cumulative recession (Table 8) along reach 1 were in Bradway soil. The group of transects where the most recession occurred per interval was also in Bradway soil for three of the four intervals. Likewise, the highest recession per transect occurred where Bradway soil was dominant in three of the four intervals (Table 8). However, Bradway soil also occurred along transects where the lowest recession per interval was measured.

Along reach 2 Salchaket soil is most common and occurs in the only eroded well. It is also predominant in the uneroded wells and along transects where the cumulative and per interval recession are highest and lowest. Nothing conclusive can be stated from these observations. It is probably true that Salchaket soil is most frequently eroded along reach 2 only because it is most common, not because it is more erodible.

In addition, the portion of the bank eroded by the river includes more than just the upper few feet where the soils have formed. The river erodes the entire bank from the waterline to the bottom of the channel. As previously mentioned, the Tanana River can be 32 ft deep along reach 1 (Fig. 8).

On 6 October 1979 when cross section 4A was taken, the water surface was between 417 and 418 ft msl, equivalent to a discharge of approximately 17,000 cfs. The river stage and discharge are generally higher than these for five months of the year, from late April through September, and lower for seven months, from October to late April. Typically, in non-flood conditions, the high water level reaches about 423 ft msl when the summer discharge peaks between 70,000 and 80,000 cfs (Burrows et al. 1981). This peak period lasts for approximately two weeks.

The typical Bradway soil profile extends to only 3 ft (Table 7). So normally the river water level reaches the lower 1 to 2 ft of the Bradway soil profile for about two weeks of the year. During the rest of the year, the river water erodes the 29 ft of the bank below the Bradway soil.

Bradway soil may be more erodible than the Tanana or Salchaket soils and therefore erodes more rapidly during this two-week high water period. However, the evidence is insufficient to demonstrate a relationship between any of the three soil series and areas of erosion along these reaches. Consequently, I suspect that the soils do not significiantly influence the location or rate of bank erosion and bankline recession.

SEDIMENTS AND PERMAFROST

Data on sediments and permafrost were available from maps and from well logs. The map information was general and the log data were site-specific and more reliable in characterizing bank conditions. Consequently, I analyzed the site-specific well logs more thoroughly than the maps. However, as mentioned previously, the logs do not generally show the sediment and permafrost characteristics in the eroded zone unless the well site was eroded. I assumed that the well site data were representative of the sediments and permafrost along the transects through a well.

The Tanana River lowland was unglaciated but contains several hundred feet of glacially fed river silt, sand and gravel deposits called the Chena alluvium. The alluvium consists of well-stratified sands and gravels (Q_c) and swale and slough deposits (Q_{cs}) (Fig. 11). Since Illinoian time these deposits have been modified by alternating periods of deposition and erosion, with the formation and destruction of permafrost. The next three paragraphs, summarized from Péwé et al. (1976) and Péwé and Bell (1974, 1976a, b, c), give a brief description of the Tanana sediments in this area.

The Q_c sands and gravels are usually 10 to 400 ft thick, with well-stratified and unconsolidated sands in rounded gravels, 1/4 to 3 in. in diameter. Gray silts and clays, $\leq$ 15 ft thick, overlay the sands and gravels. Permafrost, 2 to 275 ft thick, occurs locally. Ice content of the permafrost is usually low and restricted to pore spaces and thin seams (<1/16 in.) in the silts and clays.

The Q_{cs} swale and slough deposits are poorly stratified, unconsolidated, angular to subrounded silts and silty sands usually less than 15 ft thick, although they are up to 30 ft locally. These silts and sands are fairly well sorted and contain organic material and 10 to 30% clay. Permafrost occurs locally with ice contents that vary from moderate, with ice restricted to pore spaces and seams 1/16 to >1/4 in. thick, to high, with large ice masses.

Other than the dominant sediment particle size and sediment layer thickness of the overlying the sands and gravels, there is little substantial difference between Q_c and Q_{cs}. Drainage is usually better in Q_c, but both are subject to flooding [Table 10]. The depth of the permafrost is usually greater in Q_c and the seasonal frost layer is 2 to 9 ft thick. The depth of permafrost is 1.5 to 4 ft in Q_{cs}. The ice content in the permafrost is low to moderate in Q_c and moderate to high in Q_{cs}. The water table is 10 to 15 ft in both units. The silts of Q_c are moderately to highly susceptible to frost action, while Q_{cs} is highly susceptible. Both units have high bearing strength when frozen, but low strength when thawed. Thawed Q_c silts are poorly drained. Slopes in Q_c usually are steeper because Q_{cs} sediments slough and slide easily when thawed.

Reach 1

Sediments - General. Thirteen wells were drilled in Q_c and five in Q_{cs} (Table 2). Six of the eight eroded sites were in Q_c, while two were in Q_{cs} (Table 11). Seven of the 10 uneroded well sites were also in Q_c, and three were in Q_{cs}. These results are not conclusive. The percentages of wells eroded and uneroded in each unit are about equal. Possibly Q_c may be more common than Q_{cs} along reach 1 (see Fig. 11).

The following observations are based on the transect method of analysis. Q_c sediments were more common than, or equal to, Q_{cs} sediment along transects where cumulative recession was greater than 800 ft (Table 2), Q_c dominated along all transects with 600 to 800 ft of cumulative recession. The transects where recession was less than 600 ft were also through predominantly Q_c sediments. Thus these results are also inconclusive. The highest and lowest cumulative recession occurred where Q_c predominated. The results from the comparisons of recession by interval are no more definitive.

From 1966 to 1975, recession along 10 of 11 transects (Table 4) occurred in predominantly Q_c sediments (Figs. 4 and 11), no recession occurred along six transects where Q_c also predominated, and the highest recession occurred in Q_{cs} sediment. From 1975 to 1980, more erosion occurred along 11 of 15 transects in Q_c and four of 15 through Q_{cs} and no recession occurred along three transects also in Q_c. Thus these comparisons using Q_c and Q_{cs} data produced inconclusive results and the comparisons using the site-specific well log data were equally inconclusive.

Sediments - Site-Specific. Sediment data (Table A5) obtained from 18 well logs (Fig. 12) show the following. Generally along reach 1, the upper 15 ft of the bank (410 to 425 msl) is predominantly composed of silts and fine sands (ML, Table A1) near the surface (Table A5) with silty sands (SM) and gravelly sands (SP) at depth. The silts and fine sands have low permeability and shear strength and high compressibility (Table A3). The silty sands have low to medium permeability and medium shear strength and compressibility. Gravelly sands are highly permeable, having high shear strength and low compressibility. Below 410 msl (Table A5), most of the bank sediment is poorly graded sand or gravelly sands (SP) and clean gravels (GP). The GP gravel has very high permeability, high shear strength and low compressibility.

The sediments in the group of eight eroded wells (Table A6) and in the group of 10 uneroded wells (Table A7) are similar to those along the reach as a whole (Table A5) and are similar to each other (Fig. 13). In most of the classes within the seven depth intervals (Fig. 13), the difference between the groups of eroded and uneroded wells was in the percentage of a particular class, and the dominant sediment class in the eroded and uneroded wells was the same at four of the seven levels. In the 430- to 425-ft interval there was only one well (Fig. 13). The dominant sediment, SM and GP, at two of the three remaining levels in the eroded wells had higher shear strength than the sediments at the same levels in the uneroded wells, which seems contrary to what would be expected.

Clean to sandy gravels (GP) are the predominant sediments in four of eight eroded wells and one of 10 uneroded wells (Table 2). Silty to gravelly sands (SM-SP) predominate in three of the eroded and six of the uneroded wells. Inorganic silts (ML) are dominant in one of the eroded and three of the uneroded wells. This suggests that wells with finer-grained sediments in the column are more stable than those with coarser sediments.

The highest cumulative recession (>600 ft) occurred along 13 transects through wells 2170 to 662 (Table 2). Silty to gravelly sands (SM-SP) dominated along seven clean to sandy gravels (GP) along three, and inorganic silts (ML) along three. Cumulative recession less than 600 ft occurred along five transects. The dominant sediment was SM-SP along two, GP along two and ML along one. The lowest and highest cumulative recession occurred in wells with very similar sediments (Table 2).

The analysis of the interval recession produced the following results. The transects with most recession had predominantly SM and SP or GP sediments (Table 2). Each sediment class was dominant during two intervals. The intervals with the highest and lowest average recession (Table 3) had similar sediments along the group of transects where the most recession occurred.

The sediment along the transect with the highest recession during two intervals was GP, while it was ML and SM during one (Table 11). The same classes were also dominant along transects with the lowest recession during various intervals. The dominant sediments in every interval were SP and SM, and in decreasing order, GP and ML (Table 11). Even though the average recession varied per interval (Table 4) no obvious major difference was discernible from the available sediment data. This suggests that either these data cannot be used for defining bank sediment differences sufficiently to evaluate their erodibility or that the sediments are similar enough that they do not influence erosion preferentially in any way.

Permafrost. The distribution of frozen ground detected in the wells does not show any relationship to the location of the eroding bank. The deepest frozen ground is at well 2168 (Fig. 12). Most of the frozen ground deep enough to be eroded by the river was located in wells 2104, 2102, 2101, 2293, 2172, 2171, and 2229. The zone of most recession (wells 2169 to 2101) has frozen ground that is variable; for example, 2171 was frozen to about 28 ft and 2173 was unfrozen. At most of the other wells, frozen ground is found above 422 ft msl, which is above the portion of the bank affected by the river for most of the year.

A comparison of eroded and uneroded wells in regard to permafrost occurrence gives the following observations. In the eight eroded wells (Tables 2 and 11), five (2165, 2169, 2170, 2164 and 2228) had only seasonal frost to a depth of 2.5 ft and three wells (2229, 2171, and 2101) had permafrost up to a depth of 0-28 ft. In the 10 uneroded wells, five (2172, 2168, 2293, 2102 and 2104) had permafrost that was up to 50 ft deep. Most of the permafrost in uneroded well 2168 was below the 32-ft erosion zone (Fig. 12). Five uneroded wells and three eroded wells had permafrost within the erosion zone. This suggests that the presence of permafrost cannot be used to predict where bank erosion may occur.

Permafrost occurred along 5 of 13 (38%) transects where cumulative recession was greater than 600 ft (Table 11). Two of five (40%) transects in that part of the reach where recession was less than 600 ft had permafrost. The similarity of these percentages also suggests that permafrost may not affect bank erosion. This is speculative, however, considering the previously mentioned shortcomings of the available data.

Permafrost predominated along transects where the most recession occurred during two intervals, yet from 1961 to 1970 none of the transects in the high-recession group had permafrost (Table 11). Along the transects where recession was highest or lowest during an interval, permafrost was present about as frequently as it was absent (Table 11).

Permafrost was absent more often than it was present along transects where recession occurred during each interval except during the 1970-1975 interval. Recession during this interval was 250 ft, the highest of the four intervals (Table 4). This suggests that more recession may occur where permafrost is common along a bank.

Reach 2

Sediments - General. The Q_{cs} sediments do not occur along reach 2 within the area of the bank eroded from 1966 to 1980. So it is impossible to speculate about the comparative erodibility of these units along reach 2.

Only well 124 was eroded from 1970 to 1980 (Table 5) and its measured recession was variable. From 1970 to 1975 the bank near well 124 receded 260 ft but it did not recede at all from 1975 to 1980 (Table 6). While the banks adjacent to uneroded wells 651 and 33 receded in both intervals, nothing conclusive can be said about the erodibility of sediments in well 124 compared to those in the adjacent uneroded wells.

Sediments - Site-Specific. Thirteen well logs (Fig. 14) along reach 2 were analyzed. I used three October 1979 cross sections (Fig. 8) to determine the depth of the north bank that could be eroded by the river. Earlier cross sections were not available. This depth varies from west to east: 13 ft (417 to 430 ft msl) along 7A, 15 ft (418 to 433 ft msl) along 8A, and 12 ft (421 to 433 ft msl) along X9. The sediment sizes increase with depth in the zone from 417 to 435 ft msl (Table A8).

Generally the upper 10 ft of the bank are peat (PT) and inorganic silts (ML), while the lower part is silty to gravelly sands (SM to SP) and sandy to clean gravels (GP-GW) (Table A8). The silts have low permeability and shear strength and high compressibility (Table A3). The sands have low to high permeability, medium to high shear strength and medium to low compressibility. The gravels are highly permeable, have high shear strength and low compressibility.

The most common sediment class in the one eroded well was GW, while ML and PT were secondary (Table 11). ML dominated in 10 of the 12 uneroded well sites, suggesting that the larger sediments along reach 2 may be more erodible.

The sediment in the eroded well (Table A9; Fig. 15) had a higher percentage of gravels than that in the uneroded wells (Table A10). These gravels were nearer the surface in well 124 (Fig. 14) than in the uneroded well 39 (which was drilled in the river channel). Nothing conclusive can be said based on data from one eroded well, but I do not think that a bank with gravel near the surface will necessarily be more erodible than a bank with gravel below the surface.

I made the following observations based on recession measurements and the well sediment data. Cumulative recession both greater and less than 400 ft occurred most frequently where ML predominated along the transect (Table 11). ML also was most common along the transects within the group where most recession occurred and along the highest recession transect during the four intervals. However, ML predominated where the lowest recession occurred. The dominant sediment was ML along the transects where recession was measured in each interval. There is very little difference between the sediment in the wells having the highest and lowest recession.

These results are inconclusive. It may be that ML is simply the most common sediment along the reach, and since the sediments are not different enough to affect bank erodibility, ML occurs where recession is highest and lowest. As along reach 1, the sediments along reach 2 are also similar and do not show sufficient differences to be useful in trying to explain if a particular bank location is more or less erodible than another.

Permafrost. Permafrost was not encountered in any of the wells along reach 2. Comparisons between sites with and without permafrost could not be made.

Discussion

Comparisons of the apparent erodibility of Q_c and Q_{cs} sediments and of bank sites with or without permafrost between reaches 1 and 2 could not be made because Q_{cs} sediment and permafrost did not occur along reach

2. The well data (Figs. 12 and 14) for the two reaches suggest that the sediments along reach 1 are more variable than those along reach 2. Also the sediments along reach 1 are generally coarser, although this may simply reflect the fact that the reach 2 wells were shallower and did not get into the coarser sediment as frequently. Visually comparing the logs in the upper 15 ft substantiates this.

Based on the available cross sections, the river eroded about 18 ft of the north bank along reach 2 and 32 ft along reach 1. Since more sands and gravels were eroded along reach 1, this may help explain the higher average recessions along reach 1 (Tables 4 and 5). This may also be explained by the river's angle of attack along the two reaches. The river hit the bank at reach 1 at a steeper angle from 1948 to 1980 than it did along reach 2, and therefore the erosive forces of the flow would be much higher. This is especially true along reach 1 from 1970 to 1980.

The sediment data for the two reaches are similar. The lack of any consistent relationships between sediments and recession suggests that the sediments do not influence bank erodibility enough to be detectable with the available data.

SUMMARY AND CONCLUSIONS

Available data on vegetation, soils, sediments and permafrost were compared to the locations and amounts of historical bank recession southeast of the Fairbanks International Airport. I found only inconclusive relationships between these data and the recession.

The differences in the vegetation units do not appear to be great, since each tree species of a given unit occurs in two other units found along the reaches. No vegetation unit occurred consistently in eroded areas. Cumulative recession data suggest that unit 2 vegetation is found where most recession occurs and unit 9 where it least occurs. However, recession measured during historical intervals does not relate in any consistent way to available vegetation units.

The Bradway soils that were eroded along reach 1 were absent in the eroded zone along reach 2. The Salchaket soils, eroded least along reach 1, were eroded most along reach 2. Along both reaches, Tanana soil was generally eroded the least. But any relationship between soils and bank recession is questionable. The soil only covers the upper 2 to 4 ft of the bank and the river erodes down to 32 ft along reach 1 and 18 ft along reach 2.

I suspect that apparent relationships between high recession and Bradway soil along reach 1 and Salchaket soil along reach 2 result from the fact that these two soils dominate along the respective reaches and are simply eroded more frequently than the others.

Along the two reaches, the sediments are similar in the eroded and uneroded wells and along transects with high and low recession. Sediments in the groups of eroded and uneroded wells are similar within and between the groups. As with the soils data, many of the apparent relationships were probably a result of one sediment type being dominant along the reaches and not due to real differences in bank erodibility.

The USCS sediment classes, as generally defined, are not sufficiently dissimilar and do not give enough detailed sediment information to allow evaluation of differences in the sediment that may influence bank erodibility. Permafrost occurrences are about equal in eroded and uneroded sites, although it appears that recession can be higher where permafrost is common than where it is absent.

Because most of the results from the comparative analysis were inconclusive and because the surface sediments are so similar and the soils and vegetation root zones occur in only the upper few feet of the banks, the hydraulic forces of the river water (i.e. the distribution of currents, current velocities and meandering patterns), are almost certainly the predominant erosion factors. For most of the year, the river erodes a bank zone well below the upper few feet of the bank, and the similar sediments, soils and vegetation do not act as significant controlling factors of bank erosion.

I conclude that available data cannot be used to anticipate where future erosion may occur. A systematic field study of bank characteristics and erosion processes would be required to evaluate possible relationships among vegetation, bank sediment, permafrost, and erosion.

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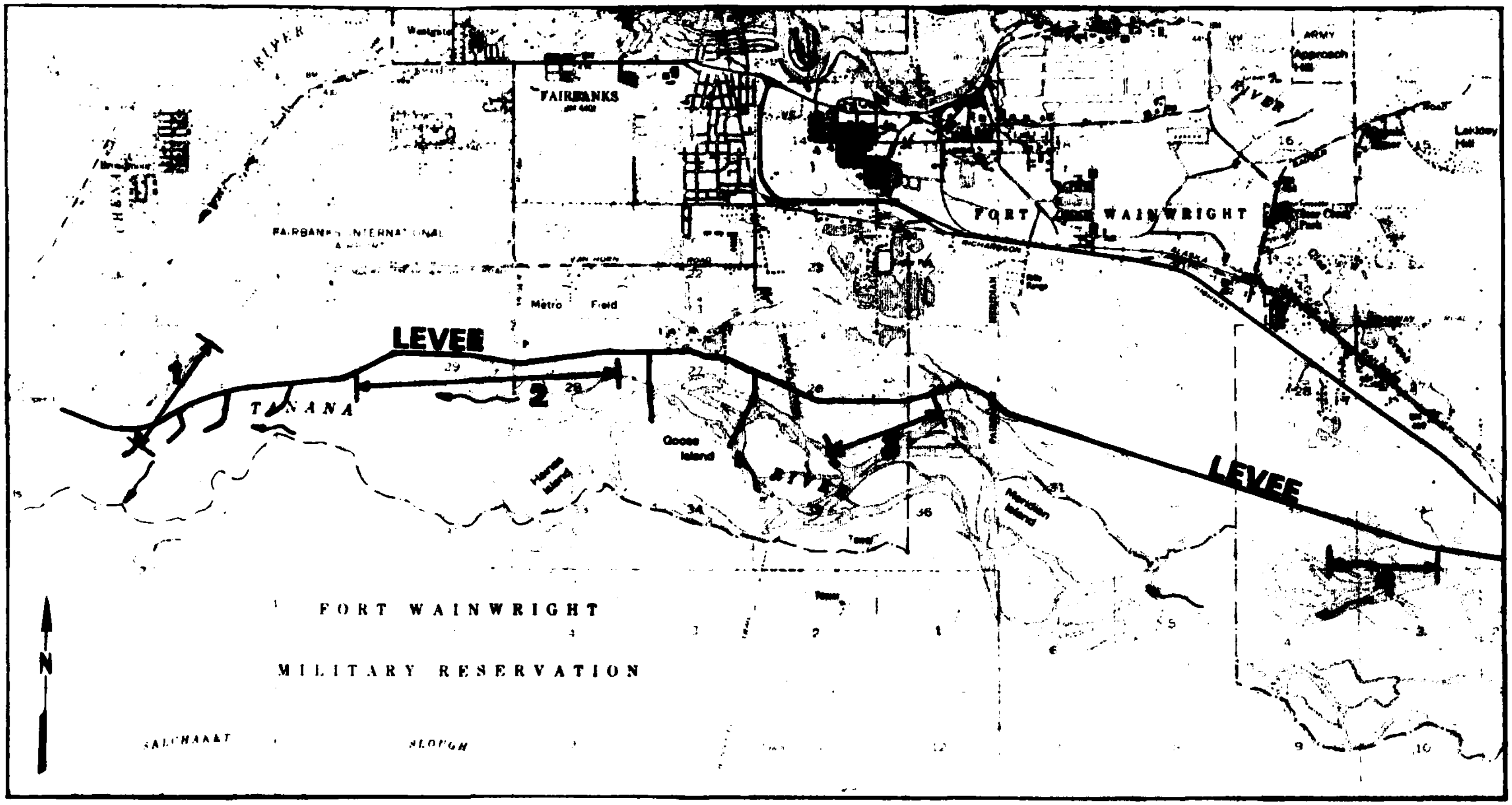


Figure 1. Location map (from USGS 1:63360 Fairbanks D-2 quadrangle).

a. Upstream end of revetment.

b. Downstream end of revetment.

Figure 2. Upstream portion of reach 1 with riprap revetment (white arrow), 2 October 1980.

c. Bank erosion just downstream of revetment. Note the sandy-silt bank sediment (field book for scale).

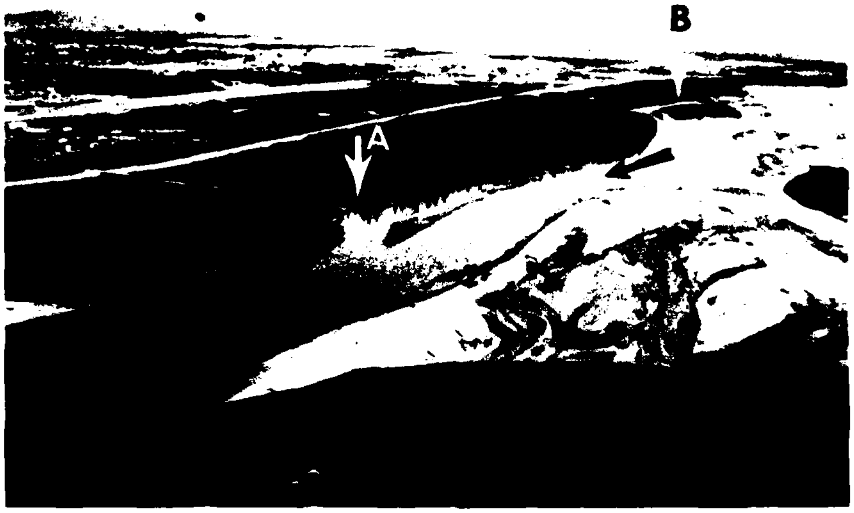


Figure 3. Upstream portion of reach 2, 9 May1980; USGS gauging station (A) and the approximate location of well 43(B).

a. Reach 1, note revetment shown in Figure 2.

Figure 4. Approximate historical bankline positions (from Buska 1981) and well and river cross-section locations (photographs taken 7 May 1980; 1:5000 scale).

b. Western part of reach 2.

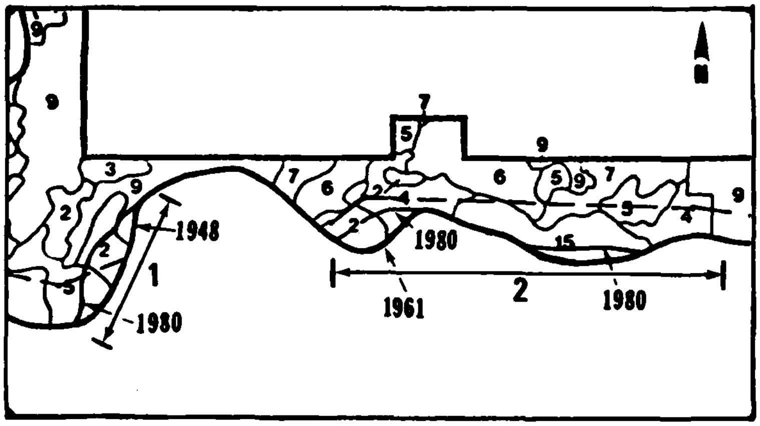
Figure 4 (cont'd).

c. Middle part of reach 2; note the USGS gauging station.

Figure 4 (cont'd).

a. Eastern part of reach 2.

Figure 4 (cont'd).



2	White spruce/paper birch
4	Balsam poplar/paper birch
5	Paper birch/black spruce (usually a wetland)
9	Water and cultural features
15	Balsam poplar/white spruce

Figure 5. Vegetation distribution (Graham 1975); bankline position similar to that in 1948 along reach 1 (Fig. 4) and 1961 along reach 2 (Fig.4).

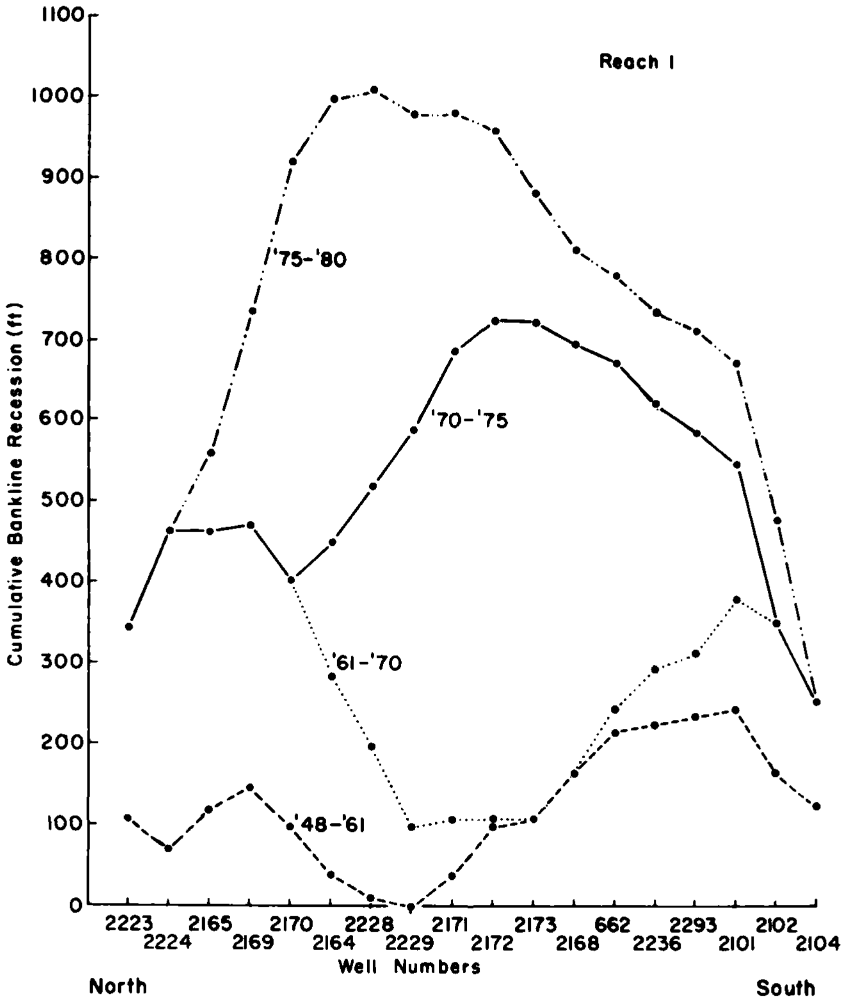


Figure 6. Bankline recession adjacent to the wells along reach 1.

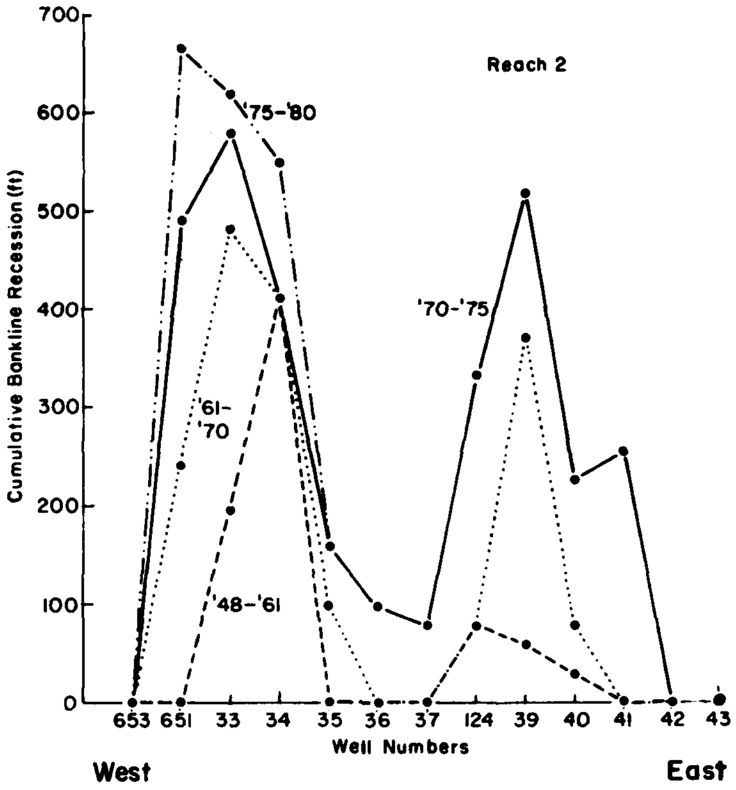


Figure 7. Bankline recession adjacent to the wells along reach 2.

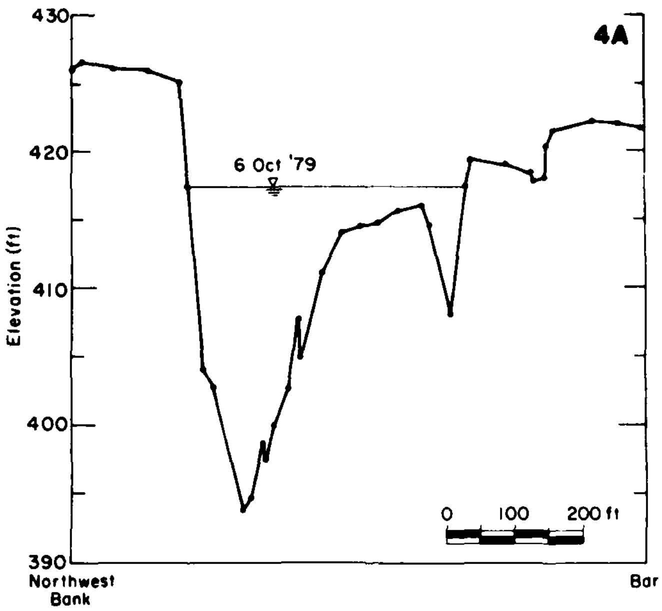


Figure 8a. West part of cross-section 4A (locations on Fig. 4).

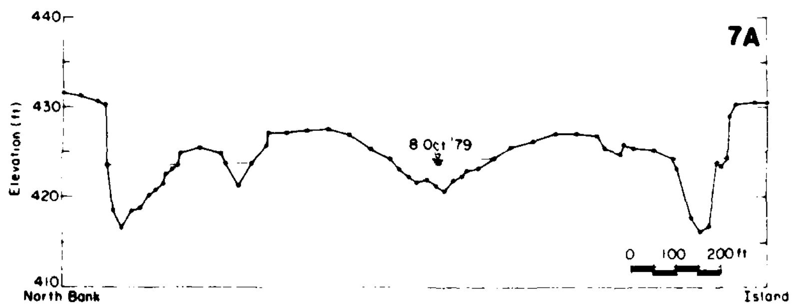


Figure 8b. Cross section 7A.

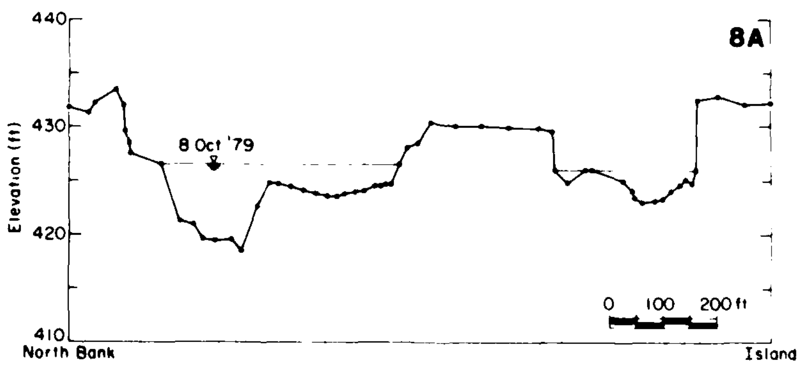


Figure 8c. Cross section 8A.

Figure 8. Cross sections 4A, 7A, 8A and X9.

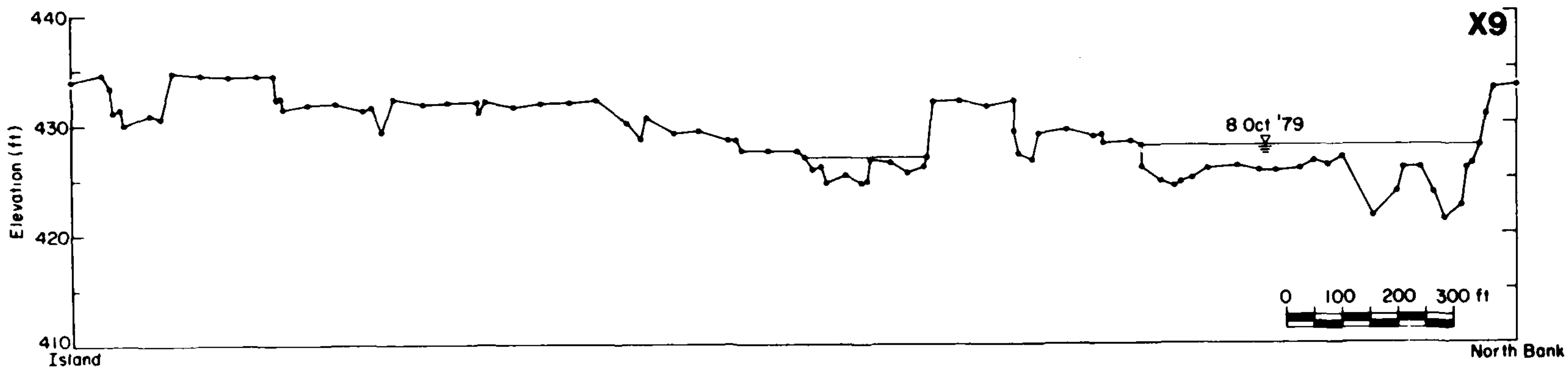
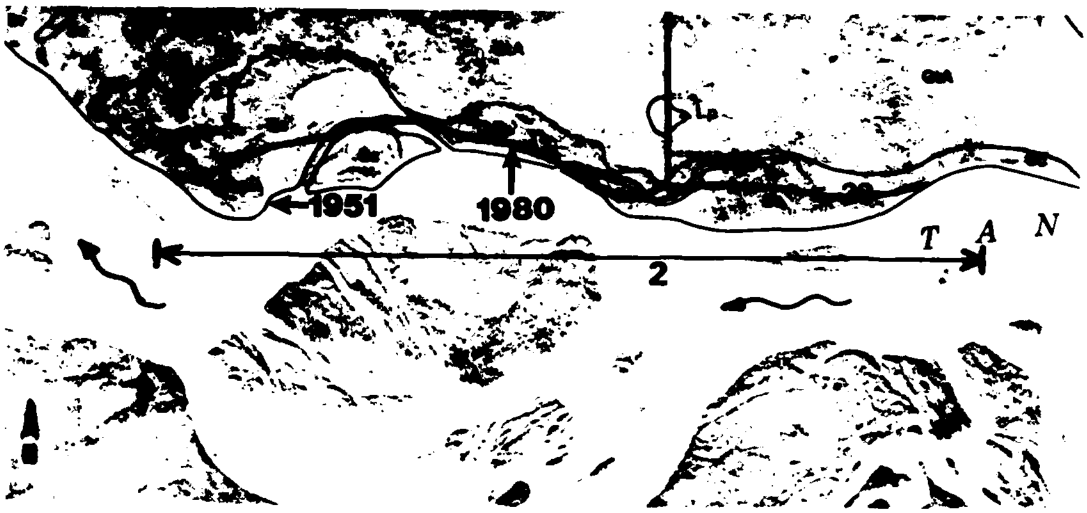


Figure 8d. Cross section X9.

Figure 8 (cont'd)

a. Reach 1.

Figure 9. Soil series (from Rieger et al. 1963). The bankline is as shown in 1951 photography and is similar to that in 1948 (Fig. 4a). For purposes of this analysis, the two banklines were considered the same.



b. Reach 2.

Figure 9 (cont'd).

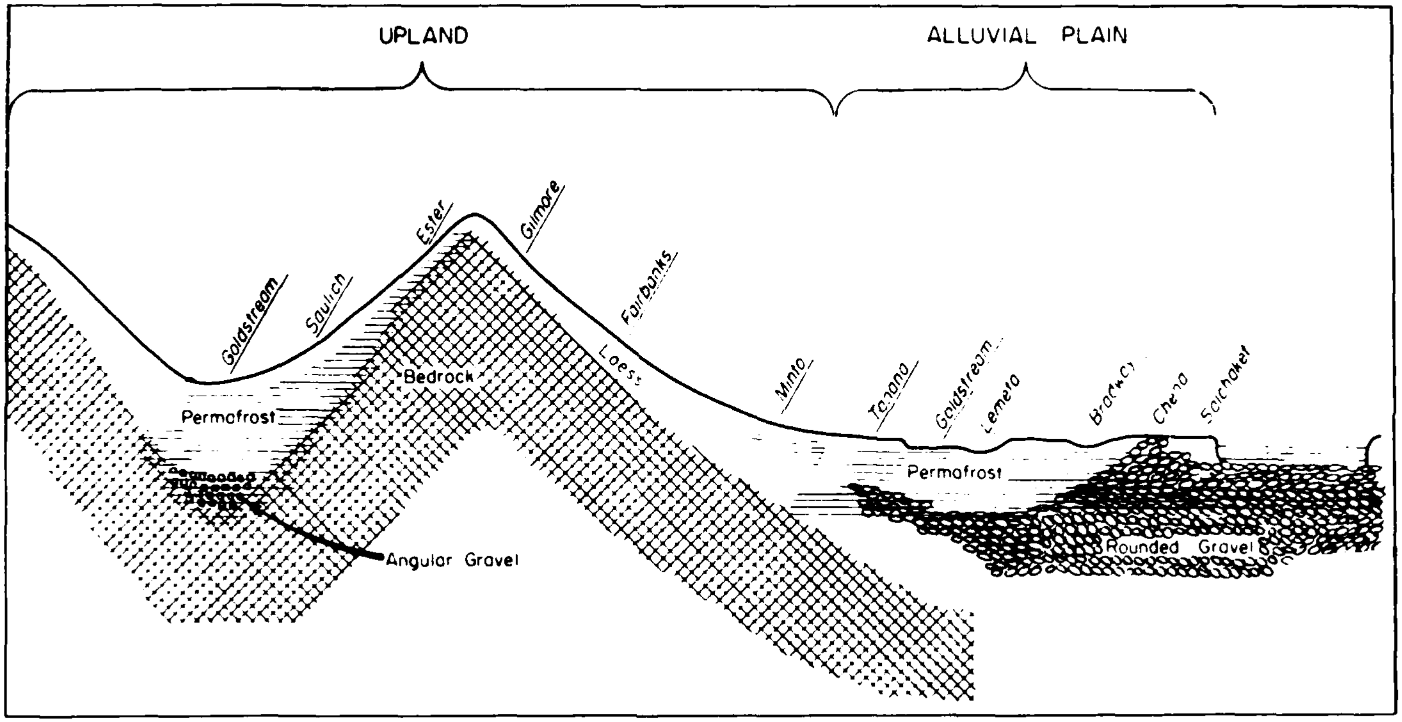


Figure 10. *Generalized landscape showing relative distributions of soil series, underlying material and permafrost (from Rieger et al. 1963).*

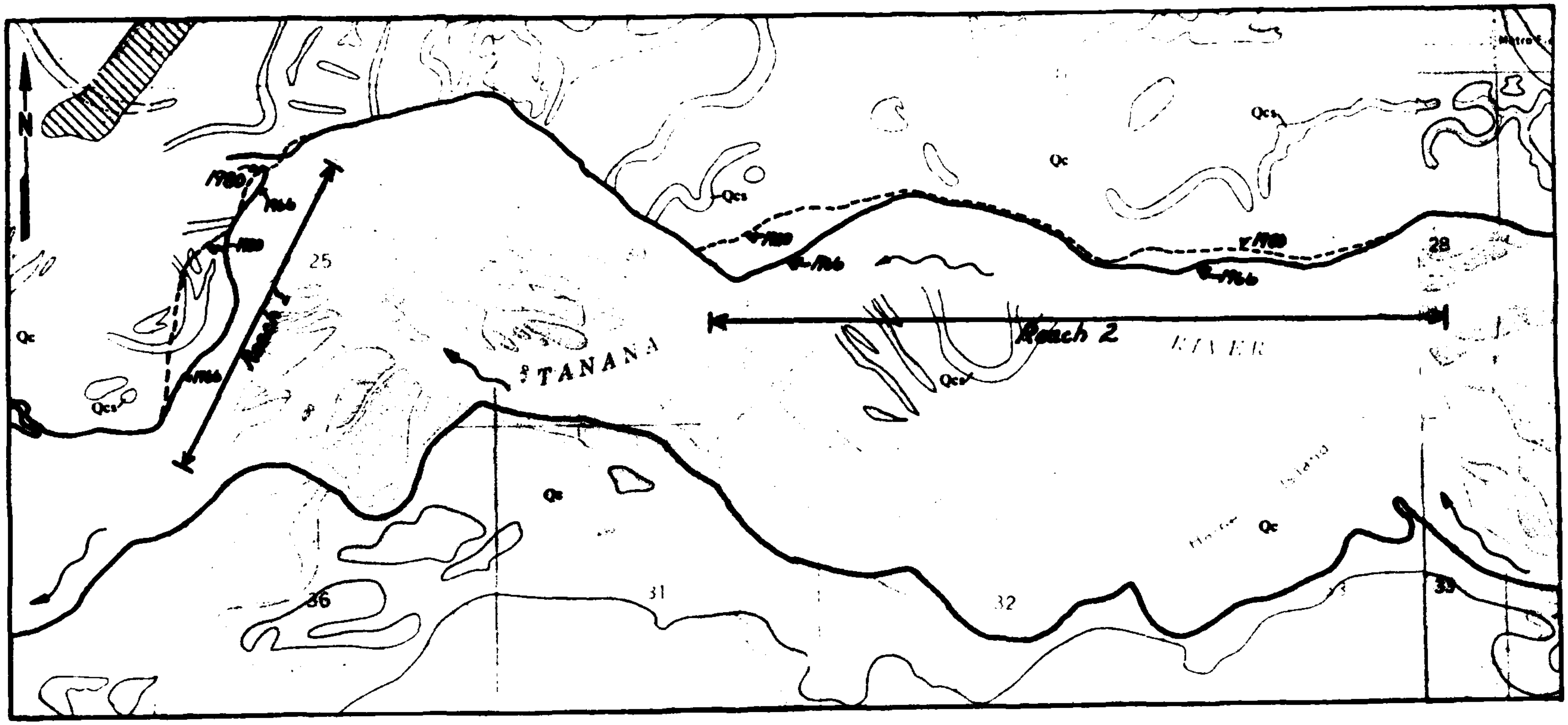


Figure 11. Distribution of the sands and gravels (Q_c) and swale and slough deposits (Q_{cs}) of the Chena alluvium (from Péwé et al. 1976). The bankline is as shown on 1966 photographs and is similar to that in 1970 (Fig. 4). For this analysis, the two banklines were considered the same.

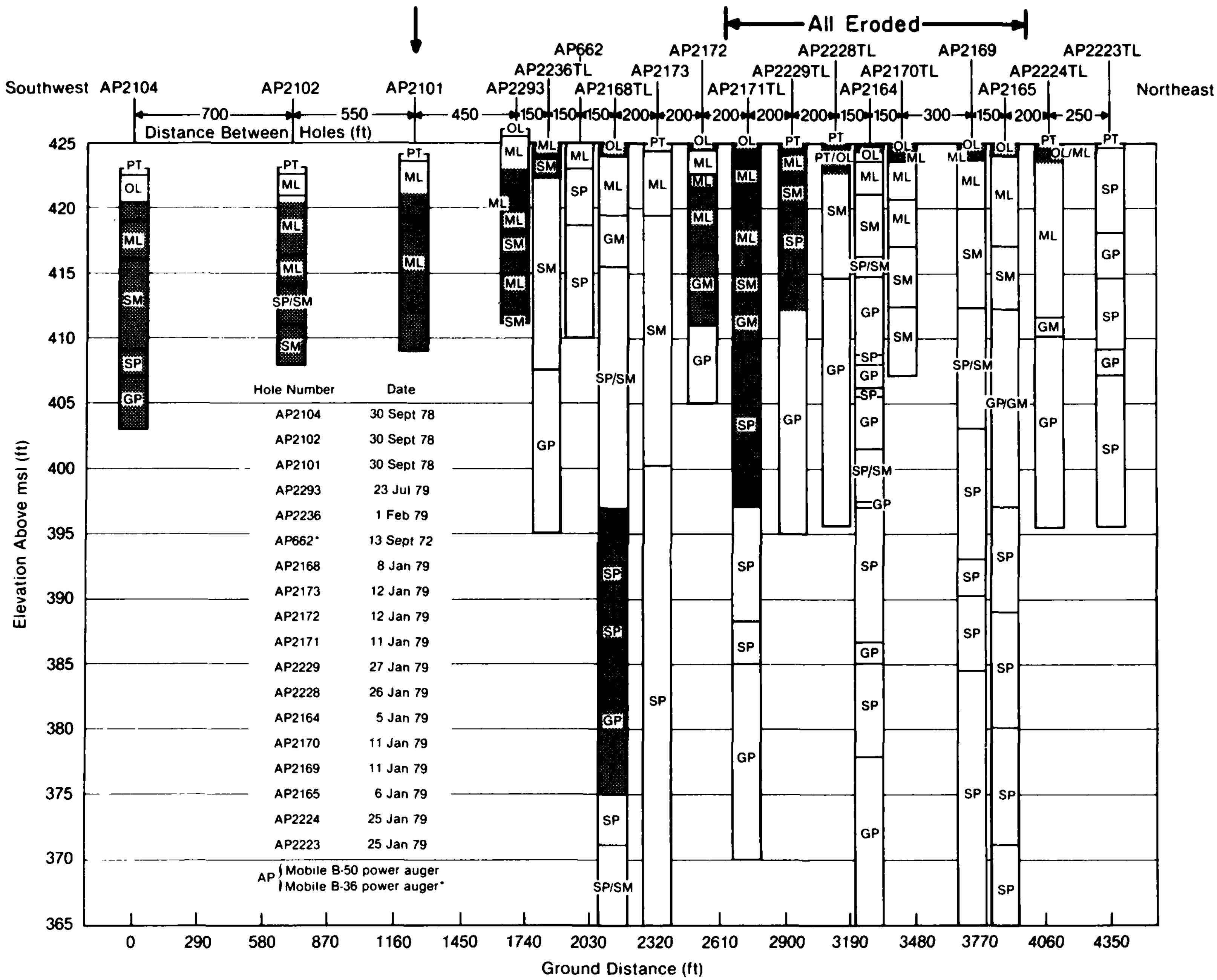


Figure 12. Well logs, reach 1; stipled areas were frozen when drilled.

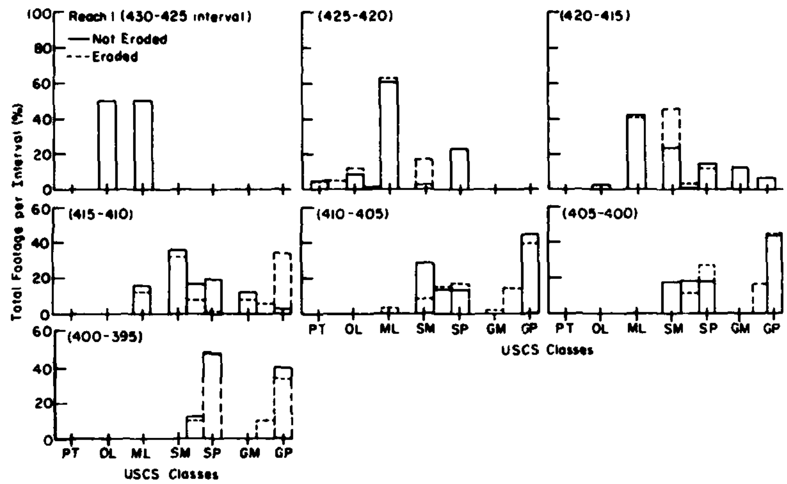


Figure 13. Sediments in eroded and uneroded wells, reach 1.

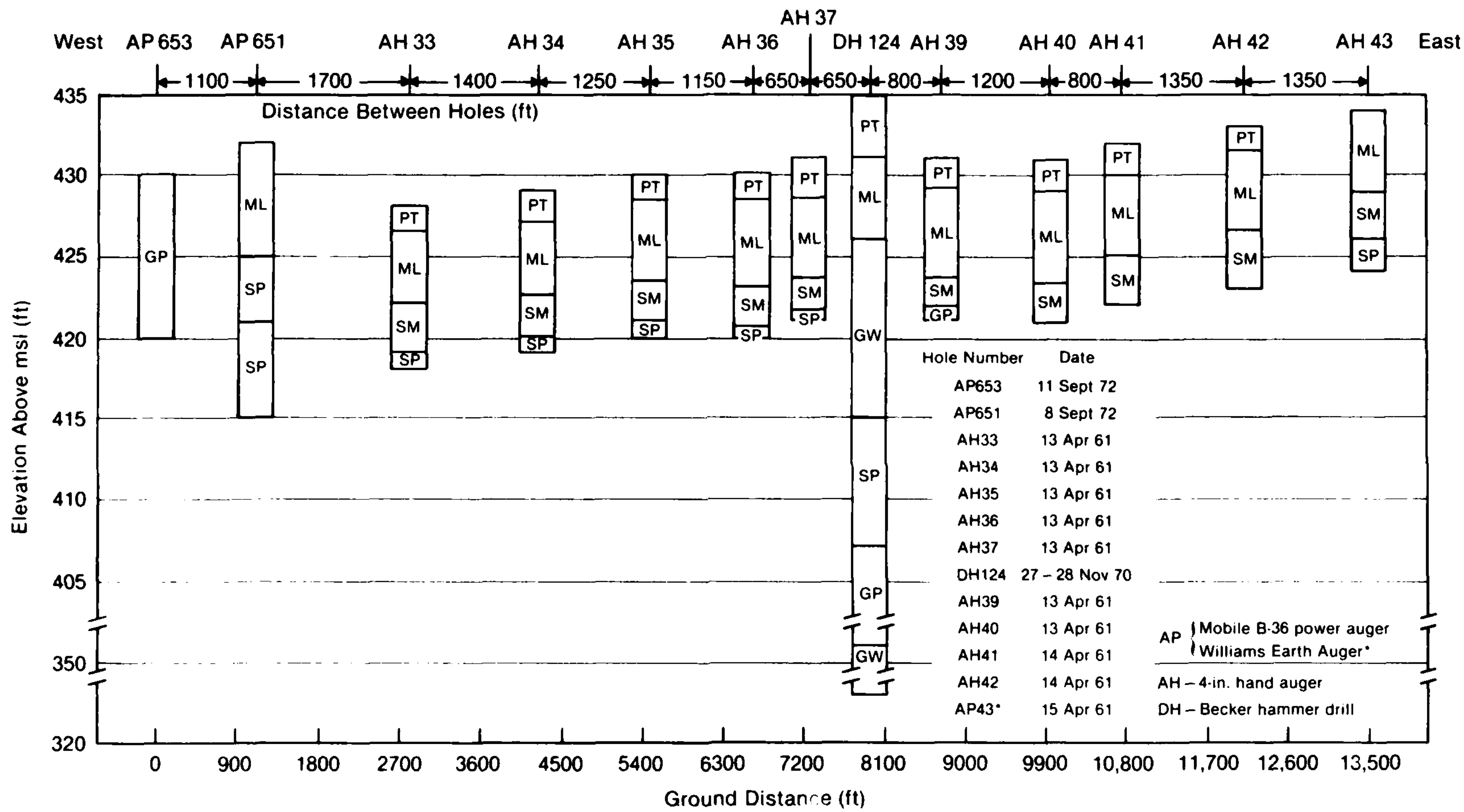


Figure 14. Well logs, reach 2.

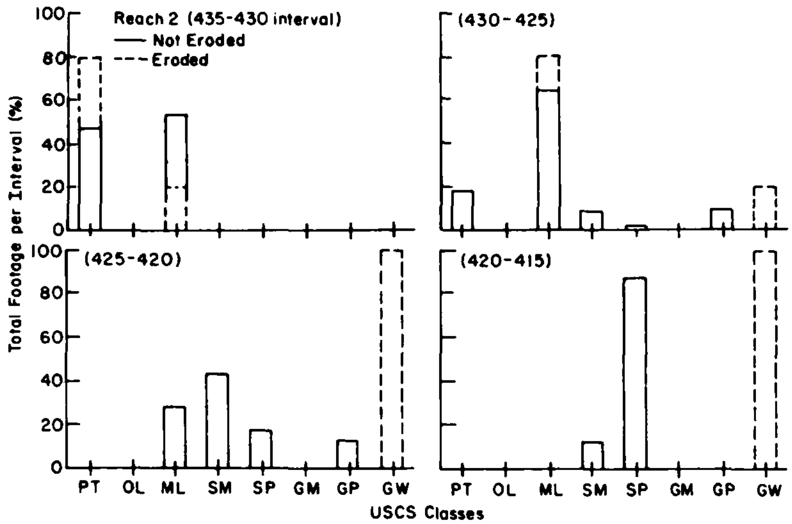


Figure 15. Sediments in eroded and uneroded wells, reach 2.

Table 1. General characteristics of locales along the Tanana River that have the vegetation shown (from Van Cleve et al. 1980).

Age (yr)	Elevation	Frequency of flooding	Vegetation type	Effects of alluvial erosion and deposition and other physical controls	% Shrub cover
2-5 (newly-deposited alluvium)			Open shrub (willow/alder)		0-35
5-10			Closed shrub		35-55
20-40			Young balsam poplar		10-100
80-100	Increasing	Decreasing	Mature balsam poplar, Young white or black spruce, Alder	Decreasing	30-50
125-175			Old balsam poplar, Young white or black spruce		10-50
200-300 (old Alluvium)			Mature white or black spruce		10-20

Table 2. Bank characteristics at well locations, reach 1.

Well no.	Eroded	Cumulative recession (ft)	Vegetation (unit no.)	Soils	Sediments: General	Site specific (%)*: PT	PT/OL	OL	OL/ML	ML	SM	SP	SP/SM	GM	GP	GP/GM	Permafrost (depth interval,
2223	No	350	9	Ta	Q_c	1.5						80			18.5		No
2224	No	460	9	Ta	Q_{cs}	1.5			2	42				4.5	50		0-1.5†
2165	Yes	560	9	Ta	Q_c			3.5		23.5	16	6.5				50.5	0-1†
2169	Yes	730	2	Ta	Q_c			2.5		15	25.5	26.5	30.5				0-1.5†
2170	Yes	920	2	Br	Q_c			4.5		40	55.5						0-1.5†
2164	Yes	1000	2	Br	Q_{cs}			5		8.5	16	11	18.5		41		0-1†
2228	Yes	1010	2	Br	Q_{cs}	.5	6				28.5				65		0-2.5†
2229	Yes	980	2	Br	Q_c	1.5				6.5	10	16.5			65.5		0-13
2171	Yes	980	2	Ta	Q_c			1.5		31.5	7	47.5		12.5			0-28
2172	No	960	5	Ta	Q_c			2.5		37.5				30	30		0-.5† 2.5-13
2173	No	890	5	Ta	Q_c	1.5				17.5	63.5	17.5					No
2168	No	820	5	Ta	Q_{cs}			3.5		15.5		6.5	61	13.5			0-1† 28-50
662	No	790	5	Ta	Q_c					13.5		86.5					No
2236	No	730	5	Br	Q_c					3.5	55				41.5		0-2.5†
2293	No	720	5	Br	Q_{cs}			3.5		78.5	18						3-15
2101	Yes	680	5	Br	Q_c	3.5				96.5							3-15
2102	No	490	5	Br	Q_c	3.5				56.5	20		20				2.5-15
2104	No	260	5	Ta	Q_c	2.5		17.5		15	35	10			20		2.5-20

* Sediment percentages from top of bank to 32-ft depth.
† Probably seasonal frost; drilled in the winter.

Table 3. Summarized results of vegetation analysis.

Analytical method	Reach 1	Reach 2
Method 1	unit 2,9,5	unit 15, 4&2&9
Method 2		
Cumulative recession	unit 2,5 or 9	unit 2,4,15,9
Recession per Interval		
1948-1961	unit 5,9,2	no data
1961-1970	unit 9&2,5,5&2	unit 15,4&2,15,15&14&9
1970-1975	unit 5,2&5,9&2&5	unit 15,2,4,4&9
1975-1980	unit 2,5,9	unit 2,4,9,15

Measured recession (method 2) decreased in units as listed.

Table 4. Bankline recession (ft) measured along transects drawn from each well through the historical banklines, reach 1 (Fig. 4).

	1948-1961		1961-1970		1970-1975		1975-1980	
Wells	Recession	Cumulative	Recession	Cumulative	Recession	Cumulative	Recession	Cumulative
2223	110	110	240	350	0	350	0	350
2224	70	70	390	460	0	460	0	460
2165	120	120	340	460	0	460	100	560
2169	150	150	320	470	0	470	260	730
2170	100	100	300	400	0	400	520	920
2164	40	40	240	280	170	450	550	1000
2228	10	10	190	200	320	520	490	1010
2229	0	0	100	100	490	590	390	980
2171	40	40	70	110	580	690	290	980
2172	100	100	10	110	620	730	240	970
2173	110	110	0	110	620	730	160	890
2168	170	170	0	170	530	700	120	820
662	220	220	30	250	430	680	110	790
2236	230	230	70	300	320	620	110	730
2293	240	240	80	320	270	590	130	720
2101	240	240	140	280	170	550	130	680
2102	170	170	190	360	0	360	130	490
2104	130	130	130	260	0	260	0	260
	Avg=130		Avg=160		Avg=250		Avg.=210	

Table 5. Bank characteristics at well locations, reach 2.

Well No.	Eroded	Cumulative recession (ft)	Vegetation	Soils	Sediments General	Site-specific (%)* PT	ML	SM	SP	GP	GW	Permafrost
653	No	0	--	--	Qc					100		No
651	No	660	2	Sc	Qc		41		59			No
33	No	620	4	Sc	Qc	16	44	30	10			No
34	No	550	4	Ta	Qc	20	45	25	10			No
35	No	160	15	Ta	Qc	16	49	25	10			No
36	No	100	15	Sc	Qc	16	54	24	6			No
37	No	80	15	Ta	Qc	24	50	26				No
124	Yes	340	15	Sc	Qc	22	28				50	No
39	No	520	15	Sc	Qc	18	56	18		8		No
40	No	230	15	Sc	Qc	20	56	24				No
41	No	260	15	Sc	Qc	20	50	30				No
42	No	0	4	Sc	Qc	16	48	36				No
43	No	0	9	Sc	Qc		50	30	20			No

* Sediment percentages from top of bank to 18-ft depth.

Table 6. Bankline recession (ft) along transects drawn from each well through the historical banklines, reach 2 (Fig. 4).

Wells	1948-1961 Recession	1948-1961 Cumulative	1961-1970 Recession	1961-1970 Cumulative	1970-1975 Recession	1970-1975 Cumulative	1975-1980 Recession	1975-1980 Cumulative
653	0	0	0	0	0	0	0	0
651	0	0	240	240	240	480	180	660
33	200	200	280	480	100	580	40	620
34	410	410	0	410	0	410	140	550
35	0	0	100	100	60	160	0	160
36	0	0	0	0	100	100	0	100
37	0	0	0	0	80	80	0	80
124	80	80	0	80	260	340	0	340
39	60	60	310	370	150	520	0	520
40	30	30	50	80	150	230	0	230
41	0	0	0	0	260	260	0	260
42	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0
	Avg=60		Avg=80		Avg=110		Avg=30	

Table 7. Soil series characteristics (from Rieger et al. 1963, 1979).

Series	Classification	Texture	Location/Surface Features/Topographic Position	Typical Profile (Inches)
Salchaket (Sc, very fine sandy loam)	Family: Coarse-loamy, mixed, nonacid Subgroup: Typic cryofluvents Order: Entisols Great Group*: Alluvial soil	- Sandy with silty layers - Underlain by coarse sands & gravels at 10 in. to 6 ft or more - thin silt layers or coarse sand seams at any depth - Silty surface layer absent locally, but may be up to 12 in thick	Developed in nearly level, recently deposited water-laid material; surface dissected locally by sloughs and old stream scars; contains strips of Bradway very fine sandy loam too narrow to map separately	7-0: mat of roots, moss, org. mat'l; very acid 0-3: (ML)** olive brown/greyish-brown silt loam with lenses of org. mat'l; weak granular structure; very friable; very acid 3-10: (ML) gray/brown very fine sandy loam very weak blocky structure; very friable; slightly acid 10-26: (SM or ML) gray fine sand mottled brown; no structure; loose; weak alkaline 26+: (GP or SP) gravel/coarse sand; rounded pebbles
Bradway (Br, very fine sandy loam)	Family: Loamy, mixed, nonacid Subgroup: Pergelic cryaquepts Order: Inceptisols Great Group: Low-humic gley soils	- Sandy - Gravel underlies at 4 ft or more	Usually in former stream channels (from less than 100 ft to more than a mile wide); narrow channels near Tanana River subject to flooding; lower topographic position than Salchaket soils; nearly level terrain	4-0: mat of organic mat'l mixed with small amounts of silt, medium acid; may be 12 in. thick locally 0-2: (OL) black, mucky silt loam; weak granular structure; friable; slightly acid 2-36: (ML) dark-grey very fine sandy loam mottled dark brown; weak platy structure: very friable; mildly alkaline; thin lenses of silt and fine sand, usually below 24 in.; may be greenish or bluish in lower part
Tanana (Ta, silt loam)	Family: Loamy, mixed, nonacid Subgroup: Pergelic cryaquepts Order: Inceptisols Great Group: Low-humic gley soils interfacing toward alluvial soil	- Silty - lenses of very fine sandy loam or fine sand common at any depth - gravel at 4 to 10 ft	Nearly level terrain developed in silty material usually located farther from principal streams than the Salchaket soils	5-0: mat of roots, moss, lichens; dark brown surface to black at bottom; very acid 0-4: (ML, OH or OL) olive-grey silt loam with patches of black and gray brown; massive; friable; neutral pH 4-20: (ML) olive-brown silt loam with patches of black and gray brown and dark brown mottles; massive; friable; mildly

* 1938 classification
** Equivalent classification in the USCS

Table 7 (cont'd).

Series	Drainage	Vegetation	Permafrost
Salchaket (Sc, very fine sandy loam)	Well-drained; seasonal high water table, 10-15 ft	White spruce, paper birch, quaking aspen some balsam poplar	Usually absent in soil above gravel Silty lenses under vegetation may stay frozen into summer
Bradway (Br, very fine sandy loam)	Poorly drained; usually always wet above permafrost; seasonal high water table usually 18 in.	Dense stand of sedges and grasses to low shrubs and clumps of black spruce	Present below 3-4 ft under native vegetation
Tanana (Tn, silt loam)	Imperfectly drained; always wet above permafrost; seasonal high water table, less than 1 ft	Scrubby black and white spruce, paper birch, tamarack and willow; mat of moss and low shrubs below trees	Present at 30 in. or less under native vegetation

Table 8. Summarized results of soils analysis.

Analytical Method	Reach 1	Reach 2
Method 1		
Eroded wells	5 of 8 (62%)-Br	1 of 1 (100%)-Sc
	3 of 8 (38%)-Ta	
Uneroded wells	7 of 10 (70%)-Ta	8 of 11 (73%)-Sc
	3 of 10 (30%)-Br	3 of 11 (27%)-Ta
Method 2		
Cumulative recession*	9 of 13 (69%)-Br	3 of 4 (75%)-Sc
	4 of 13 (31%)-Ta	1 of 4 (25%)-Ta
Cumulative recession†	4 of 5 (80%)-Ta	6 of 8 (75%)-Sc
	1 of 5 (20%)-Br	2 of 8 (25%)-Ta
Transects with most recession		
1951(1948)-1961	4 of 6 (67%)-Br	1 of 2 (50%)-Sc
		1 of 2 (50%)-Ta
1961-1970	4 of 7 (57%)-Ta	2 of 3 (66%)-Sc
1970-1975	4 of 6 (67%)-Br	4 of 4 (100%)-Sc
1975-1980	5 of 7 (71%)-Br	2 of 3 (66%)-Sc
Transects with highest recession		
1951(1948)-1961	Ta	Ta
1961-1970	Br	Sc
1970-1975	Br	Sc
1975-1980	Br	Sc
Transects with lowest recession		
1951(1948)-1961	Br	5 of 8 (63%)-Sc
		2 of 8 (25%)-Ta
1961-1970	Br	5 of 8 (63%)-Sc
		2 of 8 (25%)-Ta
1970-1975	6 of 7 (86%)-Ta	2 of 4 (50%)-Ta
	1 of 7 (14%)-Br	1 of 4 (25%)-Ta
1975-1980	Ta	7 of 10 (70%)-Sc
		2 of 10 (20%)-Ta
Dominant soil per interval		
1951(1948)-1961	10 of 17 (59%)-Br	4 of 5 (80%)-Sc
	5 of 17 (29%)-Ta	1 of 5 (20%)-Ta
	2 of 17 (12%)-Sc	
1961-1970	9 of 16 (56%)-Br	4 of 5 (80%)-Sc
	7 of 16 (44%)-Ta	1 of 5 (20%)-Ta
1970-1975	8 of 11 (73%)-Br	7 of 9 (78%)-Sc
	3 of 11 (27%)-Ta	2 of 9 (22%)-Ta
1975-1980	9 of 15 (60%)-Ta	2 of 3 (66%)-Sc
	6 of 15 (40%)-Br	1 of 3 (34%)-Ta

* > 600 ft, reach 1; > 400 ft, reach 2

† < 600 ft, reach 1; < 400 ft, reach 2

Table 9. Soils eroded and amount of recession per interval, reach 1.

Well	1951(1948)-1961		1961-1970		1970-1975		1975-1980	
Number	Soils*	Recession (ft)†	Soils*	Recession (ft)†	Soils*	Recession (ft)†	Soils*	Recession (ft)†
2223	Sc,Ta	110	Ta	240	Ta	0	Ta	0
2224	Sc	70	Br	390	Ta	0	Ta	0
2165	Br	120	Ta,Br	340	Ta	0	Ta	100
2169	Ta,Br	150	Ta,Br	320	Ta	0	Ta	260
2170	Ta,Br	100	Ta,Br	300	Br	0	Ta,Br	520
2164	Br	40	Br,Ta	240	Br,Ta	170	Br	550
2228	Br	10	Br	190	Br	320	Br	490
2229	Br	0	Ta	100	Ta,Br	490	Br	390
2171	Br	40	Br,Ta	70	Ta,Br	580	Br,Ta	290
2172	Br	100	Br	10	Br	620	Br,Ta	240
2173	Br	110	Br	0	Br	620	Ta,Br	160
2168	Br	170	Br	0	Br,Ta	530	Ta,Br	120
662	Br	220	Br	30	Br,Ta	430	Ta,Br	110
2236	Br	230	Br	70	Ta,Br	320	Ta,Br	110
2293	Br	240	Br	80	Br,Ta	270	Ta,Br	130
2101	Ta,Br	240	Br	140	Br	170	Br	130
2102	Ta	170	Ta	190	Ta	0	Ta,Br	130
2104	Ta	130	Ta	130	Ta	0	Ta	0
		Avg = 130		Avg = 160		Avg = 250		Avg = 210

* Soil series eroded the most in an interval is listed first.
† From Table 4.

Table 10. Engineering conditions and characteristics of Q_c and Q_{cs} deposits (from Péwé and Bell 1976b).

Map units	Terrain and natural slopes	Drainage and permeability	Permafrost	Susceptibility to frost action	Bearing strength and slope stability
Q_c	Flat plain with meandering streams and complex network of shallow swales	Drainage excellent and permeability high except locally in silt or where perennially frozen. Drainage improves with land clearing and lowering of permafrost table. Subject to flooding	Depth to permafrost 2–4 ft in older parts of flood plain and more than 4 ft on inside of meander curves near river. Depth to permafrost 25–40 ft in some cleared areas. Permafrost absent or deep beneath lakes, rivers, and creeks. Seasonal frost layer 2–9 ft thick. Permafrost 2–275 ft thick. Permafrost discontinuous; unfrozen lenses, layers, and vertical zones. Low ground-ice content and mostly interstitial in sand and gravel; ice content low to moderate in top silt layer. Water table 10–15 ft where permafrost absent or deep	Silt, moderate to high; sand and gravel, unsusceptible	High bearing strength when frozen; sand and gravel high when thawed; silt moderate to high when thawed and well drained, low when poorly drained. Slopes may stand at 1:1 to 2/3:1 except in unfrozen sand
Q_{cs}	Elongate, sinuous, flat-floored, meander and slough scars and wide shallow basinlike areas. Some intermittent streams present	Impermeable substratum of permafrost and organic silt in broad basinlike depressions creates poor drainage; marshy and undrained in summer. Drainage slightly better in linear scars. Drainage in both types improves slightly to moderately with land clearing and lowering of permafrost table. Subject to flooding	Depth to permafrost 1½–4 ft. Active layer 1½–4 ft. Permafrost 5–30 ft thick; continuous in broad basins; discontinuous in meander scars, generally absent in young sloughs. May be in contact with underlying permafrost of river sand and gravel. Moderate to high ice content as thin seams and lenses. Water table 10–15 ft where permafrost absent or deep	High	High bearing strength when frozen; very low when thawed. Slopes subject to sloughing and sliding upon thawing until well or moderately well drained

Table 11. Summarized results of the sediments and permafrost analysis.

Analytical Method	Reach 1			Reach 2††
	Q_c vs Q_{cs}	Well Log Data**	Permafrost	Well Log Data**
Method 1				
Eroded wells	6 of 8 (75%)-Q_c	4 of 8 (50%)-GP	5 of 8 (62%)-No	1 of 1 (50%)-GW
	2 of 8 (25%)-Q_{cs}	3 of 8 (38%)-SM,SP	3 of 3 (38%)-Yes	
		1 of 8 (12%)-ML	3 of 8 (38%)-Yes	
Uneroded wells	7 of 10 (70%)-Q_c	6 of 10 (60%)-SM,SP	5 of 10 (50%)-No	10 of 12 (84%)-ML
	3 of 10 (30%)-Q_{cs}	3 of 10 (30%)-ML	5 of 10 (50%)-Yes	1 of 12 (8%)-GP
		1 of 10 (10%)-GP		1 of 12 (8%)-SP
Method 2				
Cumulative recession*	13 of 13 (100%)-Q_c	7 of 13 (54%)- SM,SP	8 of 13 (62%)-No	3 of 4 (75%)-ML
		3 of 13 (23%)-GP	5 of 13 (38%)-Yes	1 of 4 (25%)-SP
		3 of 13 (23%)-ML		
Cumulative recession†	5 of 5 (100%)-Q_c	2 of 5 (40%)-SM,SP	3 of 5 (60%)-No	7 of 9 (78%)-ML
		2 of 5 (40)-GP	3 of 5 (40%)-Yes	2 of 9 (22%)-GP,GW
		1 of 5 (20%)-ML		
Transects with Most Recession				
1948-1961	No data	3 of 6 (50%)-SM,SP	4 of 6 (66%)-Yes	2 of 2 (100%)-ML
		3 of 6 (50%)-ML		
1961-1966(1970)	No data	4 of 7 (57%)-GP	7 of 7 (100%)-No	1 of 2 (50%)-SP
		3 of 7 (43%)-SP,SM		1 of 2 (50%)-ML
1966(1970)-1975	7 of 8 (88%)-Q_c	5 of 9 (56%)-SP,SM	5 of 9 (56%)-Yes	3 of 4 (75%)-ML
		2 of 9 (22%)-GP		1 of 4 (25%)-GW
		2 of 9 (22%)-ML		
1975-1980	5 of 7 (71%)-Q_c	3 of 7 (43%)-GP	4 of 7 (57%)-No	2 of 3 (66%)-ML
		3 of 7 (43%)-SP,SM		1 or 3 (34%)-SP
		1 of 7 (14%)-ML		
Transect With Highest Recession				
1948-1961	No data	97%-ML	Yes	45%-ML
1961-1966(1970)	No data	50%-GP	No, 1 of 2 (50%)-Yes	56%-ML
1966(1970)-1975	Q_c	64%-SM		1 of 2 (50%)-GW
				1 of 2 (50%)-ML
1975-1980	Q_c	41%-GP	No	59%-SP
Transects with Lowest Recession				
1948-1961	No data	66%-GP	Yes	6 of 8 (75%)-ML
				1 of 8 (13%)-SP
				1 of 8 (13%)-GP
1961-1966(1970)	No data	64%-SM	1 of 2 (50%)-Yes	6 of 8 (75%)-ML
		61%-SP/SM		2 of 8 (25%)-GP,GW
1966(1970)-1975	6 of 7 (86%)-Q_c	4 of 7 (57%)-SM,SP	5 of 7 (71%)-No	3 of 4 (75%)-ML
	1 of 7 (14%)-Q_{cs}	2 of 7 (29%)-GP		1 of 4 (25%)-GP
		1 of 7 (14%)-ML		
1975-1980	3 of 3 (100%)-Q_c	2 of 3 (66%)-SM,SP	2 of 3 (66%)-No	8 of 10 (80%)-ML
		1 of 3 (34%)-GP		2 of 10 (20%)-GW,GP
Dominant Sediment Per Interval				
1948-1961	No data	9 of 17 (53%)-SP,SM	10 of 17 (59%)-No	4 of 5 (80%)-ML
		4 of 17 (24%)-GP		1 o 5 (20%)-GW
		4 of 17 (24%)-ML		
1961-1966(1970)	No data	7 of 16 (44%)-SP, SM	9 of 16 (56%)-No	4 of 5 (80%)-ML
		5 of 16 (31%)-GP		1 of 5 (20%)-SP
		4 of 16 (25%)-ML		
1966(1970)-1975	10 of 11 (91%)-Q_c	5 of 11 (46%)-SP,SM	6 of 11 (55%)-Yes	7 of 9 (78%)-ML
	1 of 11 (9%)-Q_{cs}	3 of 11 (27%)-GP		1 of 9 (11%)-GW
		3 of 11 (27%)-ML		1 of 9 (11%)-SP
1975-1980	11 of 15 (73%)-Q_c	7 of 15 (46%)-SP,SM	6 of 15 (53%)-No	2 of 3 (66%)-ML
	4 of 15 (27%)-Q_{cs}	4 of 15 (27%)-GP		1 of 3 (34%)-SP
		4 of 15 (27%)-ML		

* >600 ft, Reach 1; >400 ft, Reach 2

† <600 ft, Reach 1; <400 ft, Reach 2

** Dominant sediment class

†† Reach 2 had only Q_c and no permafrost reported in the well logs, so no comparisons could be made

Table A1. Unified Soil Classification System (USCS) for fine-grained sediments. (From Mathewson 1981.)

				Identification Procedures on fraction smaller than no. 40 sieve size		
				Dry Strength (crushing characteristics)	Dilatancy (reaction to shaking)	Toughness (molding test)
Fine-grained Soils More than half of material is smaller than no. 200 sieve size The no. 200 sieve size is about the smallest particle visible to the naked eye.	Silts and Clays Liquid limit is less than 50	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity	None to slight	Quick to medium	None
		CL	Inorganic clays of low to medium plasticity, gravelly clays, silty clays, sandy clays, lean clays	Medium to high	None to very slow	Medium
		OL	Organic silts, and organic silty clays of low plasticity	Slight to medium	Slow	Slight, feels weak and spongy
	Silts and Clays Liquid limit is greater than 50	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Slight to medium	Slow to medium	Slight to medium
		CH	Inorganic clays of high plasticity, fat clays	High to very high	None	High
		OH	Organic clays of medium to high plasticity, organic silt	Medium to high	None to very slow	Slight to med. spongy
Highly Organic Soils		Pt	Peat and other highly organic soils	Readily identified by color, odor, spongy feel, & frequently by fibrous texture		

Table A2. USCS for coarse-grained sediments. (From Mathewson 1981.)

Unified Soil Classification System				Typical Names	Identification
Coarse-grained Soils More than half of material is *larger* than No. 200 sieve size. The no. 200 sieve size is about the smallest particle visible to the naked eye.	Gravels More than half of the coarse fraction is larger than no. 4 sieve size (For visual classification, the ¼ in. size may be used as equivalent to the no. 4 sieve size.)	Clean gravels (little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines	Wide range in grain size and substantial amounts of all intermediate particle sizes.
			GP	Poorly graded gravels or gravel-sand mixtures, little or no fines	Predominantly one size or a range of sizes with some intermediate sizes missing.
		Gravels with fines (appreciable amount of fines)	GM	Silty gravels, gravel-sand-silt mixtures.	Nonplastic fines or fines with low plasticity.
			GC	Clayey gravels, gravel-sand-clay mixtures.	Plastic fines.
	Sands More than half of the coarse fraction is smaller than no. 4 sieve size.	Clean sands (little or no fines)	SW	Well-graded sands, *gravelly* sands, little or no fines.	Wide range in grain size and substantial amounts of all intermediate particle sizes.
			SP	Poorly graded sands or gravelly sands, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.
		Sands with fines (appreciable amount of fines)	SM	Silty sands, silt-sand mixtures.	Nonplastic fines or fines with low plasticity.
			SC	Clayey sands, sand-clay mixtures.	Plastic fines.

Table A3. Sediment properties based on the USCS. (From Mathewson 1981.)

Unified Soil Classification	Permeability*	Shear Strength*	Compressibility*
GW	High	Very high	Very low
GP	Very high	High	Low
GM	Low to medium	High	Low
GC	Very low to medium	Medium	Medium
SW	High	Very high	Very low
SP	High	High	Low
SM	Low to medium	Medium	Medium
SC	Very low to low	Low	High
ML	Low	Low	High
MH	Very low to low	Very low	Very high
CL	Low	Very low	Very high
CH	Very low	Very low	Very high

*Determined on compacted, saturated samples.

Table A4. Grain size scales for sediments. (From Folk 1968.)

U.S. Standard Sieve Mesh #		Millimeters	Microns	Phi (ϕ)	Wentworth Size Class	
		4096		-12		
		1024		-10	Boulder (-8 to -12ϕ)	GRAVEL
Use		256		-8		
wire		64		-6	Cobble (-6 to -8ϕ)	
squares		16		-4	Pebble (-2 to -6ϕ)	
5		4		-2		
6		3.36		-1.75		
7		2.83		-1.5	Granule	
8		2.38		-1.25		
10		2.00		-1.0		
12		1.68		-0.75		
14		1.41		-0.5	Very coarse sand	
16		1.19		-0.25		
18		1.00		0.0		
20		0.84		0.25		
25		0.71		0.5	Coarse sand	
30		0.59		0.75		
35	1/2	0.50	500	1.0		SAND
40		0.42	420	1.25		
45		0.35	350	1.5	Medium sand	
50		0.30	300	1.75		
60	1/4	0.25	250	2.0		
70		0.210	210	2.25		
80		0.177	177	2.5	Fine sand	
100		0.149	149	2.75		
120	1/8	0.125	125	3.0		
140		0.105	105	3.25		
170		0.088	88	3.5	Very fine sand	
200		0.074	74	3.75		
230	1/16	0.0625	62.5	4.0		
270		0.053	53	4.25		
325		0.044	44	4.5	Coarse silt	
		0.037	37	4.75		
	1/32	0.031	31	5.0		
	1/64	0.0156	15.6	6.0	Medium silt	MUD
Analyzed	1/128	0.0078	7.8	7.0	Fine silt	
by	1/256	0.0039	3.9	8.0	Very fine silt	
		0.0020	2.0	9.0		
Pipette		0.00098	0.98	10.0	Clay	
		0.00049	0.49	11.0		
or		0.00024	0.24	12.0		
		0.00012	0.12	13.0		
Hydrometer		0.00006	0.06	14.0		

APPENDIX C

BANK RECESSION AND CHANNEL CHANGES IN THE AREAS NEAR THE NORTH POLE AND FLOODWAY SILL GROINS, TANANA RIVER, ALASKA

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ABSTRACT

Two diversion groins, one near North Pole, Alaska, and the other 7 miles upstream on the Tanana River near the floodway sill, were built in 1975 and 1979 along the flood control levee that protects Fairbanks from flooding of the Chena and Tanana rivers. A flood control plan includes construction of new groins wherever it appears likely that bank erosion may threaten the levee.

The objectives of this analysis were to measure bank recession, to describe channel changes before and after construction of the two groins, and to evaluate relationships among erosion, channel changes and discharge. Data from this analysis and future evaluations will be used in selecting sites for future groins.

Aerial photographs were used to measure bank recession and to document lateral changes from 1948 to 1982. Two river cross sections were also used to measure changes from 1977 to 1982. Most bank recession near the North Pole groin occurred along the north channel prior to the 1974-75 winter, when the groin was built. The average rates of preconstruction recession were 11 ft/yr along the north bank and 8 ft/yr along the north channel islands. The average rates along the south bank and south channel islands were 2 and 1 ft/yr, respectively. The average rates of bank land lost were 3.5, 2.3, 0.7 and 0.2 acres/yr along the north bank, north channel islands, south channel islands and south bank, respectively.

After construction, the North Pole groin diverted flows away from the north bank, and bank erosion increased along the south channel. The average rates of recession along the south channel islands and the south bank were 15 and 30 ft/yr, respectively. The average rates of land lost were 1.4, 2.9, 2.7 and 3.3 acres/yr along the north bank, north channel islands, south channel islands and south bank, respectively.

The average bank recession along the north bank before construction of the floodway sill groin was 27 ft/yr; it dropped to 8 ft/yr after construction. The post-construction rates along the north and south channel islands and the south bank increased from 17 to 28, 20 to 25, and 11 to 18 ft/yr, respectively. Post-construction rates of land lost show a similar pattern; the north bank average decreased from 3.2 to 0 acres/yr, and the north and south channel islands and the south bank rates increased from 3.7 to 4.1, 2.1 to 3.1 and 2.2 to 3.1, respectively.

Regression tests of the amount of land lost and the river discharge showed that the best linear relationship was between total number of days above 30,000 cfs and the amount of erosion ($r^2 = 0.95$). Generally the relationships of erosion and discharge were closer when comparing the days above a particular discharge level rather than the total water flow above a discharge level.

Cross-sections near the sill groin were taken repetitively after it was constructed and show that the deepest part of the south channel was near the south bank; before the groin was built more of the flow had been along the north channel. Major seasonal lateral shifting and in-channel erosion and deposition occurred in the north channels. Cross sectional changes between the groins show effects that appear to be related to dike construction. Most north channel changes occurred on the rising limb of the discharge hydrograph, while the south channel changed most as the discharge receded.

Both groins effectively reduced north bank erosion at the sites immediately downstream of the groin. However, it appears that this solution may be temporary. In the reaches where the groins were built, the river is re-establishing its preconstruction length by forming meanders at the ends of the groins. The river is again attacking the north bank downstream of the preconstruction locations, and erosion rates at some of these new sites are high.

Based on this historical analysis, it is unlikely that the north bank in the areas where the bankline is not near the 500-ft safe zone along the river side of the levee or where recent recession rates have been low would recede quickly enough to encroach into the levee safe zone in the near future. Analysis of aerial photography would easily detect any changes in historical trends and alert personnel to potential problem locations.

PREFACE

This report was prepared by Lawrence W. Gatto, Research Geologist, Earth Sciences Branch, Research Division, and Kenneth W. Riley, Physical Sciences Aid, formerly of that branch, U.S. Army Cold Regions Research and Engineering Laboratory. The work was funded by the U.S. Army Engineer District, Alaska, under Intra-Army Order E-86-82-0005, Tanana River Monitoring and Research Program.

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The analyses discussed and information presented in this report include data collected through September 1982. This report was reviewed in September 1982 and May 1983 at program review meetings. It has been changed based on the commments from these meetings and is current as of May 1983.

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BANK RECESSION AND CHANNEL CHANGES IN THE AREAS NEAR THE NORTH POLE AND FLOODWAY SILL GROINS, TANANA RIVER, ALASKA

by

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INTRODUCTION

The purpose of this analysis was to provide detailed data and information on the locations, magnitudes and patterns of historical bank recession and channel changes in the areas near the North Pole (groin 13) and floodway sill (groin 19) groins in the Tanana River (Fig. 1). The locations and magnitudes of future recession can be anticipated based on these data. The Alaska District, Corps of Engineers, bank will make decisions regarding the placement of future groins along the Tanana River levee based in part on these results.

The specific objectives of this analysis were to:

1. determine historical patterns of bank recession and channel changes before and after *construction* of the groins to infer possible effects of the groins on river processes, and

2. determine north bank sites where future recession would likely occur and estimate the amounts of this anticipated recession based on historical patterns.

This study is part of the Alaska District, Corps of Engineers, Tanana River Monitoring and Research Program (TRMRP). The TRMRP was initiated to provide detailed data on the effects of the Corps' in-river construction on the Tanana River. In preparation for the in-river construction, the Alaska District (1979) completed a preliminary study of the general historical river changes and Buska (1981) updated some of the District's historical maps. However, site specific recession rates for all the sites were not estimated and detailed descriptions of channel changes were not made.

APPROACH

Aerial photographs (Table 1) were used to map all or some of the following features in the areas near the groins (Fig. 1):

1. north and south banklines
2. banklines of "treed" islands
3. waterlines around bare and vegetated bars
4. standing water in intermittent channels.

Selected aerial photographs (9 in. x 9 in; 1:24000 scale) taken on 7 May 1980 were enlarged to 41 in. x 45 in., 1:4700 scale. These enlargements were used as mapping bases. The areas covered by each mapping base (frame 17-10, 17-08, 17-06, 18-18 and 18-16) are shown in Figure 1.

A Bausch and Lomb Zoom Transfer Scope (ZTS) was used to get a "best fit" of the historical photography superimposed onto the mapping bases and the above features observed on the historical photography were mapped on plastic overlays registered to the mapping bases. These overlays were redrafted as final maps which were used to measure areas of land lost and bank recession and to analyze channel changes.

Maps were not made for all the aerial photography available. Twelve sets of photography (1948-1981) were used for 17-10 and all of the above features were mapped. The 17-10 base was completed first and we wanted to map all the features to determine if the complete maps were useful. After evaluating the information gained versus the time spent in mapping all the features we decided not to continue mapping the bars and standing water and limit the maps to north, south and "treed" island banklines. For 1982, bankline recession was minor and no maps were prepared for any of the bases. Changes were simply observed on the photographs and described.

Four sets of photographs (1961, 1970, 1975 and 1980) were used for mapping the banklines on 17-08. No mapping was done in the 17-06 area mid-way between the two groins (Fig. 1) because this area was not as important as the areas nearer the groins. Changes in bankline positions in this 17-06 area were observed, however, on the twelve sets of photography from 1961 to 1982. Six maps (1970, 1974, 1978, 1979, 1980 and 1981) were made for the 18-18 but none for 18-16. Only visual comparisons of bankline changes were made in the 18-16 area.

We measured the amount of bankline recession per time interval along lines drawn as nearly perpendicular as possible to the historical bankline positions in the 17-10, 17-08 and 18-18 areas. In addition, we digitized the amounts of land area eroded during each interval. These areal measurements show the amount of land eroded along the banks and both types of data are discussed here. Due to the sources of error when using aerial photography, we consider these recession measurements as estimates that are useful in evaluating historical trends and estimating future magnitudes of bank recession.

There are several shortcomings inherent in an aerial photographic analysis of a very dynamic and complex river. Firstly, only net bank recession can be observed. Short-term recession that occurs between the times of photo acquisition cannot be analyzed nor can short-term changes in the river channel be observed. Consequently, only long-term trends, of recession and channel change can be studied.

Secondly, the quality of the aerial photography greatly influences the amount of information that can be obtained. Fortunately, the visual quality of the photos used for this study was good. However, they were not always acquired when the water level was low and there are large gaps in some of the earlier photo coverage (Table 1).

HISTORICAL BANK RECESSION AND CHANNEL CHANGES

NORTH POLE GROIN AREA

The North Pole groin was built during the 1974-1975 winter. The bank recession and channel changes that occurred from 1948 through October 1974 are pre-construction. Post-construction recession and changes occurred since May 1975.

1948-1961

Results for this interval are not complete because the historical aerial photography was not available for the southern portion of the channel. The north channel appeared to be the main channel during this interval and a meander in the north channel eroded the north bank at most of the measuring line sites (Fig. 2; Table 2). The maximum bankline recession was 350 ft along line 4D, the minimum was <30 ft along lines 3A,C,D. Approximately 57% of the north bank receded from 1948 to 1961 (Fig. 3).

The high water in the 1948 photography causes confusing patterns along parts of sites 13-15 (Fig. 2). The bankline in 1948 appeared to be inland from that observed in 1961 but it is clear that erosion occurred along site 13. The bankline receded 30 ft at 13A and 190 ft at 13C (Table 2). The channel between sites 14, 15 and 19 also began to widen and the bankline receded 40 ft at line 15A and 220 ft at line 19A. The average linear recession rates per line along the north bank was 12 ft/yr and along the north channel islands was 7 ft/yr (Table 2; Fig.4).

Most of the land, 48.3 acres, eroded during this interval was along the north bank (Table 3; Fig. 5). The north channel islands lost 16.6 acres and the south channel islands lost 7.6 acres. The rate of land lost during this interval were 3.7, 1.3 and .6 acres/yr for the north bank, north channel islands and the south channel islands, respectively (Table 3; Fig. 6).

1961-1970

Results for this interval are also incomplete because photography was not available for parts of the southern channel. The large north channel meander present from 1948 to 1961 broadened and erosion continued along most of the measuring lines at sites 1 to 5 (Fig. 2). Bank recession varied from 360 ft at line 4A to <30 ft at lines 2A,B,D, 3A and 4C and was concentrated at line 3E and along site 4 (Table 2).

The downstream end of this broad channel shifted south and erosion along site 2 and the area between sites 1 and 2 was less during this interval. The upstream portion of the meander became tighter and site 28 (where the groin was to be built) appeared stable as vegetation on the bars in the area expanded.

Inter-island channels widened between lines 2C and 13C-E and between lines 14A, 15A and 19A. The island banklines along site 13 receded from 80 ft to 430 ft, 230 ft at line 14A, 210 at 15A and 200 ft at 19A (Table 2).

These data suggest that the downstream end of the channel shifted south during this interval.

The average linear recession rates (Fig. 4; Table 2) show that the measured portions of the north bank and the north channel islands receded faster from 1961-1970 than from 1948 to 1961, although less (35%) of the north bank receded between 1961 and 1970 (Fig. 3). This also suggests that the main channel shifted southerly between 1961 and 1970.

Most of the land area lost during this interval continued to be eroded along the northern channel with 33.9 and 31.8 acres lost along the north bank and north channel islands, respectively (Table 3; Fig. 5). The rate of land lost along the north channel islands increased to 3.4 acres/yr which also suggests that the main north channel shifted to the south. Erosion along the south channel islands was less than during the 1948-1961 interval (Figs. 5 and 6).

1970-1973

Results for this interval are also incomplete because of partial photographic coverage. The large north channel meander previously observed shifted away from site 3 and bankline recession was generally less than 40 ft (Table 2). The north channel meander continued to tighten from 1970 to 1973 and most of the north bank recession occurred from lines 4C to 4H and varied from 30 ft at 4C and G to 220 ft at 4D. This large meander was well formed by 1973 and was cut off when the North Pole groin was constructed.

The bars between lines 1A and 2B and island site 28 continued to be stable and vegetation expanded. Island site 13 showed no detectable recession during this interval while channel widening continued between sites 14A and 15A and between 22A and B and the south bank. With more water flowing through the widening channel between 14 and 15, recession at site 18 increased.

The south channel also appeared to be widening and possibly carrying more flow. Outer banks (sites 20, 22, 8, 7) along the upstream meanders of the south channel were eroded as the meanders tightened. The percentage of the north bank that receded during this interval decreased to about 23% while only 12% of the south bank receded (Fig. 3). The average linear recession rates (Fig. 4) for this interval indicate that recession along the south bank was greater than along the north bank and island sites.

The amount of land lost along the northern part of the channel decreased from the previous interval (Fig. 5) and the rate of loss along the north channel islands was higher than along the north bank (Fig. 6). The amount and rate of land lost along the south channel islands increased from the previous interval.

1973-1974

Bank recession along the north bank measuring lines except 4H was less than 30 ft (Table 2). The rest of the sites and the area between 1A and 2B (Fig. 2), the bar south of line 2C, the large area of bars on the inside of the large north channel meander centered around site 28 appeared to be stable. Average linear recession rates for north and south bank lines decreased while the rates for the island lines increased slightly (Fig. 4). The percentage of north and south bank that receded decreased (Fig. 3).

The amount of land lost and the rate of loss decreased along the northern channel while the rates increased along the southern channel. It appears that erosion along the southern channel was increasing prior to construction of the North Pole groin (Figs. 5 and 6).

Groin construction began over the winter of 1974-1975 and was complete prior to May 1975 (Figs. 7 and 8). The groin completely cut off the large north channel meander and diverted the river away from the north bank for a distance of about 1.3 miles to a site downstream of site 3 (Fig. 2). The groin reduced the active channel which was 5900 ft wide by 3300 ft. The width of the post-construction channel was 2600 ft, 46% smaller than the pre-construction width.

The May photography (Fig. 8) shows the remnants of the diversion dike that extended upstream from the bend in the groin and a dike off the end of the groin. Both dikes were constructed with the sediment excavated from a pilot channel along the south side of the groin. These dikes also aided in diverting the river southward.

The temporary dike at the downstream end of the groin was breached at "A" and was nearly breached at "B" by 14 May 1975 (Fig. 8). By September

1975 (Fig. 9) the dike downstream of "C" was nearly completely eroded away. Only a remnant between "A" and "B" remained. The river was again attacking the banks at sites 2 and 3 (Fig. 9).

1975-1976

All the north bank recession occurred from lines 2A to 3D, downstream of the reach that was eroding prior to groin construction (Table 2). Recession varied from 30 to 90 ft but no measurable recession occurred along site 4 (Table 2). Upstream from the groin the north channel meander continued to be stable and sites 5 and 6 did not recede, although major recession occurred at island site 28. Inter-island channels appeared unchanged.

Most bankline recession occurred along the south channel. The amount of south bank that receded during this interval increased to 20% while only 13% of the north bank receded (Fig. 3). The average linear recession rate for the south channel island and south bank lines increased significantly during this interval while the north bank and north channel island lines increased less (Fig. 4). This suggests that the water diverted southward by the groin may have caused more bank erosion along the south channel because of the larger flows. Of course, this is supposition. It is equally feasible that the south channel would deepen in response to the larger discharges.

The amount of land lost and the rate of loss along the southern channel increased during this first post-construction interval (Figs. 5 and 6) while they decreased or remained about the same along the north channel.

1976-1977

The meanders in the north channel tightened and eroded laterally causing measurable bank recession at lines 2A, 3, 5B, 13A, 19B, 23 and 24 (Fig. 2; Table 2). The rate of linear recession was the same for the north bank and north channel island measuring lines (Fig.4). The north channel was straightened when the groin was built and meanders reformed and tightened between 1975 and 1977 at locations up- and downstream of the groin.

Linear recession along the southern channel was minor (Table 2) and the meanders at the head of the southern channel continued to tighten. The amount of south bank that receded remained 20% (Fig. 3) while only 6% of the north bank receded during this interval. However, the average linear recession along the north channel measuring lines was greater (Fig. 4) than along the south channel lines.

The land lost and rate of loss along the south channel decreased during this interval but remained higher than along the north channel. This further suggests that the rapid increase in south channel erosion observed during the first post-construction interval (1975-1976) was caused by the groin diversion. After the initial rapid increase the larger south channel flow is eroding more of the bank than before construction but will be less than the initial high amount.

1977-1978

The north channel meander continued to migrate laterally shown by recession along lines 3A-D, 6B, 13F and 23B (Table 2). Linear recession varied from 30 to 70 ft. The inside of the north channel meanders continued to be stable. Recession was greatest also the site 3 lines. The meander that was being re-established at the end of the groin was not tight enough to directly erode the north bank upstream of site 3.

South channel meanders continued to erode at lines 8A, 9, 10B, 11, 16, 17, 20, 21A,C and 22 (Table 2). Linear recession varied from 30 to 130 ft. Sixteen percent of the south bank receded during this interval while six percent of the north bank receded (Fig. 3). The average linear recession rates (Fig. 4) for the south channel lines continued to be higher than the north channel lines.

The amounts and rates of land lost along the north channel decreased during this interval (Figs. 5 and 6) while losses along the south bank remained about the same. Land loss along the south channel islands decreased.

1978-1979

Meanders along the north channel continued to tighten and erode laterally and the north channel split downstream of the groin and the southern portion eroded the downstream north channel sites. Linear bank recession was high at lines 3A-C (90-150 ft), at the island just downstream from the tip of the groin, at lines 6B (40 ft), 13B,C (30 ft), 19B (60 ft) and 23A-C (70-100 ft) (Table 2). The area inside the meander at site 6 appeared to be stable.

The south channel continued to erode the bank along the outside of the migrating meanders at sites 7, 9, 20, 21 and 22B (Table 2). Linear recession varied from 30 to 140 ft. The average linear recession rate increased along the north channel lines, decreased along the south channel island lines and was unchanged along the south bank lines (Fig. 4). The percentage of the north and south bank that eroded during this interval was 5% (Fig. 3).

The amounts and rates of land lost increased during this interval except along the south bank (Table 3). Erosion along the south channel continued to be greater than that along the north channel.

Cross sections were not taken before the North Pole groin was built. After construction, cross-sections at the 16A location (Fig. 10) were taken on 5 October 1977, 17 August 1979 and 3 October 1979. The north reference for the cross-sections was near the groin about 250 ft downstream of the bend in the groin and the cross-sections extended toward the south bank.

On 5 October 1977 the deepest part of the channel at 16A (Fig. 11) flowing past the island on the south side of the groin was about 250 ft from the north reference and was at elevation 448 ft. The other cross-sections in Figure 11 were not re-surveyed but are shown to illustrate the general configuration of the channel. By 17 August 1979 (Fig. 12) the deepest part of 16A had migrated to within 150 ft of the reference and was still at elevation 448 ft. The north bank also shifted about 150 ft.

In addition to these lateral shifts toward the groin, the channel had changed shape by 1979. In 1977 it was about 130 ft wide at the top and about 12 ft deep. In 1979 it was about 150 ft wide and about 9 ft deep. The channel widened by about 20 ft.

Between August and October 1979 the channel shape was about the same but the deepest location shifted another 10-15 ft toward the groin. The north bank of the island did not recede but the 3 October 1979 cross-section shows that the north side of the channel is a few feet south of its August position.

1979-1980

Bank recession (50-90 ft) continued at lines 3C,D, 6 and 13C, along the north channel while the area between lines 1A and 2A (Fig. 2) was stable and the area northeast of site 19 had changed. The south channel meanders continued to tighten but banks receded along only three lines, 7A (40 ft), 22B (40 ft) and 27A (30 ft) (Table 2). The percentages of the north and south banks that receded are 6 and 7, respectively (Fig. 3).

The land lost and the rates of loss decreased except along the north channel islands (Table 3). The land eroded along the southern channel was less than that along the northern channel for the first time since the groin was built (Figs. 5 and 6).

1980-1981

Bank recession along the north channel continued at lines 3B, 6A, 13C and 23B,C (Table 2). It appears that the river is re-establishing its pre-groin length by forming large, tight bends and the island between sites 3 and 24 was eroded due to meander formation. South channel meanders continued to migrate laterally and erode the banks at 7, 8, 9, 25A, and 26 (Table 2). More of the south bank (12%) receded during this interval than the north bank (Fig. 3). The rate of linear recession was highest along the south bank and had increased from the previous interval (Fig. 4).

The amounts of land lost increased along the north and south channel islands and the south bank, but decreased slightly along the north bank (Table 3). The rate of loss along the north bank decreased while the rate increased along the south bank (Fig. 6).

1981-1982

This interval includes only the low flow portion of an effective erosion year and we did not measure bank recession. Based on visual examination of the 1982 photography it was evident that only minor recession had occurred along the north banks of the islands between 19A and 23A

(Fig. 2) and between 8A and 8B and at 6A,B, 7A, 25A,B, 22A,B, 13B to D and south of 16B.

AREA UPSTREAM OF THE NORTH POLE GROIN

The area upstream of the north pole groin is covered on base photographs 17-08 and 17-06 (Fig. 1). Analysis of the areas covered by these base photographs was done differently than that done in the area adjacent to the groin. We did a more complete analysis of the immediate area of the groin. We followed the same procedures but did a general analysis in the 17-08 area. In the 17-06 area, we did no mapping because it is not near the groin. We simply described the historical bank changes based on photointerpretation.

1961-1970

Linear bank recession occurred along the outer bends of river meanders at six measuring lines along the north channel (Fig. 13) and along 16 lines along the south channel (Table 4). Most recession occurred along south channel lines and varied from 100 ft at 13D to 540 ft at 10A. Linear recession along the north channel varied from 70 ft at 4A to 460 ft 3B. During this interval the average rate of linear recession per measuring line was highest along the north bank, 40 ft/yr (Fig. 14). The rate along the southern channel was less, 13 ft/yr.

The amounts and rates of land lost were highest along the south bank (Table 5; Figs. 15 and 16) and least along the north bank. Bank erosion along the south channel as a whole was greater than that along the north channel. We could not compare these results to those near the groin because the data near the groin are incomplete due to partial photographic coverage.

Bank recession and channel changes during this interval in the 17-06 area (Fig. 17) were as follows. The main northern flow was in the channels between the north bank and the middle channel adjacent to C and H. The north bank between I and J receded locally but the amounts were minor and occurred along the outside of meanders. Most of the bars and partially vegetated islands in this northern channel were stable and revegetated during this interval, although the island bank at K receded. The banks (M, N, O) of some mid-channel and southern islands were eroded as more flow went through the middle of the channel. The island banks between L and P eroded as the river migrated northeasterly. The south bank remained unchanged and many of the bars were stable and revegetated, and appeared as islands (F and G) in 1970.

1970-1975

Bank recession along the northern channel occurred at most of the measuring lines and varied from 40 to 250 ft (Table 4). Recession along the southern channel was wide spread and varied from 40 to 540 ft. The rates of linear recession were highest along the southern channel as during the previous interval (Fig. 14). Although the meanders in the eastern part of the southern channel migrated from tight bends to more open bends between 1970 and 1975.

The average rate of linear recession along the north bank dropped to 6 ft/yr and increased to 20, 23 and 22 ft/yr along the north and south channel islands and the south bank, respectively (Table 4; Fig. 14). The banks along the southern channel were being eroded more rapidly than those along the northern during this interval (Fig. 14).

Less land was eroded during this interval than during the previous interval (Fig. 15) but it is evident that most erosion occurred along the southern channel. The rate of land lost (Fig. 16) along the islands and south bank increased and that along the north bank decreased.

From 1970 to 1973, the north bank sites in the 17-06 area (Fig. 17) continued to recede and the islands at A started to erode. An entire island-bar complex northeast of E was eroded away by 1973. Most of the south bank and south channel remained unchanged. The slow north bank recession continued in the I to J area between 1973-74. The south bank near and west of E started to erode and islands originally located southwest of F were completely eroded. The island at A continued to recede from 1974 to 1975 while the bank between I and J receded very little. Site E and islands near F continued to erode. It appears that more flow was moving through the middle and southern channels since 1970.

1975-1980

Bank recession occurred at only four measuring lines along the northern channel and varied from 60 ft at 4A to 150 ft at 1A (Fig. 13). The banks receded at 12 lines along the southern channel and varied from 50 ft at 9C to 260 ft at 12I. The average rates of linear recession were less during this interval, 0 ft/yr along the north bank, 8 ft/yr along the north channel islands, 12 ft/yr along the south channel islands and 11 ft/yr along the south bank (Fig. 14). The amounts of land eroded during this interval were less than during the previous intervals (Fig. 15) and the rates (Fig. 16) dropped significantly.

The banks along the northern portion of the 17-06 area (Fig. 17) remained unchanged while the southern site continued to recede from 1975 to 1976. From 1976 to 1978, areas A and E and the islands near F eroded, while the remainder of the banks was unchanged. Areas A and E and the island sites F and G continued to erode from 1978 to 1979 and middle channel sites C, D and H started to erode. Between 1979 and 1980, erosion at area A, island sites F and G and site E continued but there was no apparent change along the other north or middle channels.

1980-1982

Based on photointerpretations it is clear that minor bank recession occurred in the 17-08 area long lines 1A,B, 2C,D, between 3C and 4A, 9B,C, 12F and 13E. Measurable recession during the previous interval (1975-80) had not occurred along lines 2C,D, 9B and 12F (Table 4). Sites A, C, D, E, F, G and H in the 17-06 area continued to erode between 1980 and 1982 but the rest of the north bank was unchanged.

FLOODWAY SILL GROIN AREA

The floodway sill groin was built during the 1978-1979 winter. Bank recession and channel changes that occurred from 1970 through October 1978 are pre-construction. The post-construction interval begins in May 1979.

1970-1974

Bank recession occurred at 10 of the 17 measuring lines (Fig. 18) along the northern channel (Table 6). The recession varied from 30 ft at 2B to 270 ft at 9A. The average rates of linear recession were 25 and 12 ft/yr along the north bank and north channel islands (Fig. 19; Table 6). As mentioned previously, the eroding banks occurred along the outside of meanders. Many of the islands along the northern channel were stable and revegetating.

Recession along the south channel occurred at eight of 16 lines and varied from 30 ft at 13A to 410 ft at 8A (Fig. 18). Average rates were 18 ft/yr along the south channel islands and 7 ft/yr along the south bank. The amount of recession was greatest along the northern channel during this interval.

The amounts and rates of land eroded was also greatest along the north bank (Figs. 20 and 21; Table 7) followed by that along the north and south channel islands and the south bank.

We did not map bankline positions in the 18-16 area because it does not border the levee and is not a primary area of interest. We simply described bank changes based on photointerpretations. Major recession occurred north and east of area A from 1970 to 1973 (Fig. 22) while minor recession occurred along mid-channel islands at E and G and along the south bank (K) near the head of Salchaket Slough. During the 1973-74 interval, erosion continued at the same locations along the north bank and at E, F and south of G. The remainder of the banks appeared unchanged.

1974-1978

The bank at 14 of the 17 north channel lines receded from 30 to 260 ft while bank recession which varied from 30 to 210 ft occurred at 14 of the 16 south channel lines (Table 6). The average rate of recession remained higher along the north channel, 23 and 29 ft/yr, versus 22 and 16 ft/yr along the south channel (Fig. 19). More land was eroded during this interval than previously (Fig. 20). But the north channel islands eroded the fastest (Fig. 21).

As previously mentioned most of the erosion occurred along the outer banks of meanders. New locations erode while sites that previously eroded become stable as the river migrates laterally and the bends become more curved or straightened.

The 1974-75 aerial photographs did not cover all the 18-16 area but it was apparent that the banks in the areas covered were unchanged. There was limited photographic coverage from 1975 to 1978 but it was evident that the reach north of A (Fig. 22) and areas A, B, C, D, E, G, south of G, H, J and I had receded.

Pre-construction cross-sections near the the sill groin were taken once at locations 21X,A and C, 22A, 23A,B (Figs. 23 and 24) and several times at the GSX-5 and GSX-6 locations. The GSX-5 and -6 data were not available in time for this report but will be incorporated at a later date. Because available cross-sections were taken only once, channel changes prior to construction of the sill groin could not be measured.

In 1978, before the floodway sill groin was built, a large channel was flowing along the north bank (Fig. 25). When the groin was built (Fig. 26) during the 1978-79 winter this channel was diverted away from the north bank (Fig. 27). The groin reduced the active channel which was 6200 ft wide by 1800 ft. The width of the post-construction channel, 4400 ft, was 29% smaller than the pre-construction width. This is less of a disturbance to the river than that caused by the North Pole groin but there are measurable changes that occurred after construction of this sill groin. The increased southern erosion may be attributable to the groin diverting water to the south and causing more flow through the southern part of the channel.

1979-1980

Linear bank recession occurred along nine of 17 north channel lines and varied from 30 to 180 ft (Table 6). The recession rate along the north bank (on line) decreased to 11 ft/yr, that along the north channel islands increased to 38 ft/yr (Fig. 19). There was less linear recession along the southern channel (Table 6) but the rates increased substantially.

The amounts of the land lost during this interval decreased because the interval was shorter than previous intervals (Fig. 20). Virtually no north bank land was eroded (Table 7). North and south channel banks and the south bank were eroded the most and the rates of land lost increased (Fig. 21) as did the rates of linear recession.

By September 1980 (Fig. 28), there is not much change in the channels south of the groin and the river continued to flow along the north bank downstream of the groin. This north channel was diverted southerly only for a short distance. From 1979 to 1980, mid-channel islands and the south bank appears stable in the 18-16 area (Fig. 22), although the bank at C continued to recede.

The cross-sectional changes that occurred from 1979 to 1980 are as follows (Fig. 29). The south and north channels at GSX-5 were deeper in September 1979 at the end of the high discharge 1979 season. By 24 June 1980 the channels were generally filled-in. During the 1980 season the changes in the south channels were minor while most of the change occurred in the north channel especially during the rising limb of the hydrograph from 24 June to 31 July 1980. Changes at GSX-6 were minor throughout the 1980 season.

1980-1981

Bank recession occurred along six of 17 measuring lines along the north channel and along eight of 16 lines along the south channel (Table 6). Recession varied from 40 to 210 ft along the north channel, 40 to 110 ft along the southern. The average linear recession rates decreased along all the banks (Fig. 19). The amount of land eroded did not change substantially but the rates decreased (Figs. 20 and 21). Areas C, E, F and J in the 18-16 area (Fig. 22) continued to recede from 1980 to 1981. There was no detectable change elsewhere.

The cross-sectional changes that occurred in 1981 are as follows (Fig. 30). The south channel at GSX-5 showed little net change from 16 June 1981 to 15 October 1981. The northern part of the north channel changed considerably during the runoff season. In the middle portion it deepened about six feet and shifted to the north about 300 ft between

31 July and 15 October. At GSX-6 the southern part of the south channel shifted to the north about 50 ft during the rising hydrograph and remained virtually unchanged during the falling hydrograph. The GSX-6 north channel showed more change than in 1980 but net change over the season was small. Deposition occurred in the northern channel during the falling hydrograph.

1981-1982

Minor recession continued north of 1A and northeast of 1C, at 7A,B, 9B, 11A,B and 13B (Fig. 18). There is little detectable change from 1980 to 1982 (Fig. 31). Minor recession occurred at A, C, H and J (Fig. 22).

The cross-sectional changes that occurred in 1982 are as follows (Fig. 32). The south channel at GSX-5 showed minor changes and deposition occurred during the falling hydrograph. All the north channels showed large changes between surveys and large net changes for the season. Generally, there was a net shift to the north. The GSX-6 south channel showed little change. The north channels changed more during the rising hydrograph and showed a net northerly shift for the season.

FUTURE BANK RECESSION

NORTH POLE GROIN AREA

The apparent increase in bank recession along the south channel suggests that there is more flow through the south channel. It may be that most of the future bank recession will occur along the south channel. However, it appears that the river is trying to re-establish its original length by forming a meander at the end of the groin.

Between May 1975 (Fig. 8) and June 1982 (Fig. 33) the channel migrated northeasterly into the groin and is eroding the eastern part of area 3 (Fig. 2). This trend may continue and the river could eventually erode through the islands and erode the north bank directly. Based on the observed historical recession rates and the position of the bank on 4 June 1982, the time required for the river to erode the north bank to the 500-ft safe zone along the levee was estimated based on historical trends.

We used the maximum recession rate of 110 ft/yr at line 2A (Table 2). We measured the distance from the north bank to the 500-ft zone at six locations downstream of the groin on the 4 June 1982 aerial photography. Distances varied from 500 to 1400 ft so the estimated time varied from 5 to 13 years.

It must be emphasized that this does not imply that the river will erode to the safe zone in this time starting 4 June 1982. These values simply indicate that if bank recession occurred along the 1-mile reach of the river where the six sites are located at a rate equal to the estimated maximum historical rate, then it would take from 5 to 13 years to reach the safe zone along the levee.

Soil logs (Appendix C) taken along the approximate route of the levee in the 17-10 area give an indication of the types of sediment in the north bank along this zone of possible erosion. Usually organic and inorganic silts, 3 to 5 ft thick, overlie sandy gravels or gravelly sands which extend to the bottom of the wells at about 8 ft to 40 ft depths. Gatto (1983) reports that, it is unlikely that any bank location is more or less susceptible to erosion than any other. It is unlikely that there is a better way of providing an estimate of where future erosion will occur along this reach.

AREA UPSTREAM OF THE NORTH POLE GROIN

The north bank is within the 500-ft safe zone along the levee at a site near the gravel pit lake on the downstream end of area 17-08 (Fig. 13). But there has not been any detectable historical erosion at this location. Major bank recession has occurred upstream near site 3. The maximum recession rate was 50 ft/yr at line 3B (Table 4). Site 3 is about 2200 ft from the levee safe zone and at this maximum rate, it would take about 44 yrs for river erosion to meet the levee. The rest of the north bank is 100 to 1700 ft from the 500-ft safe zone and bank recession has not been apparent along other north bank sites.

Sediment (Appendix C) in the land between the bank and the levee is similar to that in the North Pole groin area. Sandy, organic or inorganic silt (1-5 ft thick) overlies sandy gravels or gravelly sands to the bottom of the wells (8 to 12 ft deep). Sediments were frozen in five of the six wells. However, there is not apparent relationship between frozen sediment and locations of bank erosion or of stable banks (Gatto 1983).

Most of the bank in the 17-06 area (Fig. 17) from a location north of site K to southeast of J is about 100 to 500 ft from the safe zone along the levee as observed on the June 1982 photography. We used a recession rate of 55 ft/yr averaged between 50 ft/yr for line 3B (Fig. 13; Table 4) and 60 ft/yr for line 2A (Fig. 18; Table 6) for estimating the time for the bank to erode to the safe zone. This average is based on the highest rates for the nearest north bank sites in 17-08 and 18-18. Using this averaged rate, the minimum time along this reach would be 2 to 9 years. However, there has been no detectable bank recession at the 17-06 sites since 1975, so it is debatable when erosion may begin again.

FLOODWAY SILL GROIN AREA

The levee does not border the river in the 18-16 area so only the groin area is discussed. The north bank is within the 500-ft safe zone along the levee just west of the mouth of Piledriver Slough (Fig. 18) and along the small channel between lines 1C and 2A. The north bank east of line 1C (Fig. 18) is about 100 ft from the safe zone and at line 2A, about 1100 ft. Using the highest historical rate along the north bank, 70 ft/yr for site 4A (Table 6), it would take 1.5 to 16 yrs, for the river to erode to the safe zone. However, the bank east of site 1 has not eroded since 1970 and the bank at site 2A has not receded since the groin was constructed.

Bank sediment (Appendix C) along the 18-18 reach is similar to that in 17-08. No predictions of likely locations of bank recession are possible.

SUMMARY

NORTH POLE GROIN AREA[1]

The main flow was in the northern part of the channel from 1948 to 1974. A broad meander was migrating northward against the bank. Fifty-two

[1] Area is shown in Fig. 2 and covers 3.6 straight-line miles of river channel.

percent, 95 acres (Table 8) of the land eroded during this interval was eroded along about a 3-mile reach of the north bank near and downstream of the groin site. The broad meander was tightening during the latter part of this interval and bank erosion was concentrated along about a 1-mile reach of the north bank. The rate of land loss from 1948 to 1974 for the north bank sites was 3.5 acres/yr (Table 8). The linear recession rate was 11 ft/yr/line (Table 2).

Erosion along the islands that border this main north channel removed 63 acres (about 34% of the total) from 1948 to 1974. Most of this occurred about 1.5 miles downstream of the groin site. The land loss rate was 2.3 acres/yr and the linear recession rate was 8 ft/yr/line.

Along the south channel, 20 acres (11%) were eroded from the islands and 5 acres (3%) from the south bank. All of the erosion occurred along the outside banks of channel meanders. The rates of land loss for the south channel islands and south bank sites were .7 acres/yr and .2 acres/yr, respectively. The linear recession rates were also the lowest along the south channel (Table 2).

Near the end of the 1948-74 interval, more of the bank along the south channel eroded than earlier in the interval but no obvious patterns are apparent from these measurements. The channels were migrating in a normal way prior to construction of the groin.

The North Pole groin was constructed over the 1974-1975 winter. It completely cut off the large meander in the north channel and diverted the river away from the north bank for a distance of about 1.3 miles. As a result of the diversion, most of the erosion between 1975 and 1981 occurred along the islands and the south bank.

The land eroded from the north bank was 10 acres (14%) (Table 8) and the rate of land loss was 1.4 acres/yr. This is less than half the preconstruction rate. Erosion along the islands bordering the north channel was 20 acres. The rate was 2.9 acres/yr, which is slightly higher than the rate before groin construction. The linear recession rate along the north bank increased slightly while the rate along the north channel islands nearly doubled (Table 2).

The erosion along the south channel increases substantially after groin construction. Land lost along the islands was 19 acres, along the south bank, 23 acres. Land loss rates were 2.7 and 3.3 acres/yr, respectively (Table 8), which are increases of 4 and 16 times over the pre-construction rates. This suggests that the additional flows diverted southward by the groin have increased bank erosion in the southern part of the channel. Linear recession rates increased 15 times over the pre-groin rates (Table 2).

Early in this post-construction interval a meander began to reform at the end of the North Pole groin. Meanders also reformed up- and downstream of the groin and tightened and migrated laterally. More of the bankline along the south channel was also eroded early in this interval, 20% in 1977 and 17% in 1978.

The meanders along the north and south channels continued to tighten and move laterally through the end of the interval. The river appeared to be re-establishing its pre-groin length along the north channel. The south channel carried more of the flow after the groin was built and erosion increase.

AREA UPSTREAM OF THE NORTH POLE GROIN[2]

The banks in the southern portion of the channel the 17-08 area have eroded quicker than those in the northern portion. Most of the northern portion has inter-island channels where there was not detectable recession. Usually, the islands were stable and revegetating from 1961 to 1982.

FLOODWAY SILL GROIN AREA[3]

From 1970 to the winter of 1978-1979 a main channel of the river flowed directly against the north bank and 28 acres (29%) of land were eroded. The net erosion rate for the north bank sites was 3.2 acres/yr

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[2] Area is shown in Fig. 13 and covers 3.4 straight-line miles of river channel.

[3] Area is shown in Fig. 18 and covers 3.5 straight-line miles of river channel.

(Table 9). The reach of the river in the area of the sill groin is more braided than that downstream near the North Pole groin so the flow is more distributed across the active floodplain. In the northern portion of the floodplain there was two main channels.

The islands bordering the northern portion of the channel lost 32 acres (33%) prior to construction (Table 9). The net erosion rate was 3.7 acres/yr. Most of this island erosion was done along the southern side of the main channel in the northern part of the floodplain.

The islands along the southern channel lost 18 acres (19%) and the net erosion rate was 2.1 acres/yr. South bank erosion was 19 acres and the erosion rates were about the same for the islands and bank. Erosion in the area of the sill groin prior to its construction occurred more evenly across the channel. Whereas pre-construction erosion near the North Pole groin was concentrated along the northern portion of the channel.

As observed near the North Pole groin, the bank erosion along the sill groin reach also occurred along the outside banks of meanders. New locations erode while sites that previously eroded became stable as the river migrates laterally and the bends become more curved or straightened.

After constuction of the groin during the 1978-1979 winter the bank erosion patterns changed. From 1979 to 1981 no erosion occurred at the north bank sites (Table 9). The erosion rate along the islands bordering the northern portion of the channel increased to 4.1 acres/yr but much less land was lost (12 acres). Erosion rates along the south channel islands and along the south bank also increased to 3.1 acres/yr. This suggests that the increased flows through the southern channel have caused increased bank erosion. The increased flow is due to the diversion of flow and constriction of the channel width.

As observed in the North Pole groin area, the northerly channel nearest the sill groin was beginning to migrate to the north at the end of the groin. It appears that the river is attempting to re-establish its pre-construction length.

The pre-construction changes at cross-section GSX-5 between 1977 and 1979 are: the channel on the north end of the section deepened and widened, the channel along the north side of the island deepened and the south channel widened. Post-construction GSX-5 cross-sections were taken eight times in 1980 and 1981 and six in 1982. The net changes summarized by Burrows and Harrold (1982) follow: no significant changes have occurred in overall size and shape of the south channel; major lateral shifting and erosion and deposition occurred in the north channels; and, changes occurred during flood and flow recession.

GSX-6 cross sections were taken seven times in 1980, eight in 1981 and six in 1982. Between 1980 and 1981, changes in the southern channel at GSX-6 have been seasonal but no major shifting of the deeper portions of the channel occurred (Burrows and Harrold 1982). The overall changes in the northern channels suggest that net deposition occurred between 1980 and 1981.

CONCLUSIONS

The linear recession rates and rates of land lost along the north and south portions of the channel in the areas near the groins show that the groins have successfully diverted the river away from the north bank and stopped north bank erosion in the immediate area. More water is flowing through the southern channels and we have observed and measured more bank recession along the south channel bank sites since groin construction. It may be that most of the future bank recession will occur along the south channel. However, it appears that the river is trying to re-establish its original length by forming a meander at the end of the groins.

North bank sites that should be closely monitored because either the bank is already near the levee safe zone or recent recession rates have been high are 3A-D (Fig. 2), and north of K and southeast of J (Fig. 13). Based on this historical analysis, it is unlikely that the north bank in the remaining areas would recede quickly enough to encroach into the levee safe zone in the near future. Analysis of aerial photography would easily detect any changes in historical trends and alert personnel to potential problem locations.

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Buska, J. (1981) Tree revetment and timber mattress streambank protection, Tanana River, Alaska. Section 32, Streambank Erosion Summary Report, Fairbanks, Alaska.

Gatto, L.W. (1983) Relationships among bank recession, vegetation, soils, sediment and permafrost on the Tanana River near Fairbanks, Alaska. Draft Contract Report for the Alaska District, Corps of Engineers, April.

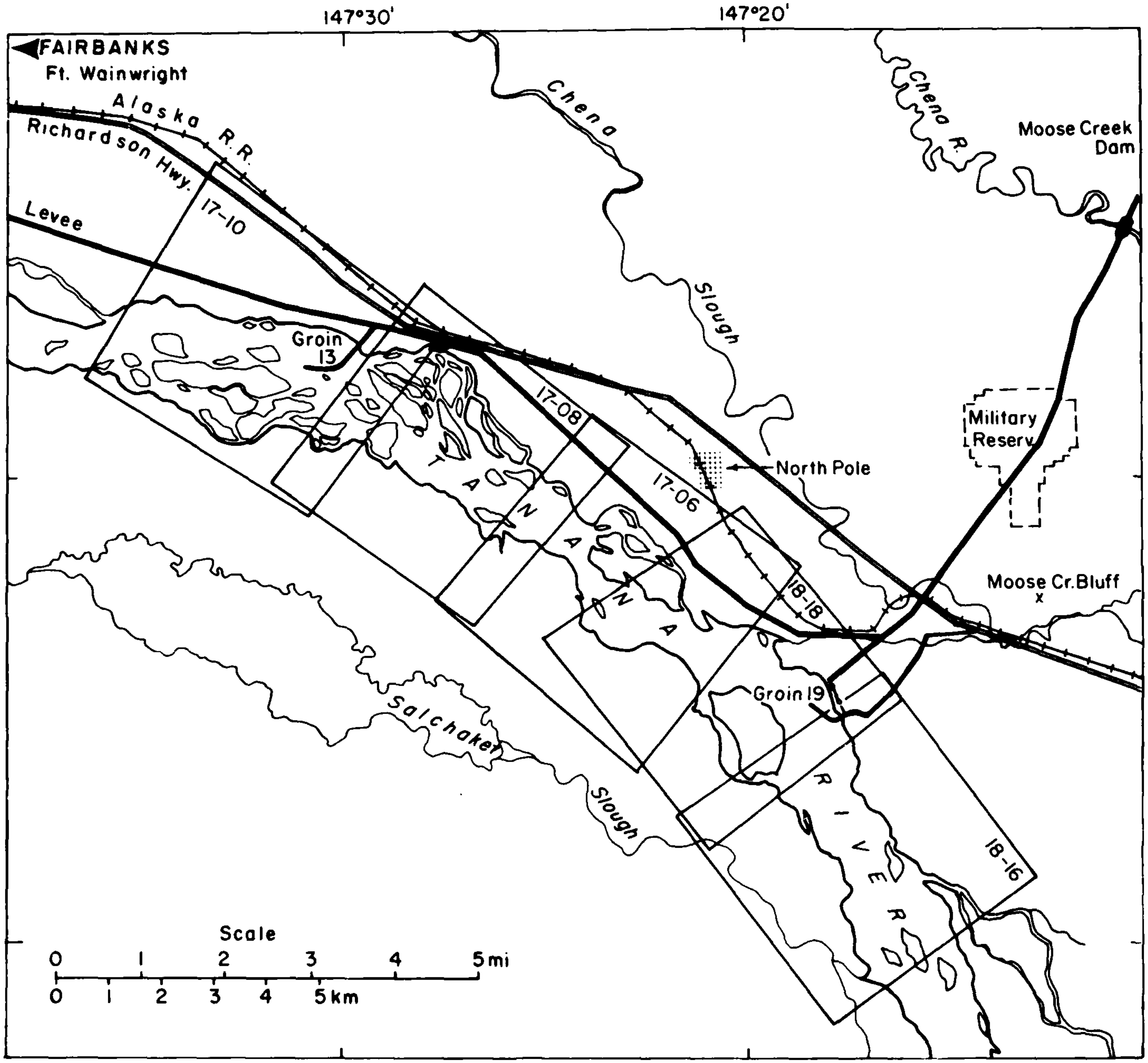


Figure 1. Location map.

Figure 2. Measuring line locations near the North Pole groin (mapping base 17-10, Fig. 1).

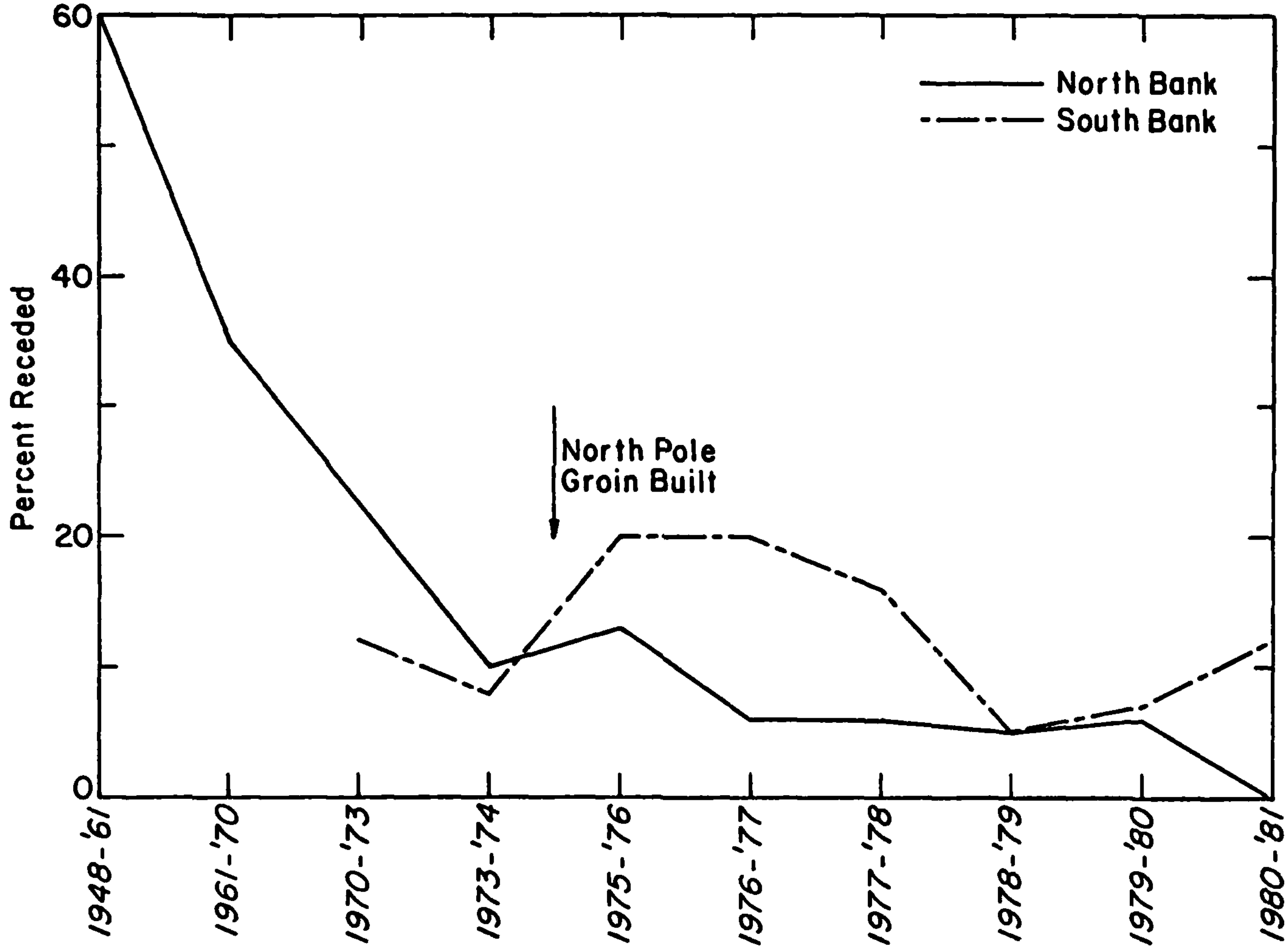


Figure 3. Percentages of north and south banks in the North Pole groin area receding per interval.

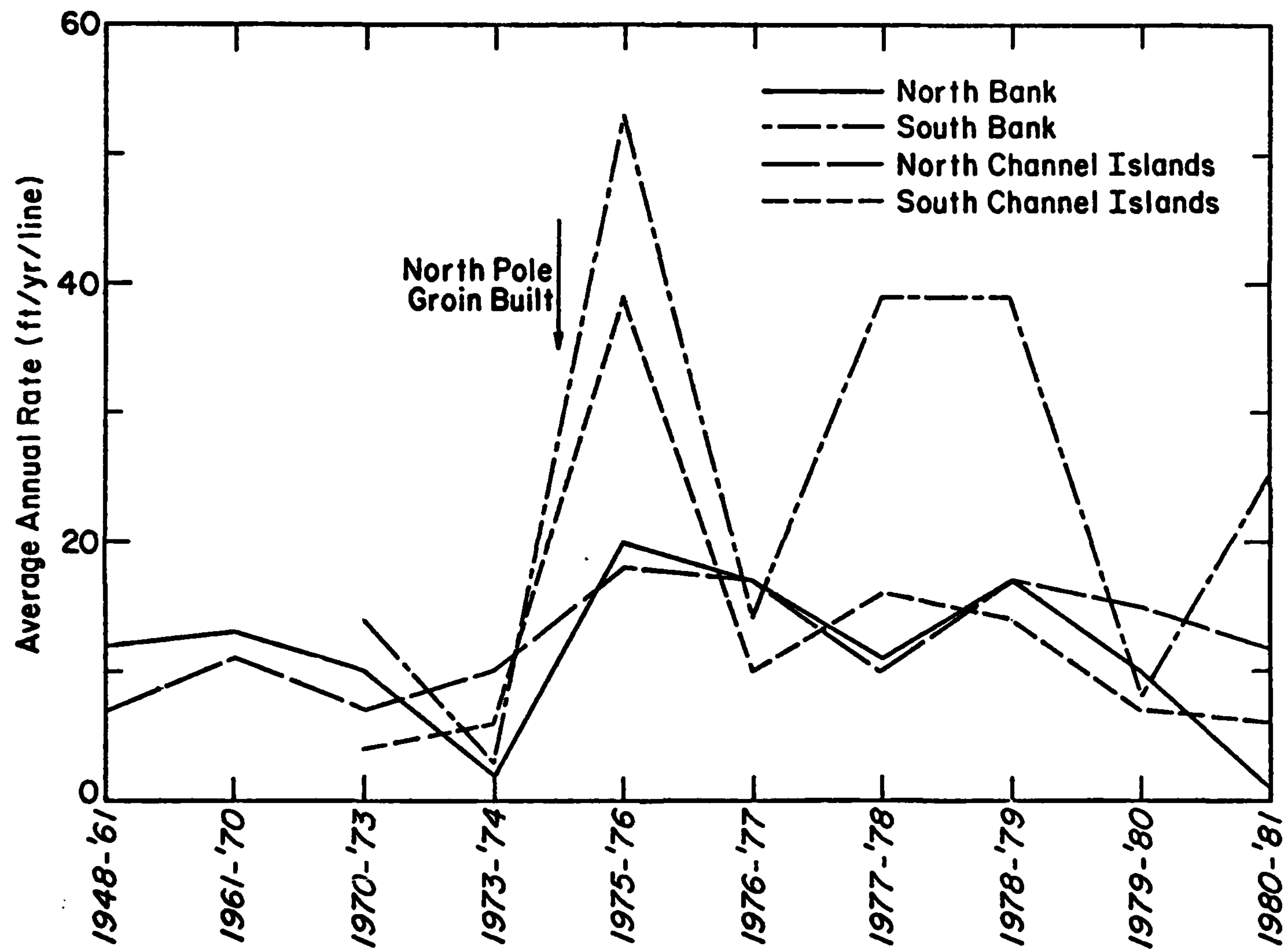


Figure 4. Average linear recession rate per measuring line in the North Pole groin area.

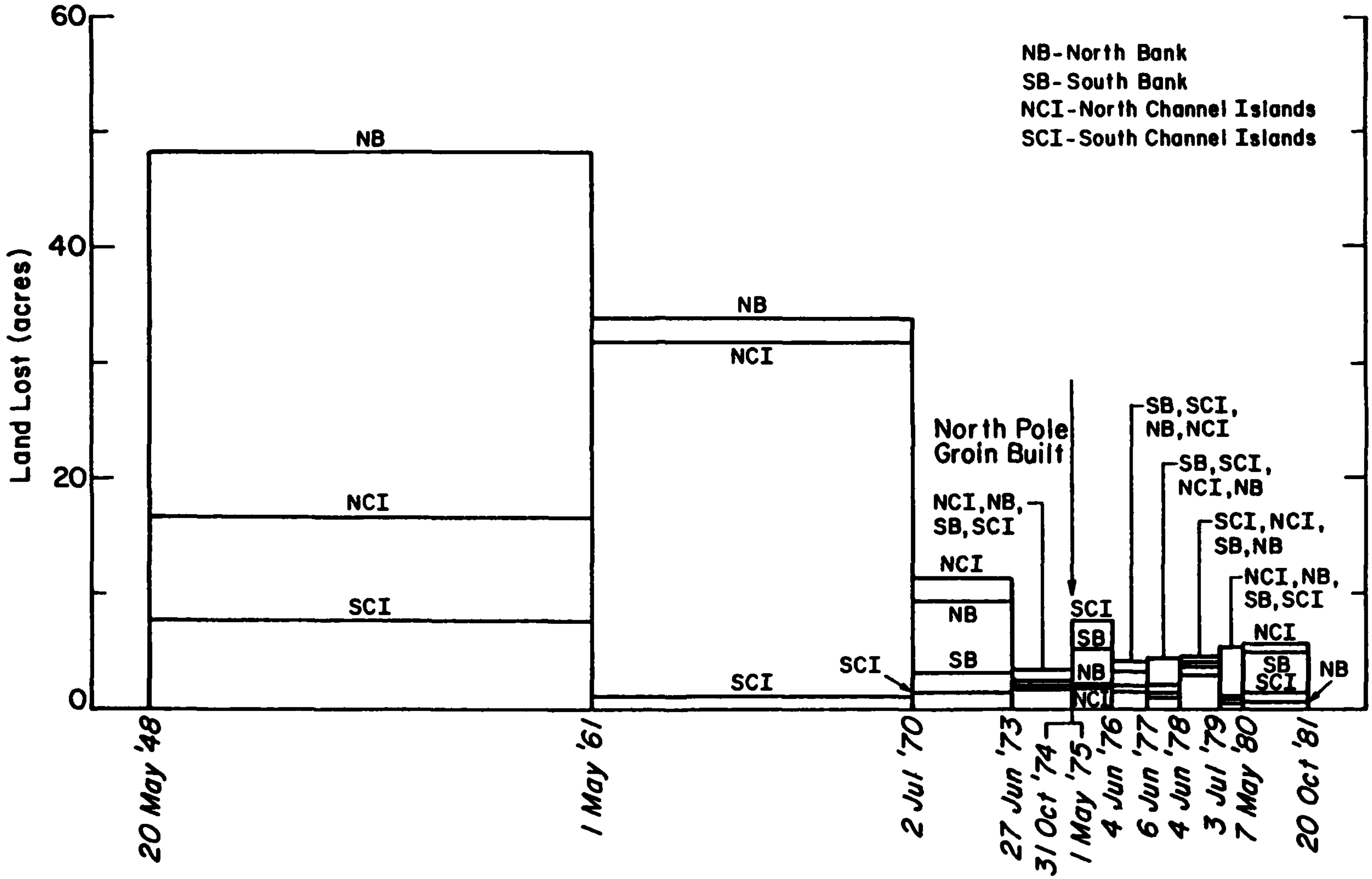


Figure 5. Land lost in the North Pole groin area.

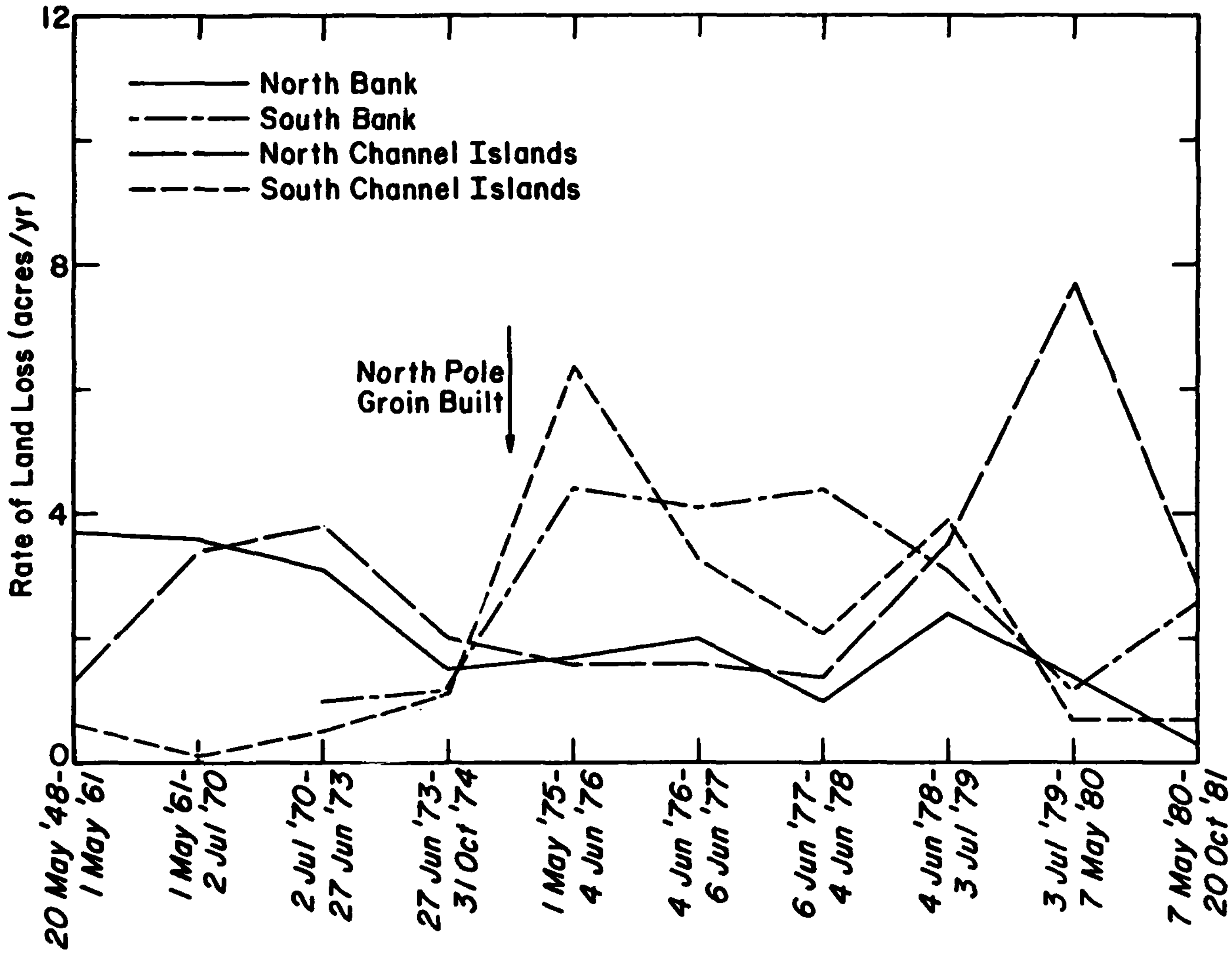
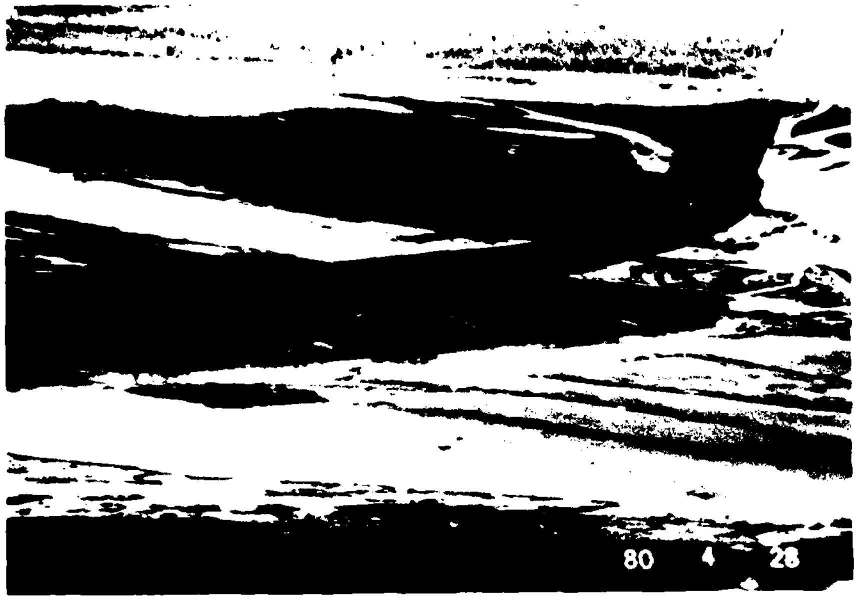
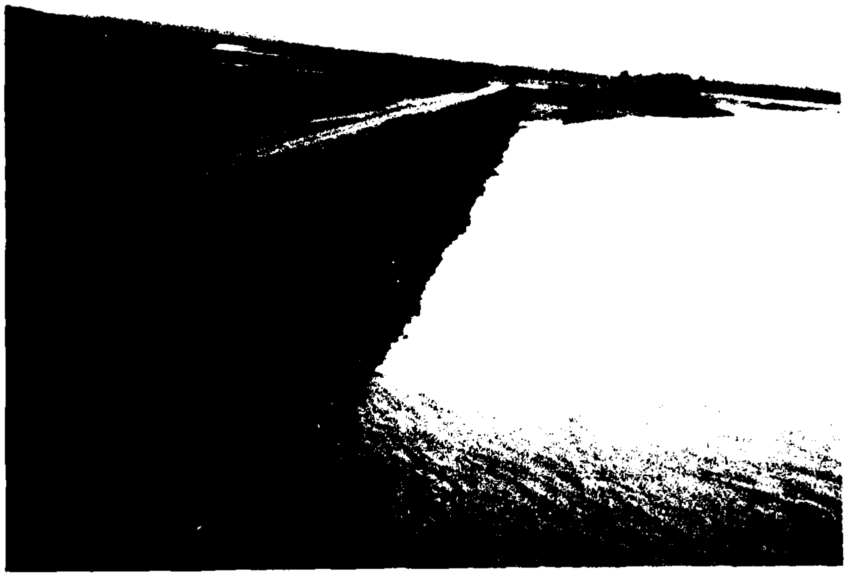


Figure 6. Rate of land lost in the North Pole groin area.



a. Upper portion where it crosses north bank and joins the levee.

b. Lower portion looking downstream.



c. Upstream side of lower portion looking east.

Figure 7. North pole groin.

Figure 8. North Pole groin, 14 May 1975

Figure 9. North Pole groin area, 26 September 1975.

Figure 10. Cross-section locations in the North Pole groin area.

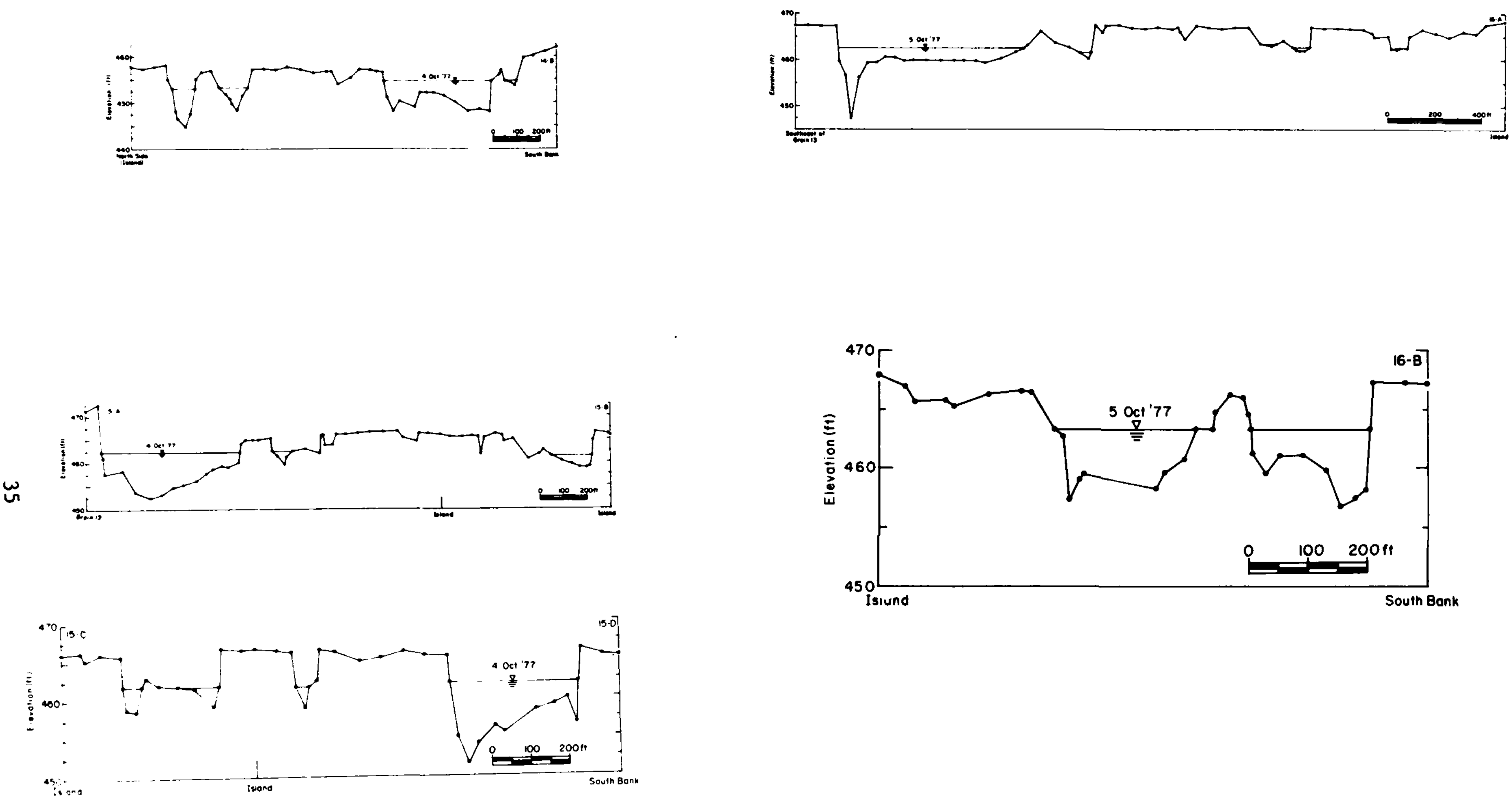


Figure 11. Cross-sections (shown looking upstream) taken on 4 and 5 October 1977 (locations shown on Figure 10).

AD-A167 790 CHENA RIVER LAKES PROJECT FAIRBANKS ALASKA OVERVIEW OF 4/4
TANANA RIVER MONIT..(U) COLD REGIONS RESEARCH AND
ENGINEERING LAB HANOVER NH C R NEILL ET AL. JAN 84
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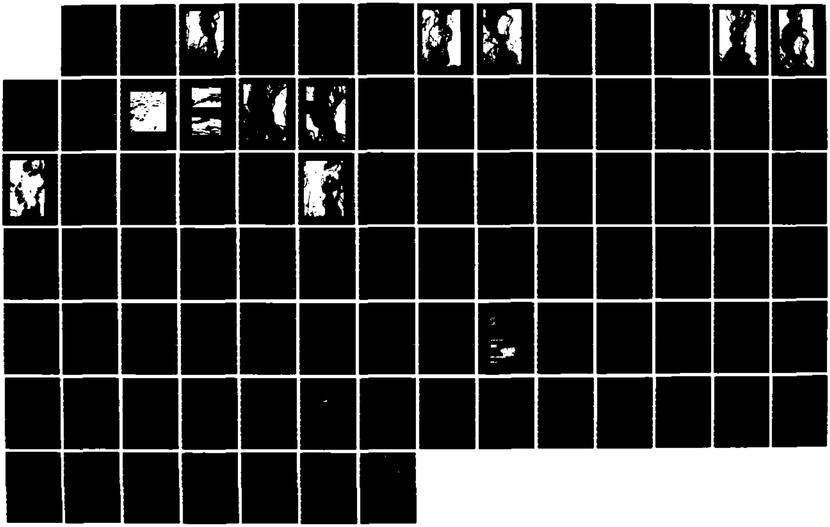
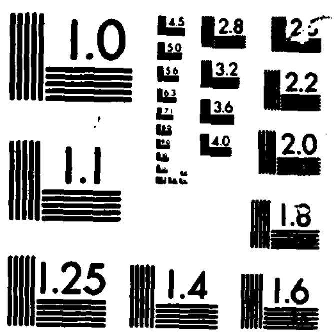




MICROCOP' CHART

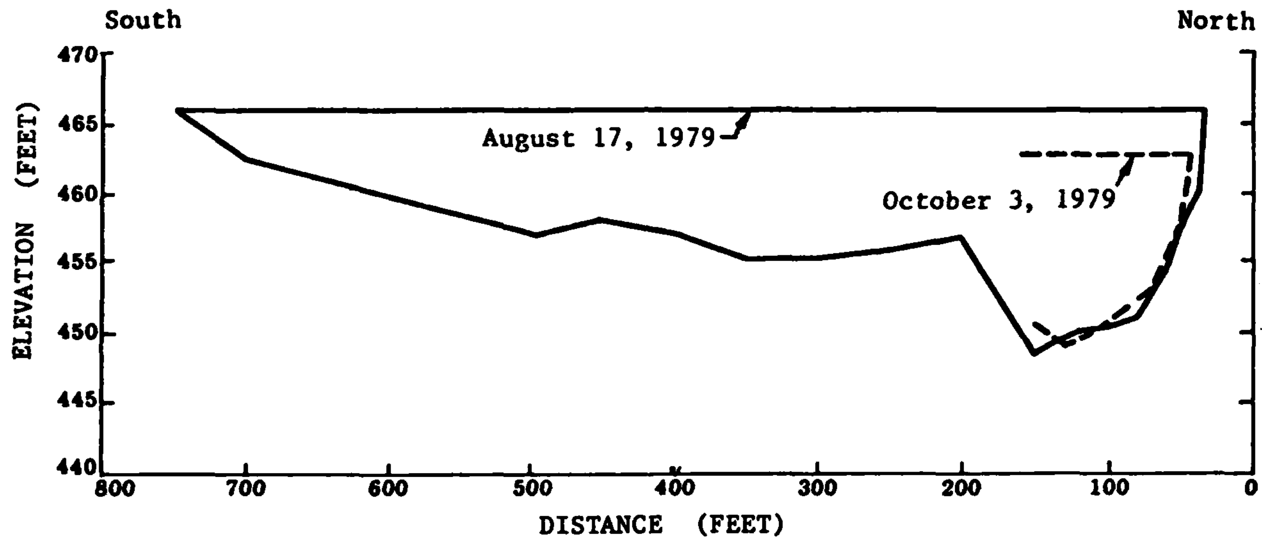


Figure 12. Cross-section 16A shown looking downstream (from Burrows 1980).

Figure 13. Measuring line locations upstream of the North Pole groin (mapping base 17-08, Fig. 1).

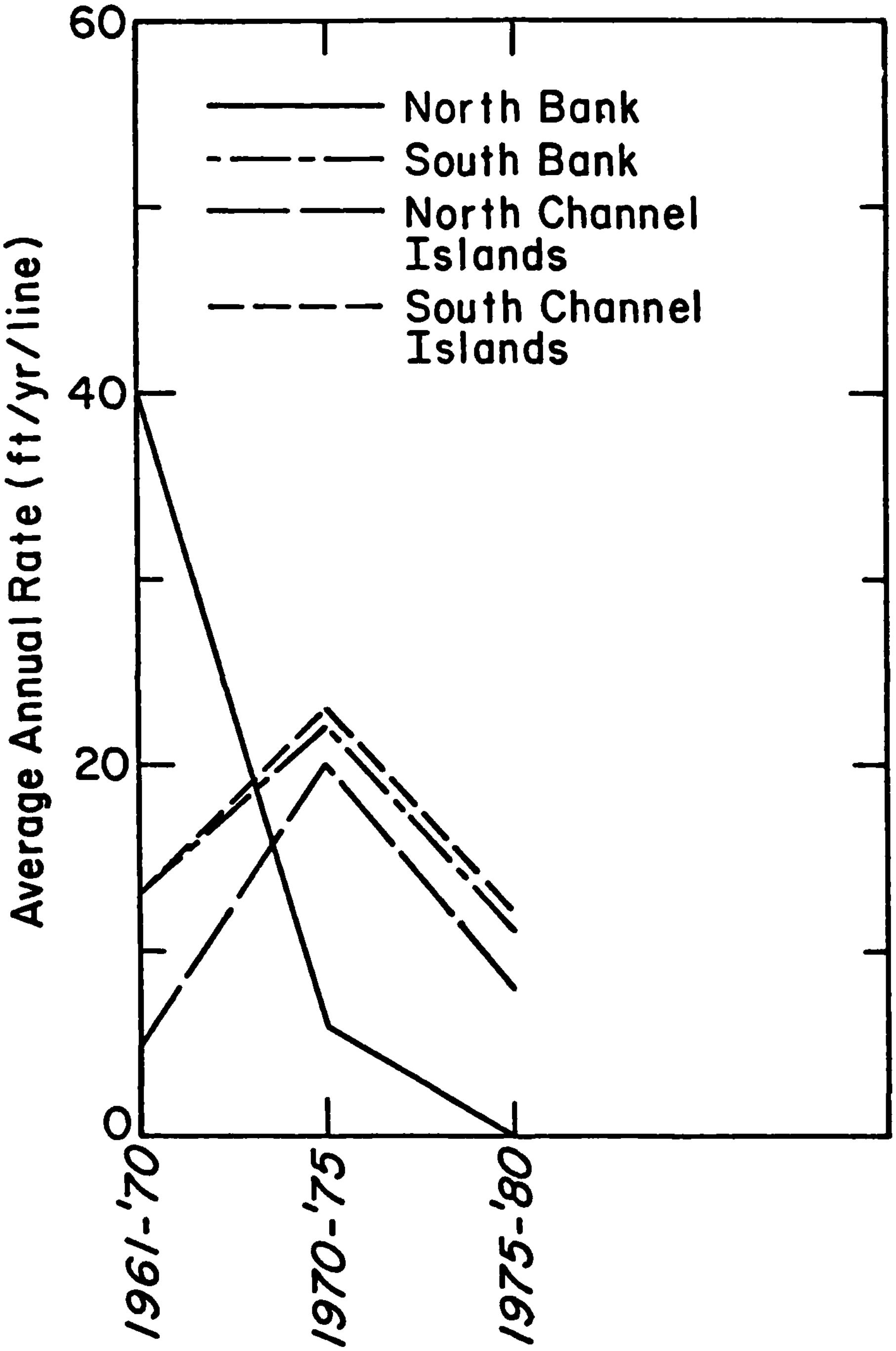


Figure 14. Average linear recession rate per measuring line in the area upstream of the North Pole groin.

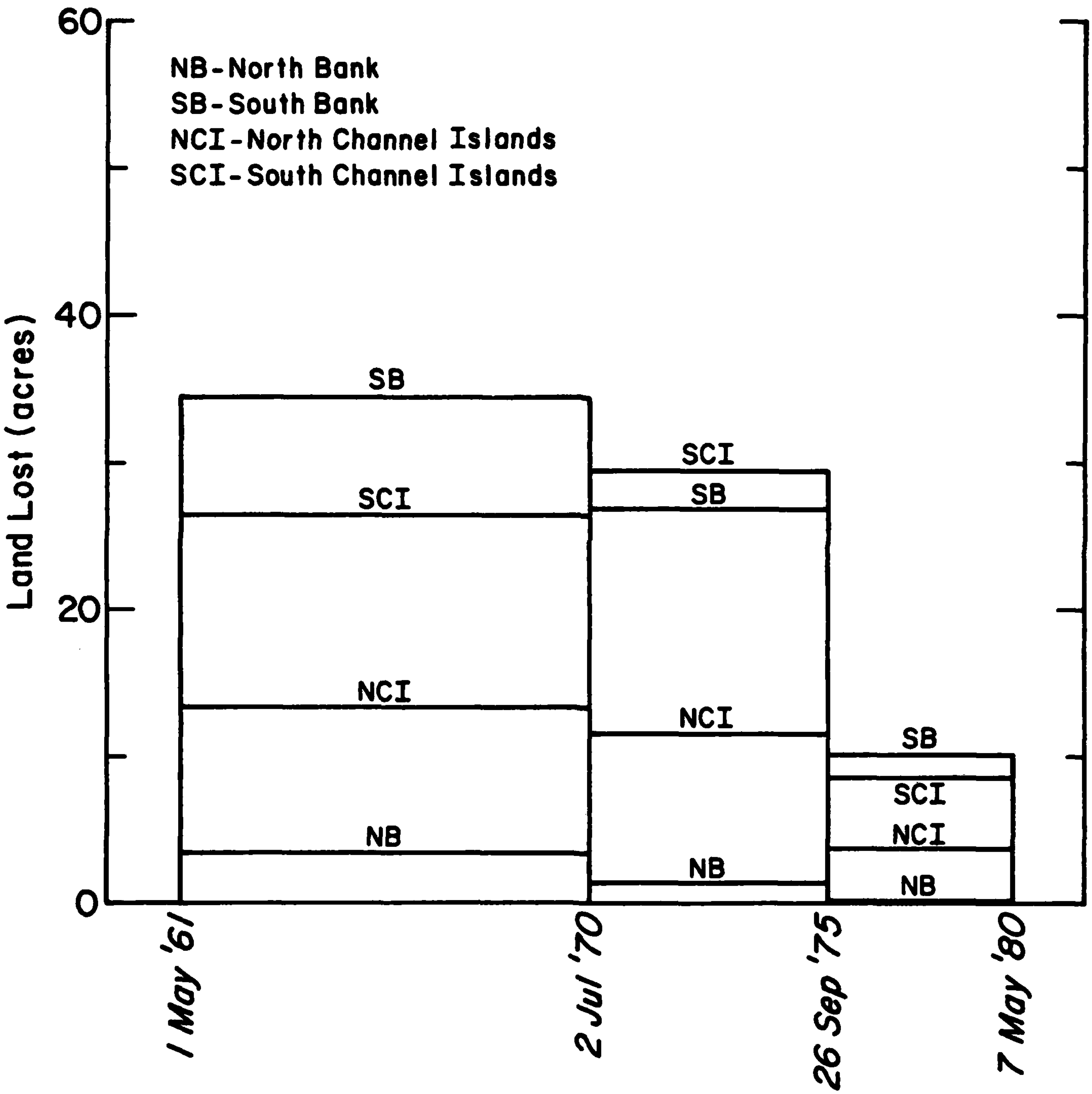


Figure 15. Land lost in the area upstream of the North Pole groin.

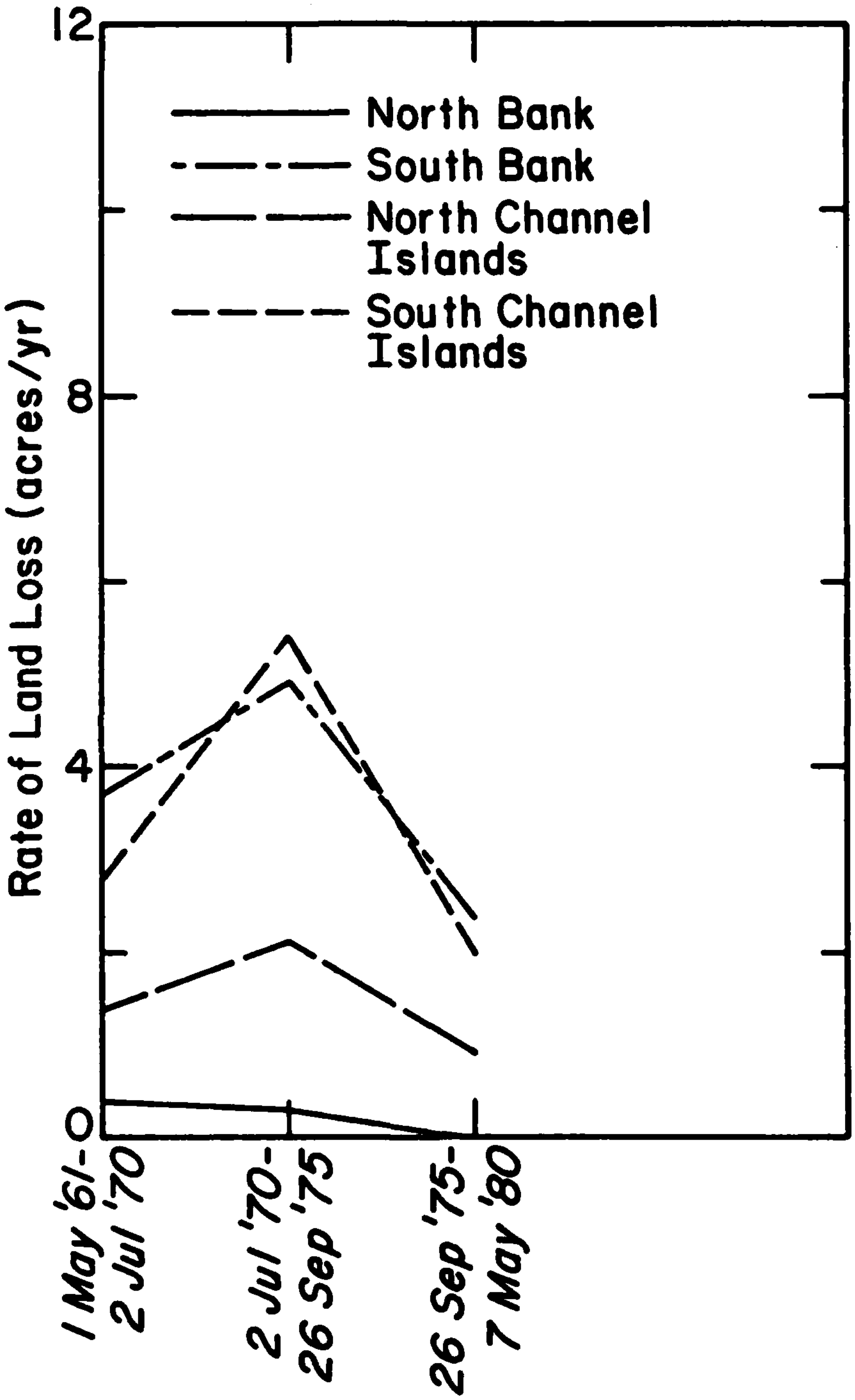


Figure 16. Rate of land lost in the area upstream of the North Pole groin.

Figure 17. Area 17-06, between 17-08 downstream and 18-18 upstream (see Fig. 1).

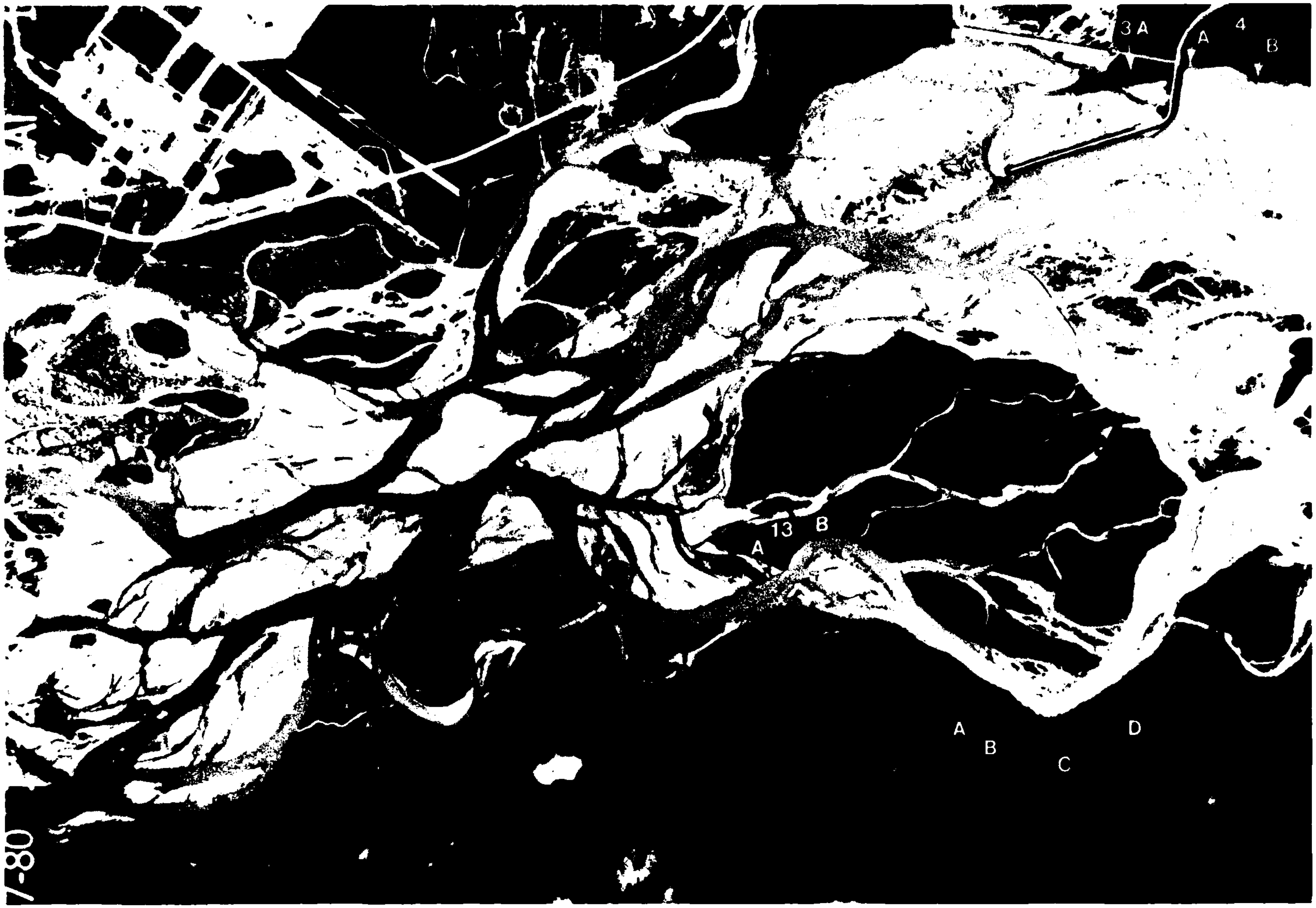


Figure 18. Measuring line locations near the floodway sill groin (mapping base 18-18, Fig. 1).

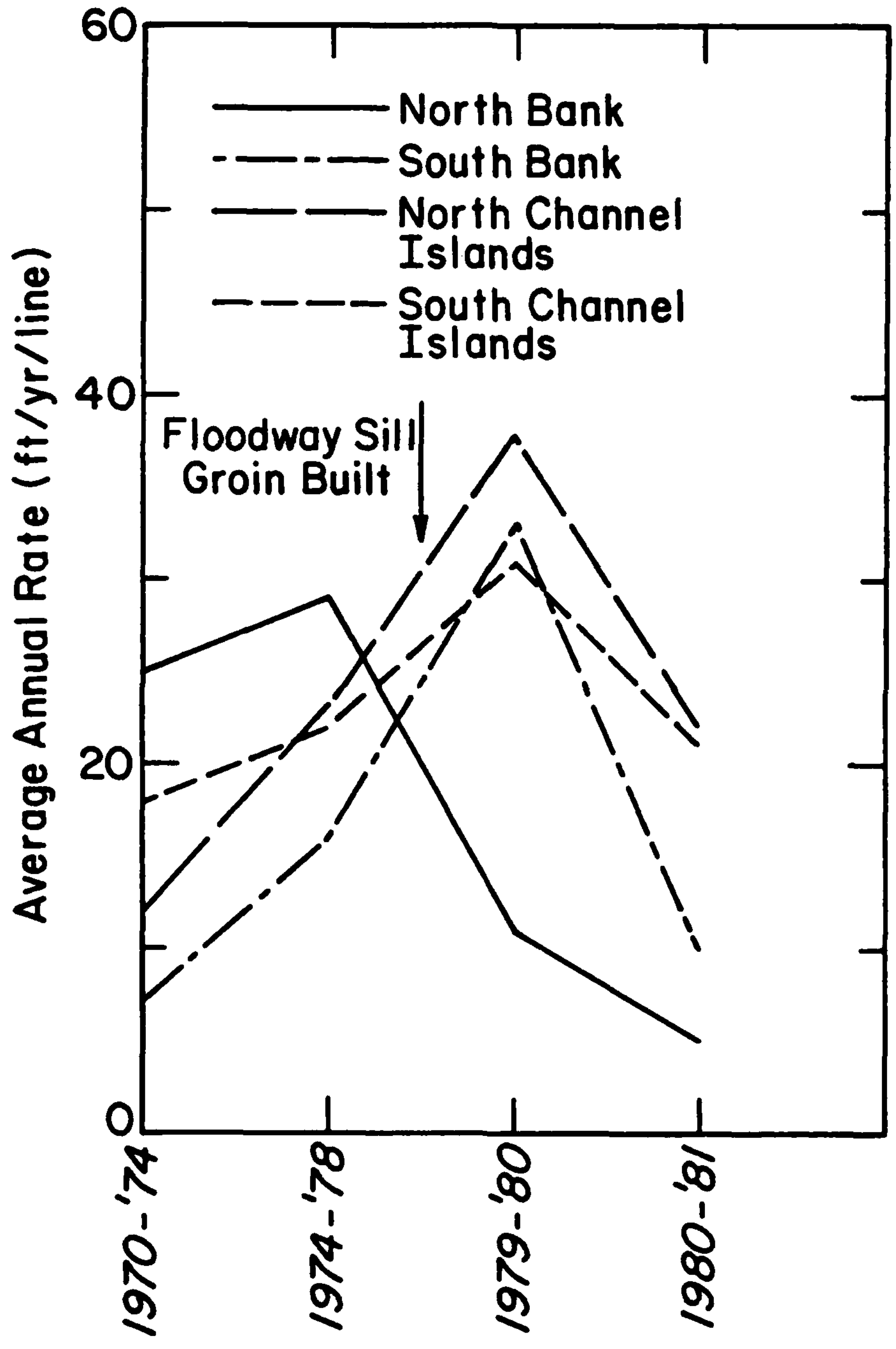


Figure 19. Average linear recession rate per measuring line in the floodway sill groin area.

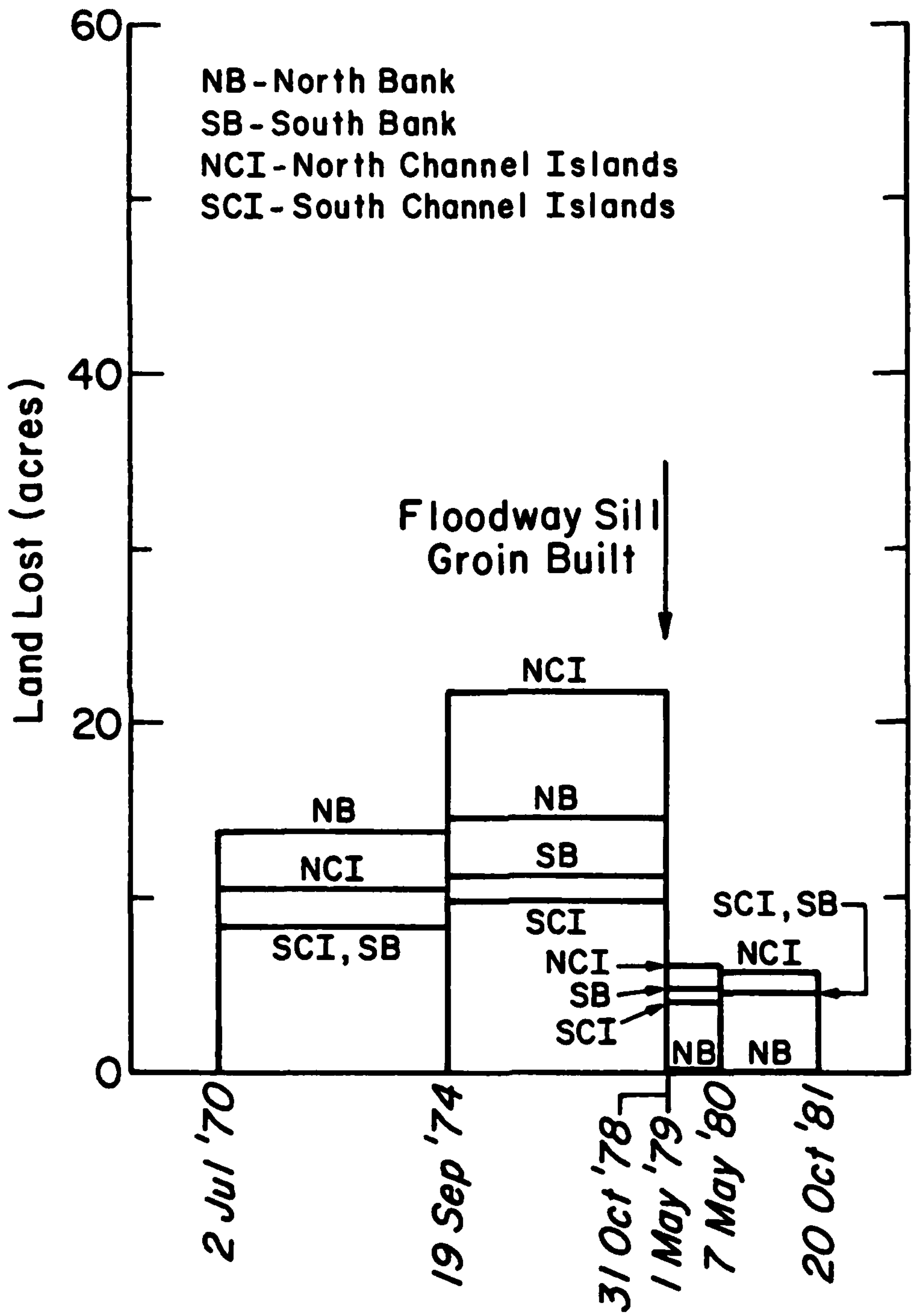


Figure 20. Land lost in the floodway sill groin area.

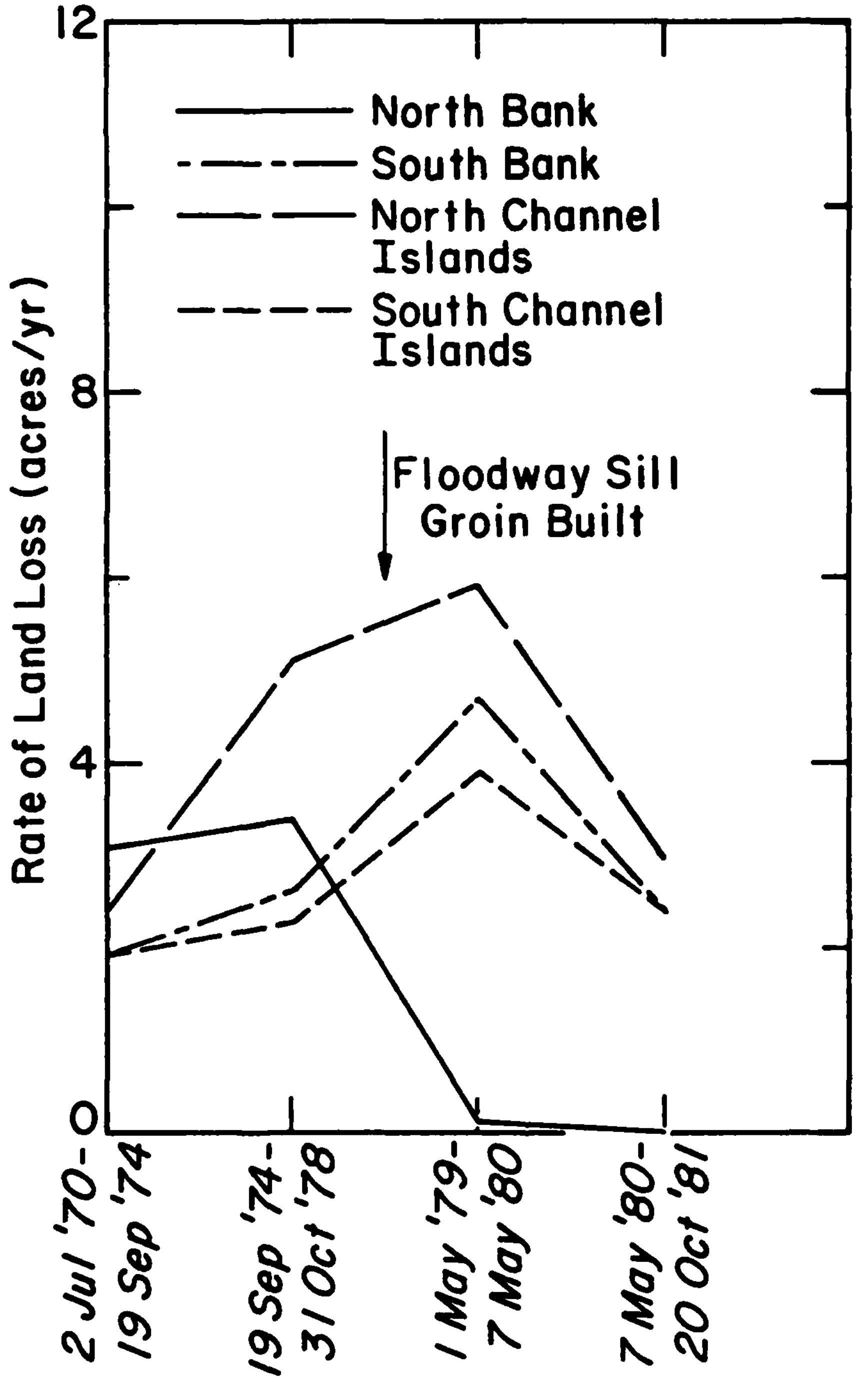


Figure 21. Rate of land lost in the floodway sill groin area.

Figure 22. Area 18-16, upstream of the floodway sill groin.

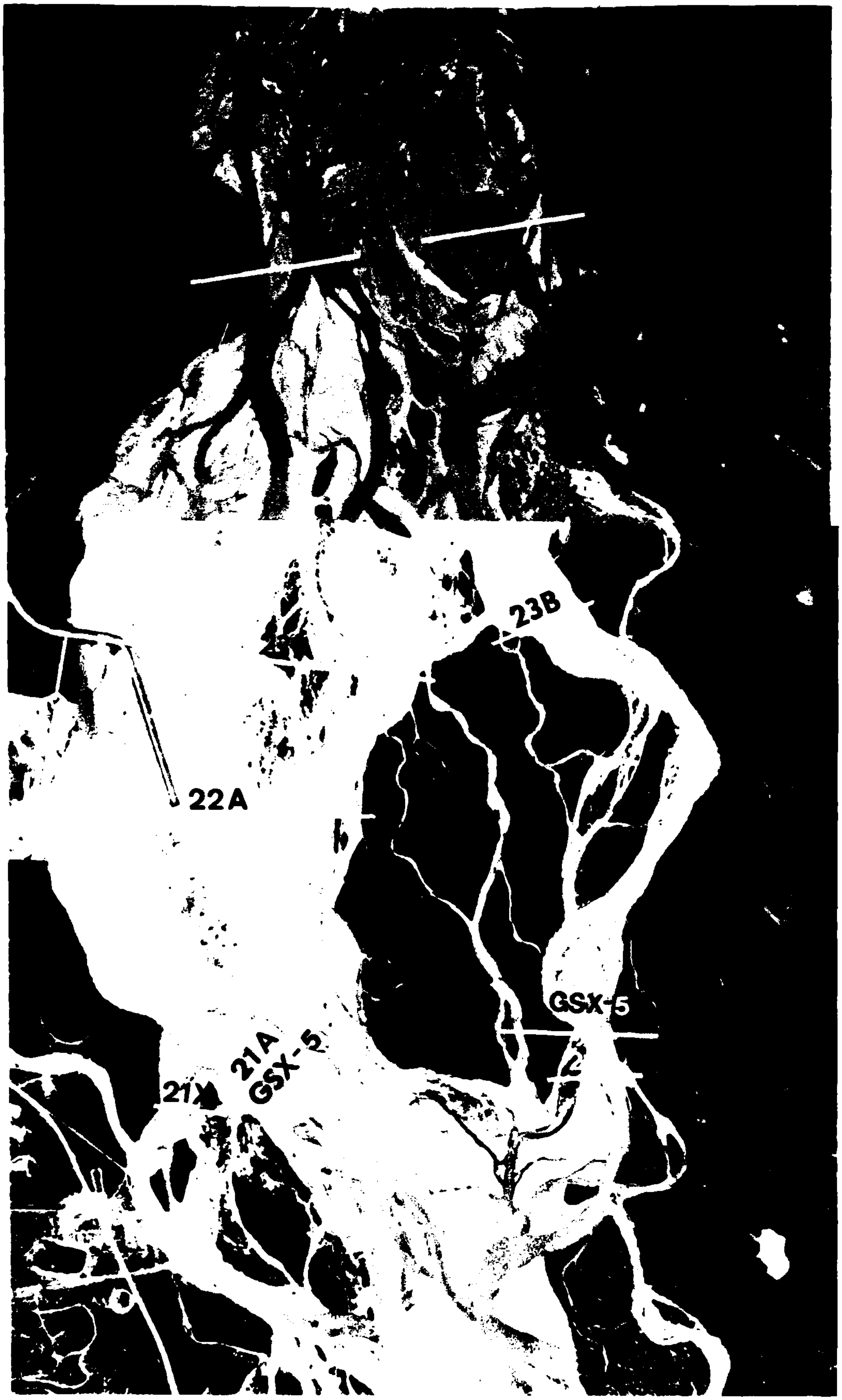


Figure 23. Cross-section locations in the floodway sill groin area.

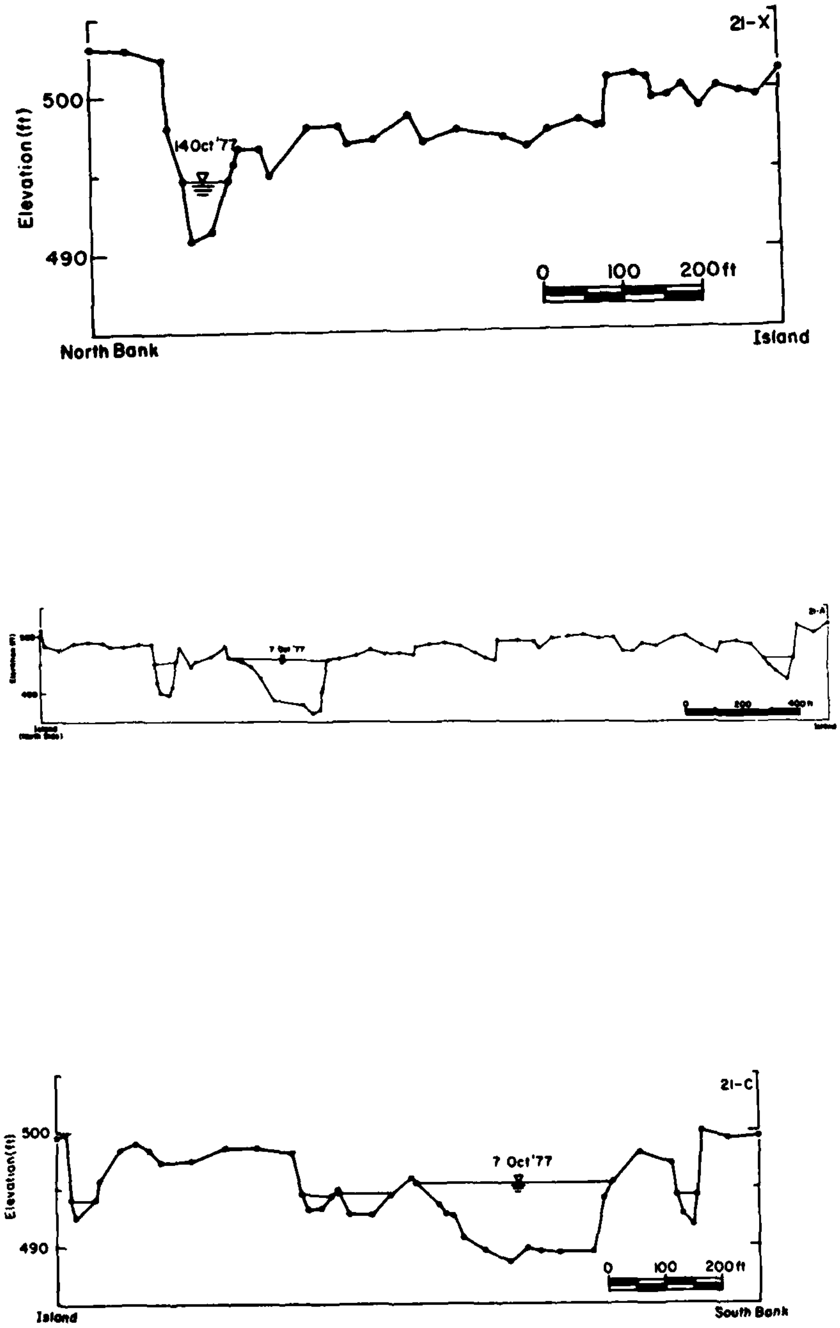


Figure 24. Cross-sections taken in 1977 and 1978 before construction of the floodway sill groin.

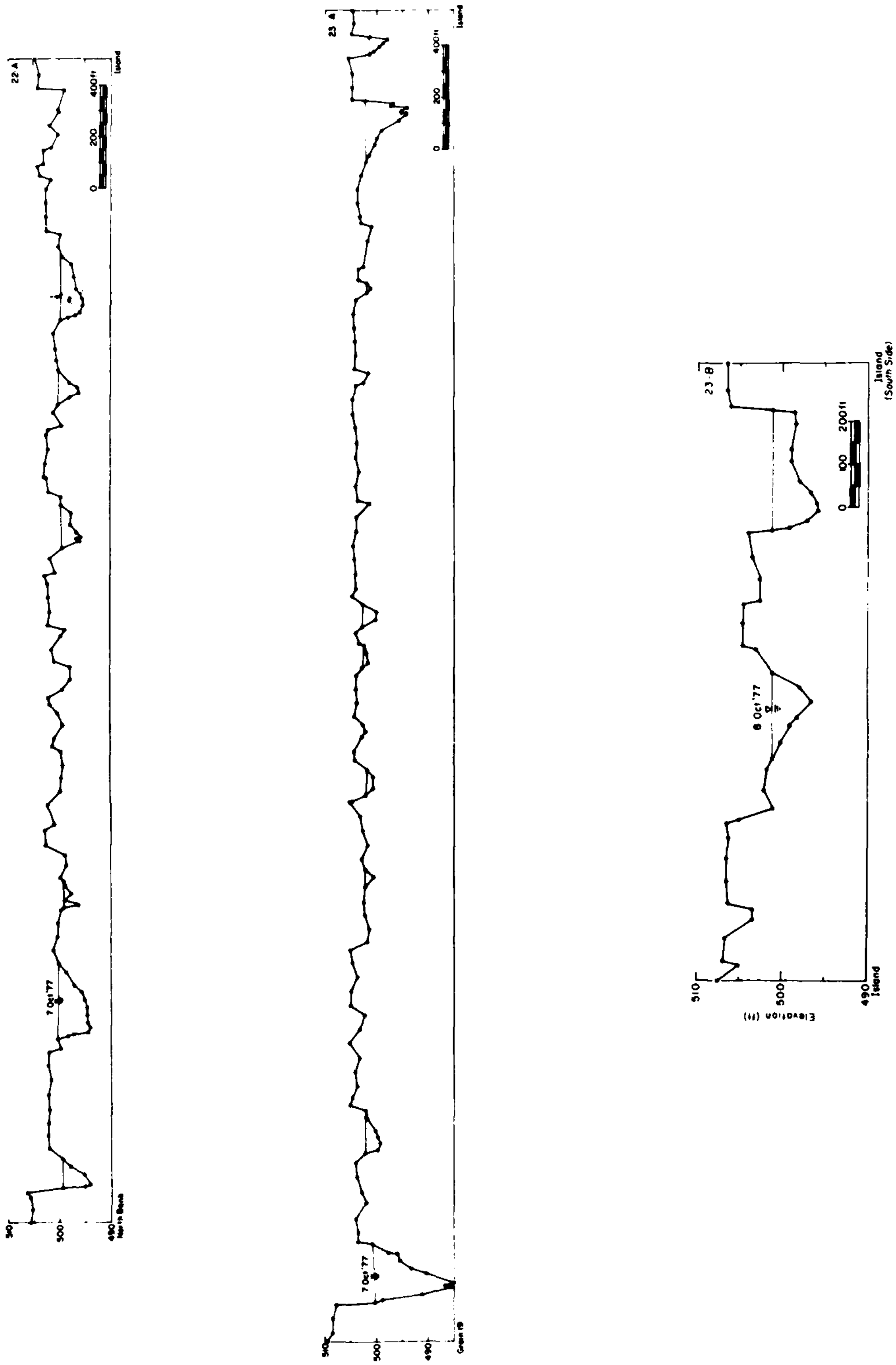
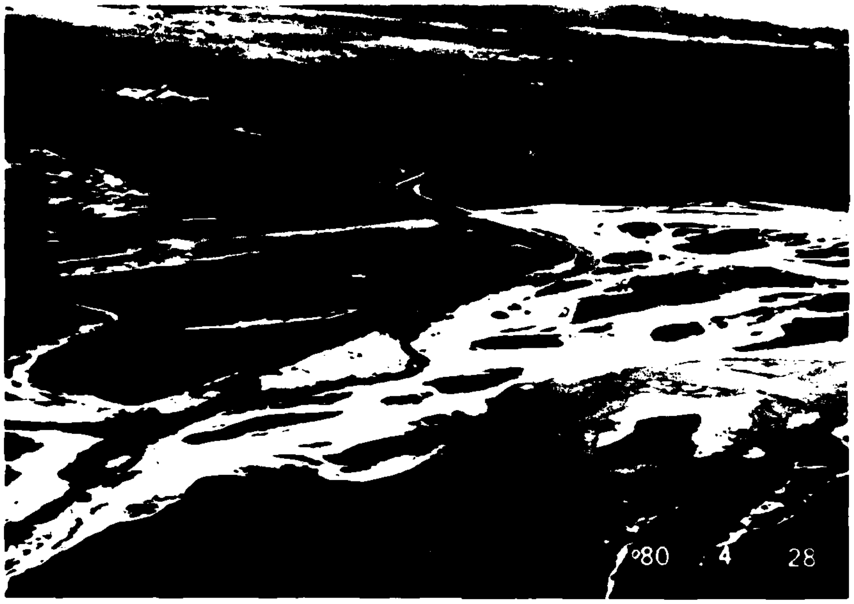


Figure 24. continued

Figure 25. Floodway sill groin area before completion of the groin, 4 June 1978.



a. Looking east.

b. Looking northeast up floodway.

Figure 26. Floodway sill groin.

Figure 27. Floodway sill groin, 29 July 1979.

Figure 28. Floodway sill groin, 8 September 1980.

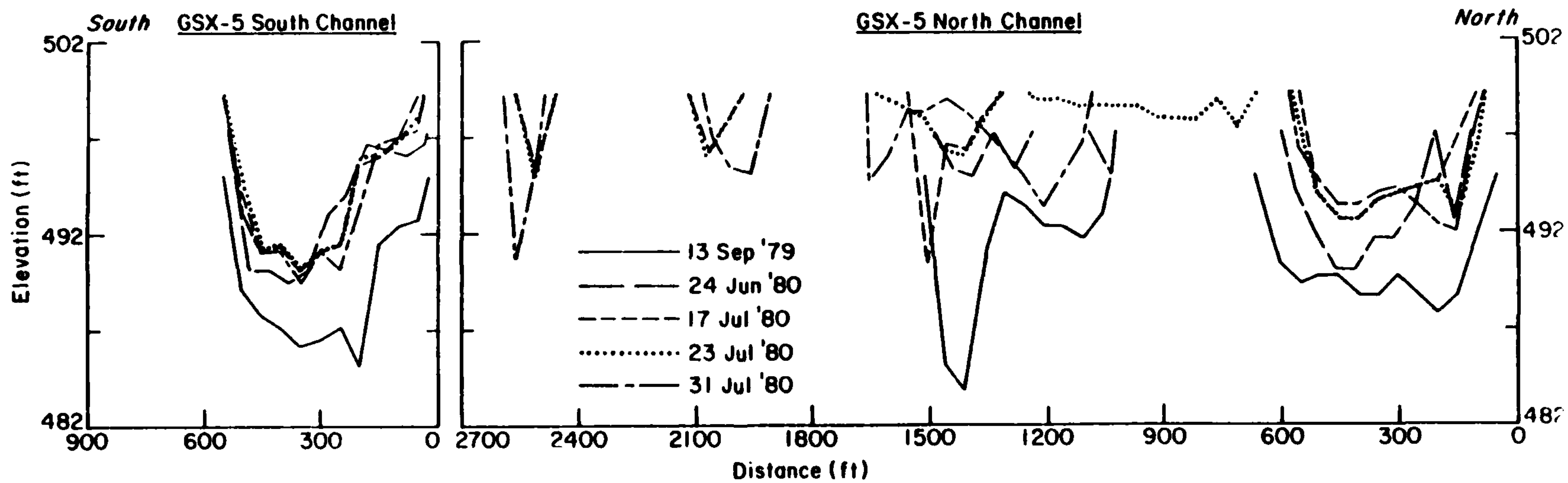


Figure 29. Cross-sections taken in 1979 and 1980 after construction of the floodway sill groin.

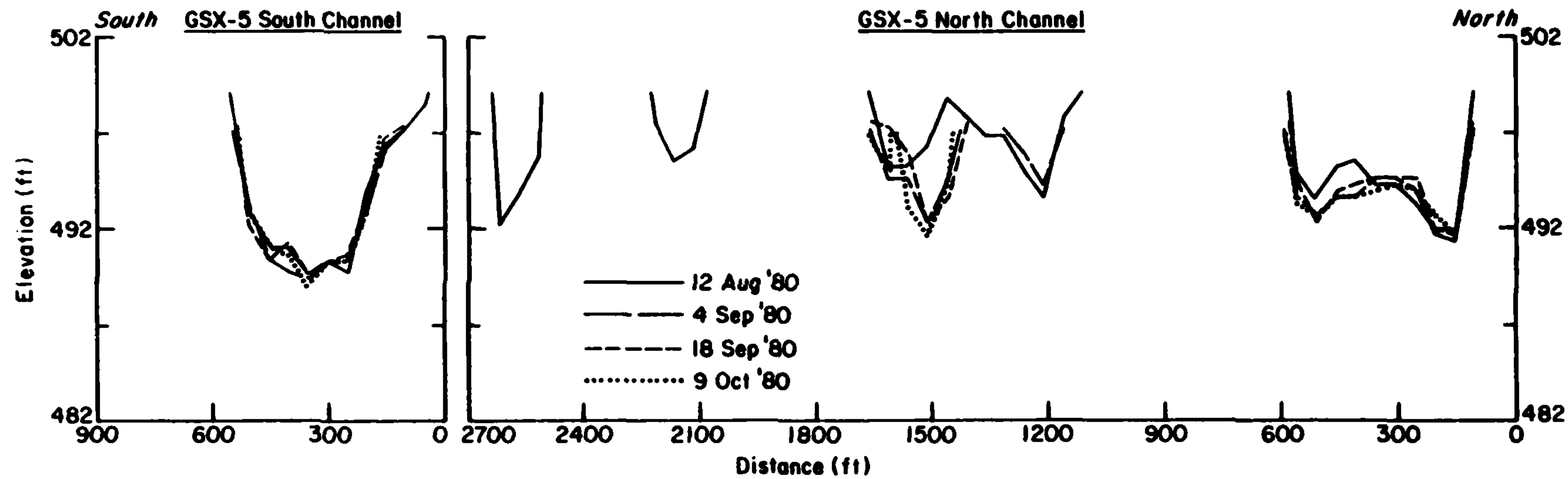


Figure 29 (cont'd).

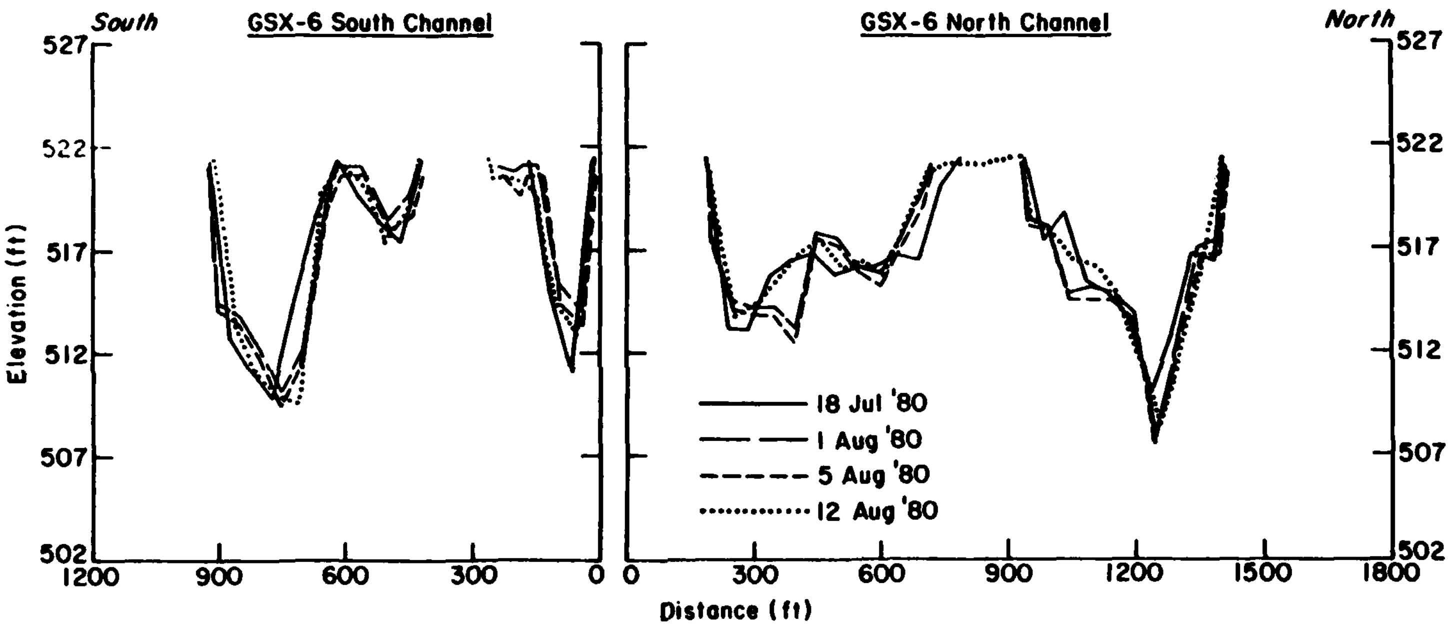


Figure 29 (cont'd).

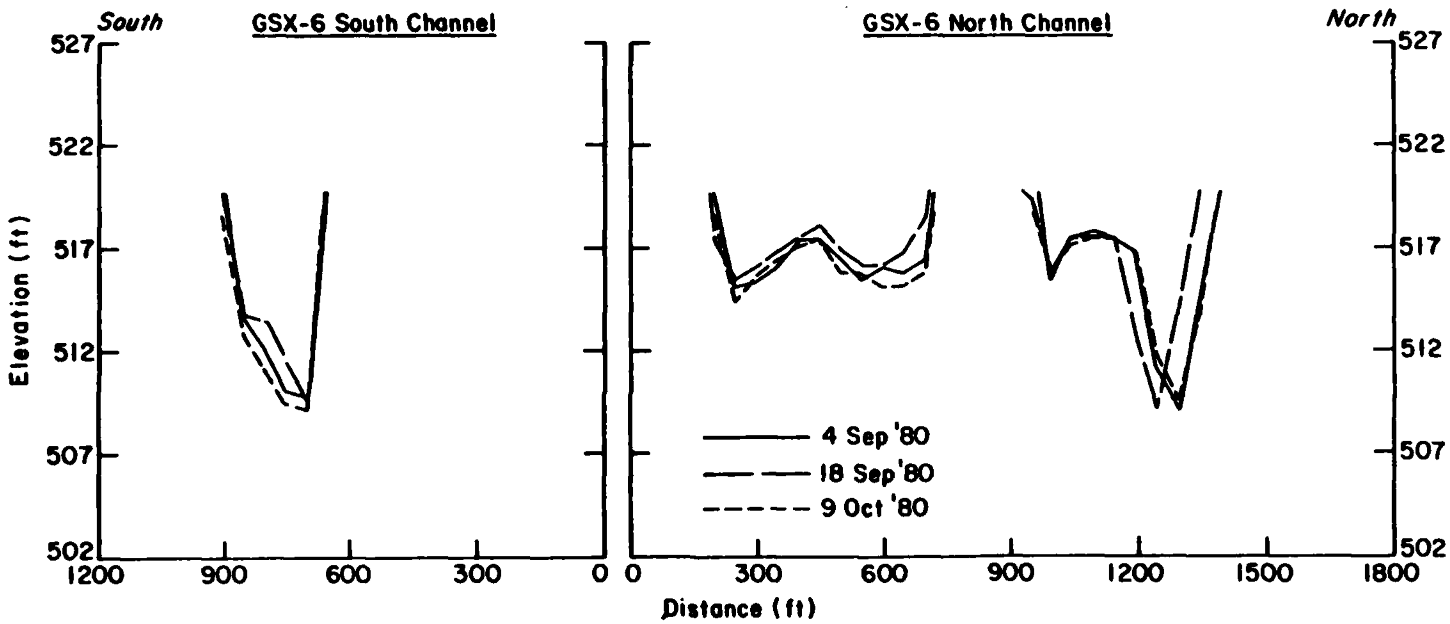


Figure 29 (cont'd).

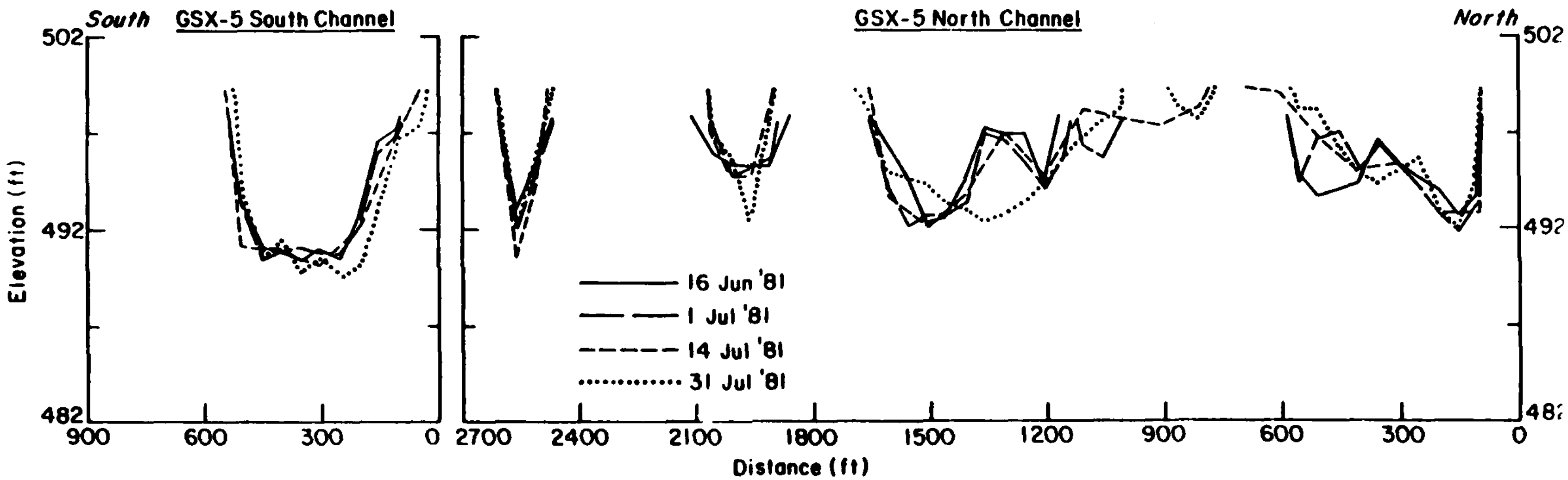


Figure 30. Cross-sections taken in 1981.

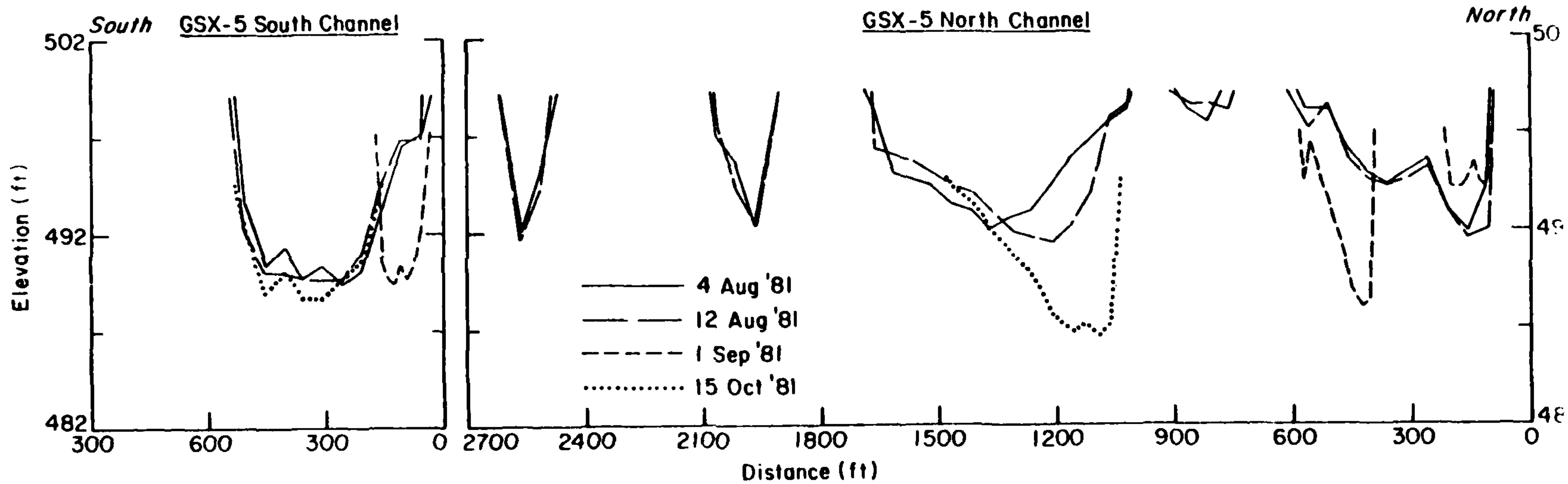


Figure 30 (cont'd).

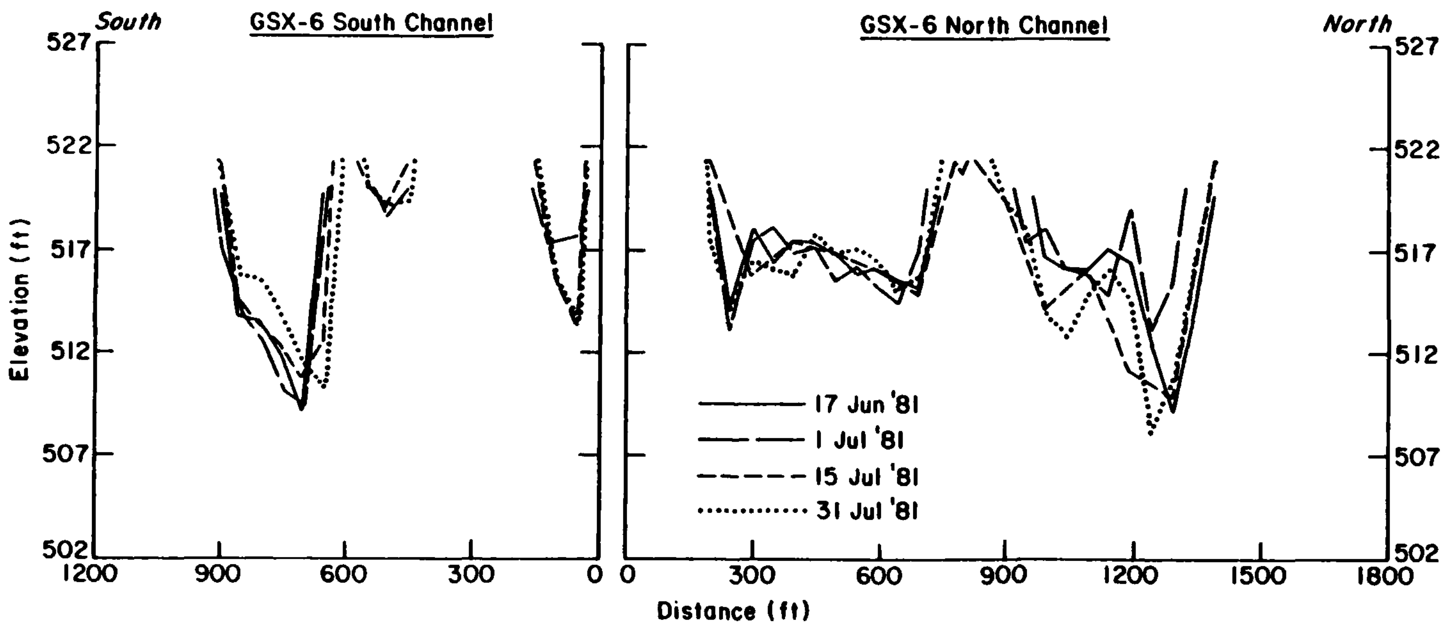


Figure 30 (cont'd).

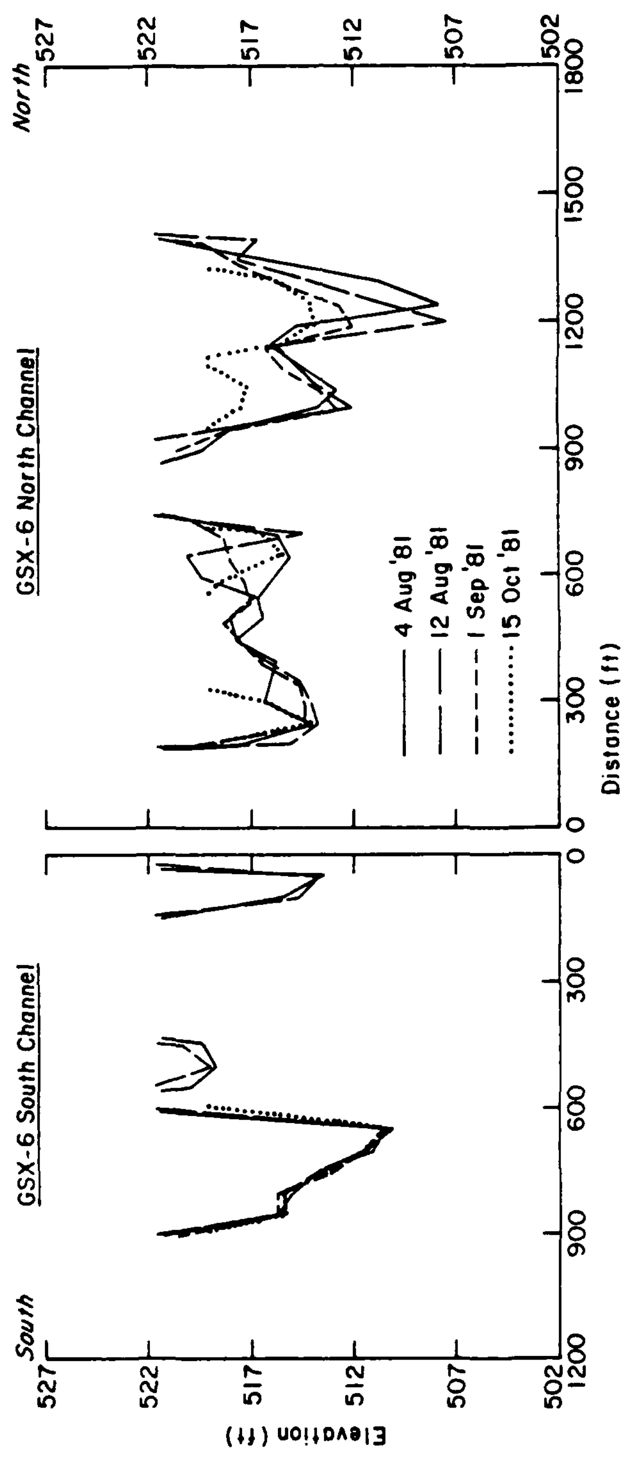


Figure 30 (cont'd).

Figure 31. Floodway sill groin, 4 June 1982.

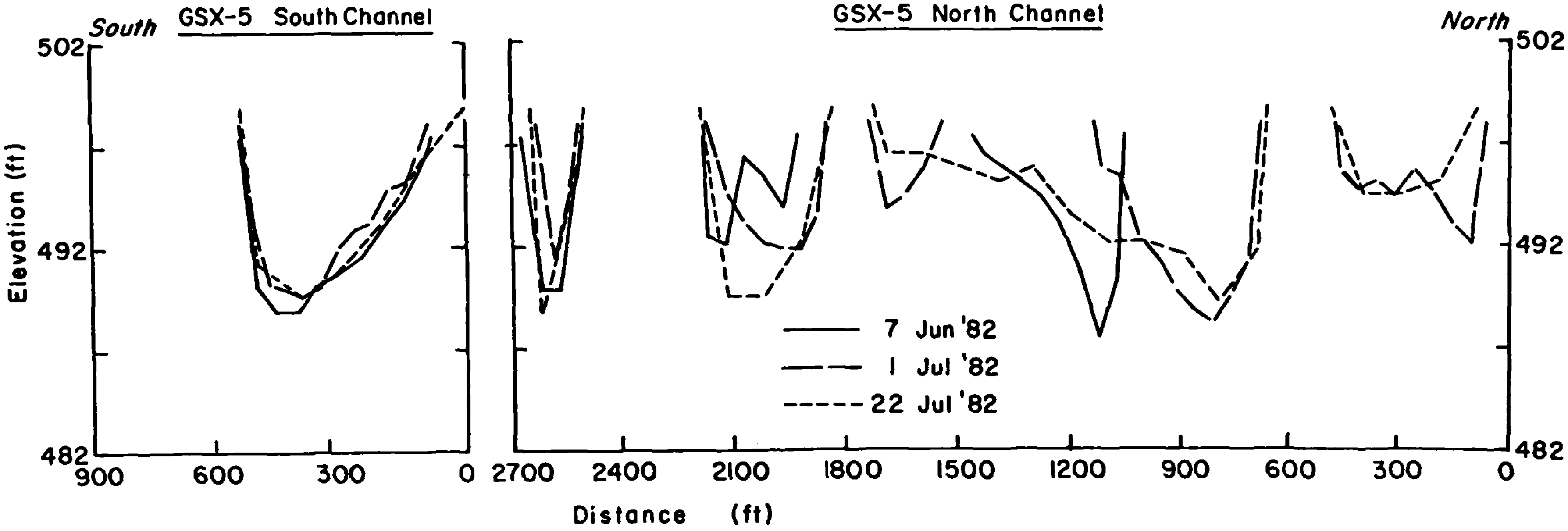


Figure 32. Cross-sections taken in 1982.

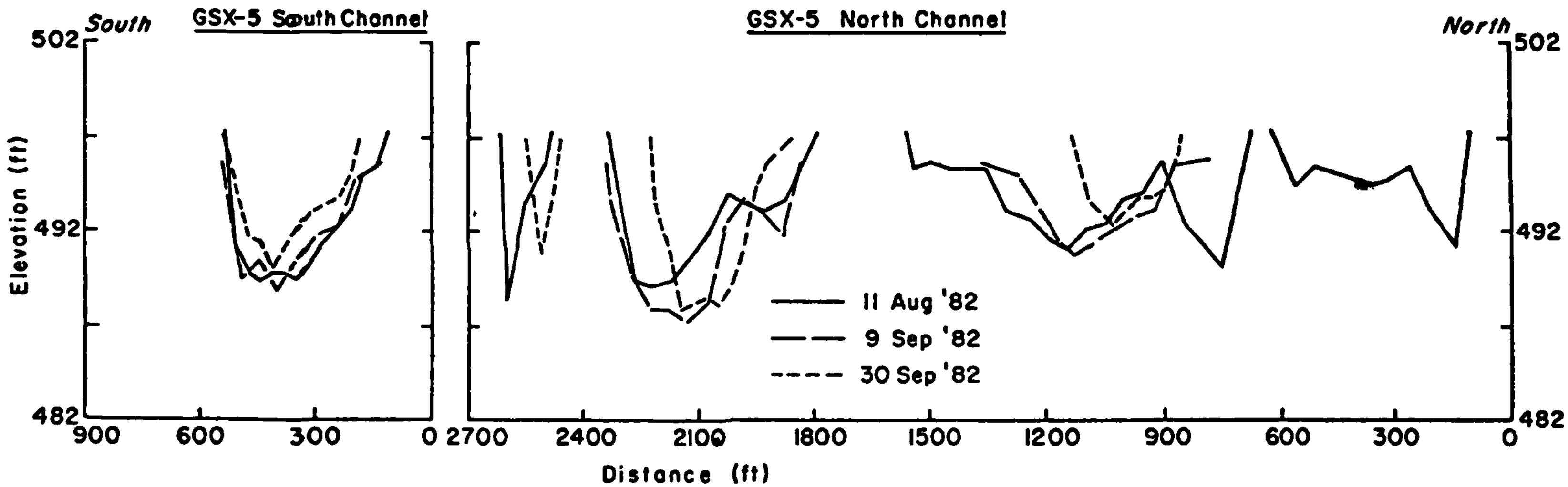


Figure 32. continued

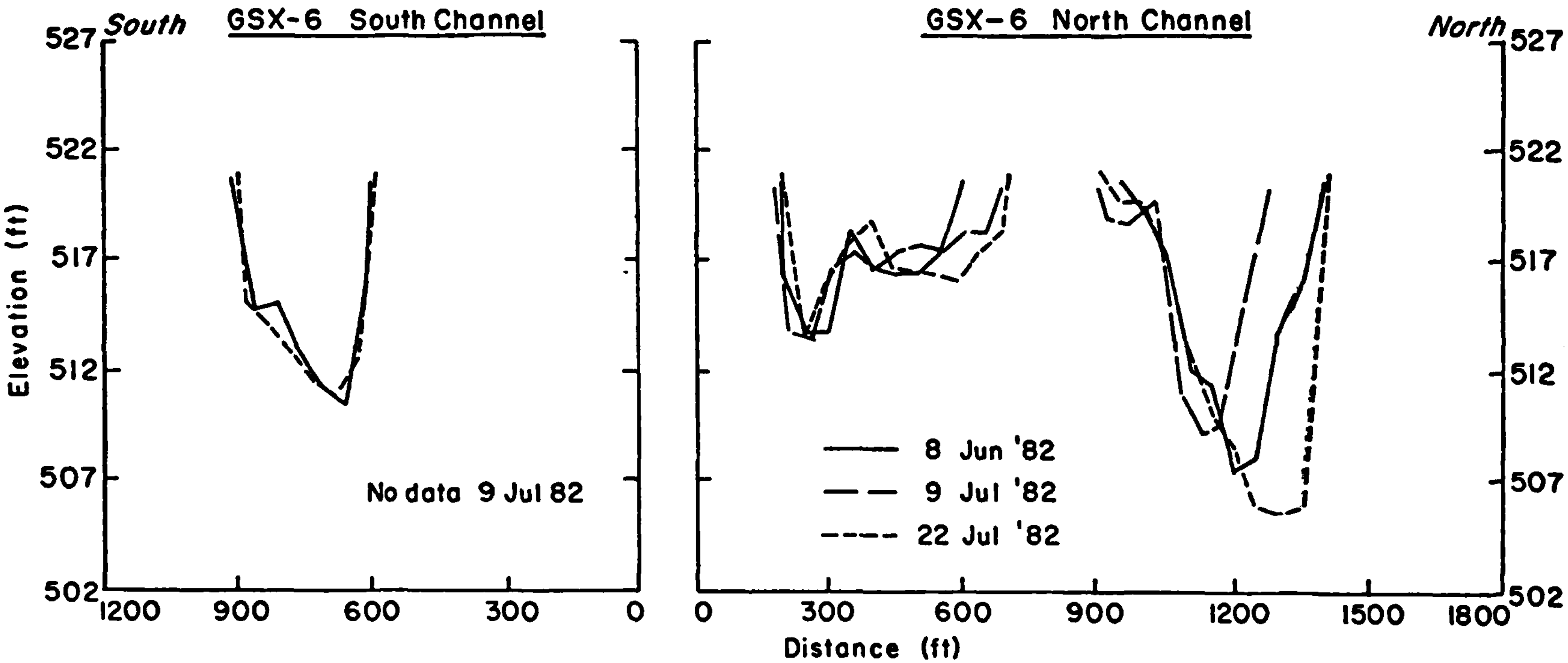


Figure 32. continued

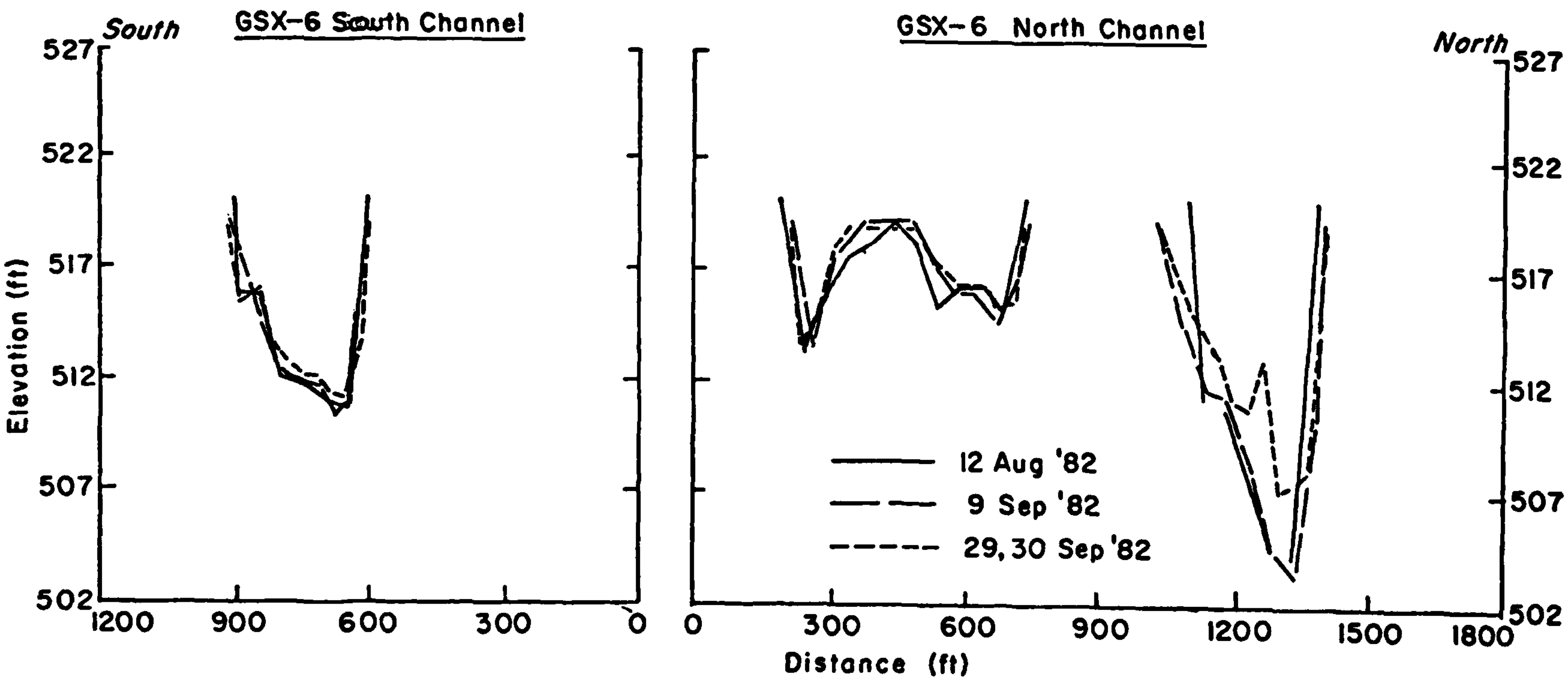


Figure 32. continued

Figure 33. North Pole groin area, 4 June 1982.

Table 1. Aerial photographs (9 in. x 9 in.) used for mapping historical bank recession and channel changes; approximate scale, 1:12000.

Date	Effective Erosion years	Visual Quality	Remarks
20 May 1948		Good	Photo coverage of northern portion of channel only; river at flood stage.
1 May 1961	12.90	Good	Coverage incomplete in southern portion of channel; ice still in river, snow on bars; estimated discharge, 18000 cfs.
2 July 1970	9.34	Good	Coverage incomplete in southern portion of channel; estimated discharge between 30,000 - 40,000 cfs.
27 June 1973	2.97	Good	Small portion of south bank not covered; discharge = 49,200 cfs*.
19 Sept 1974	1.46	Good	First year of complete photo coverage; discharge = 19,100 cfs.
26 Sept 1975	1.04	Good	Discharge = 31,300 cfs.
4 June 1976	.38	Good	Discharge = 31,200 cfs.
6 June 1977	1.09	Good	Discharge = 27,800 cfs.
4 June 1978	.99	Good	Discharge = 21,600 cfs.
3,29 July 1979	1.15,1.30	Excellent	Discharge = 39,100 cfs on 3 July. 71,000 cfs on 29 July.
7 May 1980	.69,.54	Excellent	Discharge = 17,700 cfs.
20 Oct 1981	1.91	Excellent	Discharge = 13,700 cfs.
4 June 1982	0.25	Excellent	Discharge = 44,800 cfs
	34.09		

1948-1978 photography was black and white
1979-1982 photography was color.
* Discharge data not taken earlier; cfs = cubic feet per second.

Table 2. Bankline recession measured along lines in the North Pole groin area (Fig. 2).

Line	1948–1961 (12.9 e.e.y.) ft	cumul. ft	ft/yr	1961–1970 (9.34 e.e.y.) ft	cumul. ft	ft/yr	1970–1973 (2.97 e.e.y) ft	cumul. ft	ft/yr	1973–1974 (1.69 e.e.y.) ft	cumul. ft	ft/yr	1975–1976 (1.19 e.e.y.) ft	cumul. ft	ft/yr
North Bank															
1A	310	310	24	40	350	4	--	350	--	--	350	--	--	350	--
2A	30	30	2	--	30	--	--	30	--	--	30	--	30	60	25
2B	140	140	11	--	140	--	--	140	--	--	140	--	30	170	25
2C	150	150	12	170	320	18	30	350	10	--	350	--	50	400	42
2D	170	170	13	--	170	--	--	170	--	--	170	--	60	230	50
3A	--	--	--	--	--	--	--	--	--	--	--	--	40	40	34
3B	40	40	3	110	150	12	40	190	13	--	90	--	90	280	76
3C	--	--	--	70	70	7	--	70	--	--	70	--	60	130	50
3D	--	--	--	30	30	3	--	30	--	--	30	--	70	100	59
3E	220	220	17	200	420	21	--	420	--	--	420	--	--	420	--
4A	180	180	14	360	540	39	--	540	--	--	540	--	--	540	--
4B	240	240	19	190	430	20	--	430	--	--	430	--	--	430	--
4C	180	180	14	--	180	--	30	210	10	--	210	--	--	210	--
4D	350	350	27	250	600	27	220	820	74	--	820	--	--	820	--
4E	150	150	12	340	490	36	60	550	20	--	550	--	--	550	--
4F	190	190	15	160	350	17	--	350	--	--	350	--	--	350	--
4G	210	210	16	60	270	6	30	300	10	--	300	--	--	300	--
4H	170	170	13	130	300	14	150	450	51	60	510	36	--	510	--
	2730		12†	2110		13†	560		10†	60		2†	430		20†
North Channel Islands															
5A	220	220	17	80	300	9	--	300	--	--	300	--	--	300	--
5B	310	310	24	70	380	7	--	380	--	40	420	23	--	420	--
6A	*	*	*	**	**	**	40	40	13	--	40	--	--	40	--
6B	*	*	*	**	**	**	--	--	--	--	--	--	--	--	--
13A	30	30	2	100	130	11	--	130	--	--	130	--	40	170	34
13B	170	170	13	80	250	9	--	250	--	--	250	--	130	380	109
13C	190	190	15	140	330	15	--	330	--	--	330	--	--	330	--
13D	150	150	12	430	580	46	--	580	--	30	610	18	--	610	--
13E	90	90	7	230	320	25	--	320	--	--	320	--	--	320	--
13F	60	60	5	170	230	18	30	260	10	140	400	83	--	400	--
14A	--	--	--	230	230	25	50	280	17	--	280	--	--	280	--
15A	40	40	3	210	250	22	30	280	10	--	280	--	--	280	--
18A	30	30	2	30	60	3	40	100	13	--	100	--	--	100	--
18B	*	*	*	40	40	4	90	130	30	--	130	--	--	130	--
19A	220	220	17	200	420	20	--	420	--	--	420	--	40	460	34
19B	--	--	--	--	--	--	70	70	24	30	100	18	--	100	--
23A	--	--	--	--	--	--	--	--	--	40	40	24	--	40	--
23B	--	--	--	--	--	--	--	--	--	40	40	24	--	40	--
23C	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
24A	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
28A	--	--	--	--	--	--	80	80	27	50	130	30	240	370	200
	1510		7†	2010		11†	430		7†	370		10†	490		18†

Line	1976–1977 (1.01 e.e.y.) ft	cumul. ft	ft/yr	1977–1978 (.99 e.e.y.) ft	cumul. ft	ft/yr	1978–1979 (1.15 e.e.y.) ft	cumul. ft	ft/yr	1979–1980 (.69 e.e.y.) ft	cumul. ft	ft/yr	1980–1981 (1.91 e.e.y.) ft	cumul. ft	ft/yr
North Bank															
1A	--	350	--	--	350	--	--	350	--	--	350	--	--	350	--
2A	110	170	109	--	170	--	--	170	--	--	170	--	--	170	--
2B	--	170	--	--	170	--	--	170	--	--	170	--	--	170	--
2C	--	400	--	--	400	--	--	400	--	--	400	--	--	400	--
2D	--	230	--	--	230	--	--	230	--	--	230	--	--	230	--
3A	40	80	40	30	110	30	90	200	78	--	200	--	--	200	--
3B	60	340	59	70	410	71	150	560	130	--	560	--	40	600	21
3C	60	190	59	60	250	61	120	370	104	70	440	101	--	440	--
3D	30	130	30	40	170	40	--	170	--	60	230	87	--	230	--
3E	--	420	--	--	420	--	--	420	--	--	420	--	--	420	--
4A	--	540	--	--	540	--	--	540	--	--	540	--	--	540	--
4B	--	430	--	--	430	--	--	430	--	--	430	--	--	430	--
4C	--	210	--	--	210	--	--	210	--	--	210	--	--	210	--
4D	--	820	--	--	820	--	--	820	--	--	820	--	--	820	--
4E	--	550	--	--	550	--	--	550	--	--	550	--	--	550	--
4F	--	350	--	--	350	--	--	350	--	--	350	--	--	350	--
4G	--	300	--	--	300	--	--	300	--	--	300	--	--	300	--
4H	--	510	--	--	510	--	--	510	--	--	510	--	--	510	--
	300		17†	200		11†	360		17†	130		10†	40		1†
North Channel Islands															
5A	--	300	--	--	300	--	--	300	--	--	300	--	--	300	--
5B	40	460	40	--	460	--	--	460	--	--	460	--	--	460	--
6A	--	40	--	--	40	--	--	40	--	80	120	116	110	220	52
6B	--	--	--	60	60	61	40	100	35	90	190	130	--	190	--
13A	50	220	50	--	220	--	--	220	--	--	220	--	--	220	--
13B	--	380	--	--	380	--	30	410	26	--	410	--	--	410	--
13C	--	330	--	--	330	--	30	360	26	50	410	72	90	500	47
13D	--	610	--	--	610	--	--	610	--	--	610	--	--	610	--
13E	--	320	--	--	320	--	--	320	--	--	320	--	--	370	--
13F	--	400	--	70	470	71	--	470	--	--	470	--	--	470	--
14A	--	280	--	--	280	--	--	280	--	--	280	--	--	280	--
15A	--	280	--	--	280	--	--	280	--	--	280	--	--	280	--
18A	--	100	--	--	100	--	--	100	--	--	100	--	--	100	--
18B	--	130	--	--	130	--	--	130	--	--	130	--	--	130	--
19A	--	460	--	--	460	--	--	460	--	--	460	--	--	460	--
19B	30	130	30	--	130	--	60	190	52	--	190	--	--	190	--
23A	--	40	--	--	40	--	90	130	78	--	130	--	--	130	--
23B	30	70	30	40	110	40	70	180	61	--	180	--	100	280	52
23C	30	30	30	--	30	--	100	130	87	--	130	--	190	320	99
24A	150	150	149	--	150	--	--	150	--	--	150	--	--	150	--
28A	40	410	40	30	440	30	--	440	--	--	440	--	--	440	--
	370		17†	200		10†	420		17†	220		15†	480		12†

Table 2. continued

South Channel Islands

12A	*	*	*	--	--	--	--	--	--	--	--	--	40	40	34	--	40	--	--	40	--	--	40	--	--	40	--	--	40	--
16A	--	--	--	--	--	--	--	--	--	30	30	18	--	30	--	30	60	30	30	90	30	--	90	--	--	90	--	--	90	--
16B	--	--	--	--	--	--	--	--	--	80	48	48	70	150	59	30	180	30	30	210	30	--	210	--	--	210	--	--	210	--
17A	--	--	--	--	--	--	--	--	--	--	--	--	110	110	92	--	110	--	30	140	30	--	140	--	--	140	--	--	140	--
20A	--	--	--	--	--	--	40	40	13	--	40	--	--	40	--	--	40	--	30	70	30	40	110	35	--	110	--	--	110	--
21A	--	--	--	--	--	--	40	40	13	--	40	--	30	70	25	30	100	30	30	130	30	40	170	35	--	170	--	--	170	--
21B	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	40	40	35	--	40	--	--	40	--
21C	--	--	--	--	--	--	--	--	--	--	--	--	60	60	50	--	60	--	50	110	51	60	170	52	--	170	--	--	170	--
21D	--	--	--	--	--	--	--	--	--	--	--	--	50	50	42	--	50	--	--	50	--	40	90	35	--	90	--	--	90	--
22A	--	--	--	--	--	--	70	70	24	--	70	--	80	150	67	--	150	--	40	190	40	--	190	--	--	190	--	--	190	--
22B	--	--	--	--	--	--	40	40	13	--	40	--	50	90	42	--	90	--	--	90	--	30	120	26	40	160	58	--	160	--
25A	--	--	--	--	--	--	--	--	--	--	--	--	70	70	59	--	70	--	--	70	--	--	70	--	--	70	--	50	120	26
25B	--	--	--	--	--	--	--	--	--	--	--	--	70	70	59	--	70	--	--	70	--	--	70	--	--	70	--	--	70	--
26A	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	110	110	58
27A	--	--	--	--	--	--	--	--	--	30	30	18	60	90	50	60	150	59	--	150	--	--	150	--	30	180	43	--	180	--
							190		4†	140		6†	690		39†	150		10†	240		16†	250		14†	70		7†	160		6†

South Bank

7A	*	*	*	**	**	**	220	220	74	--	220	--	--	220	--	--	220	--	--	210	--	140	360	122	40	400	58	170	570	89
8A	*	*	*	**	**	**	--	--	--	--	--	--	50	50	42	30	80	30	30	110	30	--	110	--	--	110	--	30	140	16
8B	*	*	*	**	**	**	80	80	27	30	110	18	80	190	67	--	190	--	--	190	--	--	190	--	--	190	--	50	240	26
9A	*	*	*	**	**	**	--	--	--	--	--	--	40	40	34	--	40	--	130	170	131	130	300	113	--	300	--	80	380	42
10A	*	*	*	***	***	***	--	--	--	--	--	--	110	110	92	--	110	--	--	110	--	--	110	--	--	110	--	--	110	--
10B	*	*	*	**	**	**	--	--	--	--	--	--	100	100	84	40	140	40	40	180	40	--	180	--	--	180	--	--	180	--
11A	*	*	*	--	--	--	--	--	--	--	--	--	60	60	50	30	90	30	70	160	71	--	160	--	--	160	--	--	160	--
							300		14†	30		3†	440		53†	100		14†	270		39†	270		39†	40		8†	330		25†

* No 1948 photography
** No 1961 photography
*** No 1970 photography
-- No measurable recession; recession less than 30 ft
† Units are ft/year/line

SUMMARY

	North Bank (18 lines)		North Channel Island (21 lines)		South Channel Islands (15 lines)		South Bank (7 lines)	
	Total (ft)	Ave. Ann. Rate/line	Total (ft)	Ave. Ann. Rate/line	Total (ft)	Ave. Ann. Rate/line	Total (ft)	Ave. Ann Rate/line
Pre-Construction (26.9 e.e.y.)	5460	11*	4320	8	330	1	330	2
Post-Construction (6.94 e.e.y.)	1460	12	2140	15	1560	15	1450	30

Table 3. Land lost and the rate of loss near the North Pole groin (summarized from Table A1).

Interval	North Bank			North Channel Islands			South Channel Islands			South Bank			Total	
	Area		Rate	Area		Rate	Area		Rate	Area		Rate	Land	Ave. Rate
(eff. eros. yrs.)	(sq ft)	(acres)	(acres/yr)	(sq ft)	(acres)	(acres/yr)	(sq ft)	(acres)	(acres/yr)	(sq ft)	(acres)	(acres)	(acres)	(acres/yr)
							Pre-Construction							
1948-1961 (12.9)	2103700	48.3	3.7	722000†	16.6	1.3	331500†	7.6	.6	*	*	*	72.5	5.6
1961-1970 (9.34)	1475100	33.9	3.6	1384100†	31.8	3.4	42300†	1.0	.1	*	*	*	70.3†††	7.5
1970-1973 (2.97)	400400	9.2	3.1	493600†	11.3	3.8	62200†	1.4	.5	133800†	3.1	1.0	28.8†††	9.7
1973-1974†† (1.69)	110900	2.5	1.5	149600	3.4	2.0	84400	1.9	1.1	89100†	2.0	1.2	11.7†††	6.9
(26.9)													183.3	6.8
							Post-Construction							
1975-1976** (1.19)	86800	2.0	1.7	83000	1.9	1.6	331200	7.6	6.4	228100	5.2	4.4	16.7	14.0
1976-1977 (1.01)	86300	2.0	2.0	69300	1.6	1.6	144700	3.3	3.3	180300	4.1	4.1	11.0	10.9
1977-1978 (.99)	43700	1.0	1.0	59600	1.4	1.4	90500	2.1	2.1	192800	4.4	4.4	8.9	9.0
1978-1979 (1.15)	119800	2.8	2.4	175600	4.0	3.5	197200	4.5	3.9	155800	3.6	3.1	14.9	13.0
1979-1980 (0.69)	43000	1.0	1.4	229600	5.3	7.7	21600	.5	.7	34700	.8	1.2	7.6	11.0
1980-1981 (1.91)	26500	.6	.3	242300	5.6	2.9	61800	1.4	.7	211800	4.9	2.6	12.5	6.5
(6.94)													71.6	10.3
1961-1974	61900	1.4					174200	4.0						
1970-1974							167400	3.8						

† Incomplete data set due to partial photo coverage.
* No photo coverage.
\- No measurable change.
†† Interval includes 27 Jun 73 to 18 Sept 74 = 1.46 eff. eros. yrs.
19 Sept 74 to 31 Oct 74 = .23 eff. eros. yrs.
** Interval includes 1 May 75 to 25 Sept 75 = .81 eff. eros. yrs.
26 Sept 75 to 4 Jun 76 = .38 eff. eros. yrs.
††† Includes acres distributed from variable intervals 1961-1974 and 1970-1974 (Table A1)

Table 4. Bankline recession measured along lines in the area upstream of the North Pole groin (Fig. 13).

Line	1961–1970 (9.34 e.e.y)			1970–1975 (5.47 e.e.y.)			1975–1980 (4.22 e.e.y)		
	ft	cumul. ft	ft/yr	ft	cumul. ft	ft/yr	ft	cumul. ft	ft/yr
North Bank									
3B	460	460	49	70	530	13	--	530	--
3C	280	280	30	--	280	--	--	280	--
	740		40†	70		6†	0		0†
North Channel Islands									
1A	*	*	*	90	90	16	150	240	36
1B	--	--	--	40	40	7	100	140	24
2A	--	--	--	90	90	16	--	90	--
2B	--	--	--	110	110	20	--	110	--
2C	--	--	--	250	250	46	--	250	--
2D	--	--	--	160	160	29	--	160	--
3A	330	330	35	90	420	16	70	490	17
4A	70	70	7	--	70	--	60	130	14
4B	100	100	11	200	300	37	--	300	--
5A	--	--	--	80	80	15	--	80	--
5B	--	--	--	80	80	15	--	80	--
	500		5†	1190		20†	380		8†
South Channel Islands									
6B	--	--	--	80	80	15	--	80	--
6C	--	--	--	60	60	11	--	60	--
6D	--	--	--	90	90	16	--	90	--
7A	--	--	--	540	540	99	--	540	--
7B	--	--	--	360	360	66	20	480	28
7C	330	330	35	90	420	16	--	420	--
8A	260	260	28	420	680	77	--	680	--
8B	460	460	49	70	530	13	90	620	21
8C	--	--	--	230	230	42	--	230	--
8D	110	110	12	--	110	--	--	110	--
8E	160	160	17	50	210	9	--	210	--
13A	390	390	42	40	430	7	70	500	17
13B	--	--	--	--	--	--	150	150	36
13C	200	200	21	--	200	--	100	300	24
13D	100	100	11	--	100	--	190	290	45
13E	--	--	--	--	--	--	120	120	28
	2010		13†	2030		23†	840		12†

Table 4. Cont.

South Bank

6A	--	--	--	60	60	11	--	60	--
9A	--	--	--	60	60	11	--	60	--
9B	--	--	--	190	190	35	--	190	--
9C	--	--	--	140	140	26	50	190	12
10A	540	540	58	60	600	11	--	600	--
10B	--	--	--	290	290	53	190	480	45
10C	--	--	--	340	340	62	210	550	50
10D	--	--	--	330	330	60	--	330	--
10E	--	--	--	110	110	20	--	110	--
11A	120	120	13	--	120	--	--	120	--
12A	150	150	16	--	150	--	--	150	--
12B	440	440	47	--	440	--	--	440	--
12C	390	390	42	--	390	--	--	390	--
12D	390	390	42	180	570	33	--	570	--
12E	--	--	--	370	370	68	--	370	--
12F	30	30	3	40	70	7	--	70	--
12G	160	160	17	--	160	--	--	160	--
12H	--	--	--	40	40	7	190	230	45
12I	--	--	--	110	110	20	260	370	62
	2220		13†	2320		22†	900		11†

† Units are ft/year/line
- No measurable recession
* No photographic coverage

Table 5. Land lost and the rate of loss in the area upstream of the North Pole groin (summarized from Table A2).

Interval	North Bank			North Channel Islands			South Channel Islands			South Bank			Total	
	Area		Rate	Area		Rate	Area		Rate	Area		Rate	Land	Ave. Rate
(eff. eros. yrs.)	(sq ft)	(acres)	(acres/yr)	(sq ft)	(acres)	(acres/yr)	(sq ft)	(acres)	(acres/yr)	(sq ft)	(acres)	(acres)	(acres)	(acres/yr)
1961-1970 (9.34)	144900	3.3	0.4	579400	13.3	1.4	1149600	26.4	2.8	1493600	34.3	3.7	77.3	8.3
1970-1975 (5.47)	6100	1.4	0.3	505400	11.6	2.1	1279200	29.4	5.4	1172500	26.9	4.9	69.3	12.7
1975-1980 (4.22)	4000	0.1	0	161900	3.7	0.9	368200	8.5	2	435300	10.1	2.4	22.4	5.3
======													======	====
(19.03)													169.0	8.9

Table 6. Bankline recession measured along lines in the floodway sill groin area (Fig. 18).

Line	1970-1974 (4.43 e.e.y) ft	cumul. ft	ft/yr	1974-1978 (4.24 e.e.y.) ft	cumul. ft	ft/yr	1979-1980 (1.03 e.e.y.) ft	cumul. ft	ft/yr	1980-1981 (1.91 e.e.y.) ft	cumul. ft	ft/yr
North Bank												
2A	80	80	18	260	340	61	--	340	--	--	340	--
2B	30	30	7	170	200	40	--	200	--	--	200	--
2C	190	190	43	120	310	28	--	310	--	--	310	--
3A	150	150	34	40	190	9	--	190	--	--	190	--
4A	50	50	11	90	140	21	70	210	68	60	270	31
4B	170	170	38	70	240	17	--	240	--	--	240	--
	670		25†	750		29†	70		11†	60		5†
North Channel Islands												
1A	--	--	--	--	--	--	180	180	175	70	250	37
1B	150	150	34	30	180	7	40	220	39	--	220	--
1C	50	50	11	80	130	19	--	130	--	--	130	--
9A	270	270	61	--	270	--	--	270	--	--	270	--
9B	--	--	--	260	260	61	30	290	29	--	290	--
10A	--	--	--	140	140	33	30	170	29	--	170	--
10B	110	110	25	130	240	31	--	240	--	--	240	--
11A	--	--	--	--	--	--	40	40	39	210	250	110
11B	--	--	--	70	70	17	50	120	49	100	220	52
16A	--	--	--	210	210	50	30	240	29	40	280	21
16B	--	--	--	130	130	31	30	160	29	40	200	21
	580		12†	1050		23†	430		38†	460		22†
South Channel Islands												
5A	70	70	16	--	70	--	--	70	--	50	120	26
5B	--	--	--	40	40	9	90	130	87	--	130	--
7A	150	150	34	190	340	45	--	340	--	--	340	--
7B	--	--	--	40	40	9	30	70	29	40	110	21
8A	410	410	93	130	540	31	--	540	--	--	540	--
13A	30	30	7	60	90	14	90	180	87	100	280	52
13B	--	--	--	210	210	50	80	290	78	70	360	37
14A	--	--	--	120	120	28	--	120	--	60	180	31
15A	40	40	9	60	100	14	--	100	--	40	140	21
	700		18†	850		22†	290		31†	360		21†

Table 6. Cont.

South Bank

6A	--	--	--	60	60	14	--	60	--	--	60	--
6B	--	--	--	110	110	26	100	210	97	110	320	58
6C	--	--	--	160	160	38	110	270	107	30	300	16
6D	--	--	--	90	90	21	--	90	--	--	90	--
12A	90	90	20	--	90	--	--	90	--	--	90	--
12B	80	80	18	30	110	7	--	110	--	--	110	--
12C	40	40	9	30	70	7	30	100	29	--	100	--
	210		7†	480		16†	240		33†	140		10†

† Units are ft/year/line
- No measurable recession

SUMMARY

	North Bank (6 lines)		North Channel Islands (11 lines)		South Channel Islands (9 lines)		South Bank (7 lines)	
	Total (ft)	Ave. Ann. Rate/line	Total (ft)	Ave. Ann. Rate/line	Total (ft)	Ave. Ann. Rate/line	Total (ft)	Ave. Ann Rate/line
Pre-Construction (8.67 e.e.y.)	1420	27	1630	17	1550	20	690	11
Post-Construction (2.94 e.e.y.)	130	8	890	28	650	25	380	18

Table 7. Land lost and the rate of loss near the floodway sill groin (summarized from Table A3).

Interval	North Bank			North Channel Islands			South Channel Islands			South Bank			Total	
	Area		Rate	Area		Rate	Area		Rate	Area		Rate	Land	Ave. Rate
(eff. eros. yrs.)	(sq ft)	(acres)	(acres/yr)	(sq ft)	(acres)	(acres/yr)	(sq ft)	(acres)	(acres/yr)	(sq ft)	(acres)	(acres)	(acres)	(acres/yr)
							Pre-Construction							
1970-1974 (4.43)	602600	13.8	3.1	460300	10.6	2.4	362000	8.3	1.9	358900	8.3	1.9	41	9.3
1974-1978* (4.24)	636000	14.6	3.4	949200	21.8	5.1	425200	9.8	2.3	487500	11.2	2.6	57.4	13.5
=====													=====	=====
(8.67)													98.4	11.3
							Post-Construction							
1979-1980† (1.03)	7200	.1	.1	267300	6.1	5.9	176200	4.0	3.9	208700	4.8	4.7	15	14.6
1980-1981 (1.91)	0	0	0	246400	5.7	3.0	198500	4.6	2.4	199600	4.6	2.4	14.9	7.8
=====													=====	=====
(2.94)													29.9	10.2

* Interval includes 19 Sept 1974 to 3 June 1978 = 3.42 eff. eros. yrs.
4 June 1978 to 31 Oct 1978 = .82 eff. eros. yrs.

† Interval includes 1 May 1979 to 28 July 1979 = .49 eff. eros. yrs.
29 July 1979 to 7 May 1970 = .54 eff. eros. yrs.

Table 8. Acres lost and erosion rates near the North Pole groin.

	20 May 1948-31 Oct 1974 (26.9 e.e.y.)			1 May 1975-20 Oct 1981 (6.94 e.e.y.)		
	Land lost*		Erosion	Land lost		Erosion
	Arces	Percent	rate (acres/yr)	Acres	Percent	rate (acres/yr)
North Bank	95	52	3.5	10	14	1.4
North Channel Islands	63	34	2.3	20	28	2.9
South Channel Islands	20	11	.7	19	26	2.7
South Bank	5	3	.2	23	32	3.3
	183			72		

* Photo coverage of the southern part of the channel in 1948, 1961, 1970 and 1973 was incomplete, consequently the erosion data given here do not show all erosion.

e.e.y. - effective erosion years

Table 9. Acres lost and erosion rates near the floodway sill groin.

	2 July 1970-31 Oct 1978 (8.67 e.e.y.)			1 May 1979-20 Oct 1981 (2.94 e.e.y.)		
	Land lost		Erosion rate (acres/yr)	Land lost		Erosion rate (acres/yr)
	Arces	Percent		Acres	Percent	
North Bank	28	29	3.2	0	0	0
North Channel Islands	32	33	3.7	12	40	4.1
South Channel Islands	18	19	2.1	9	30	3.1
South Bank	19	20	2.2	9	30	3.1
	97			30		

Appendix A

Land Areas Eroded

Table A1. Land areas (sq. ft.) eroded near the North Pole groin.

Sites	20 May 1948– 1 May 1961	1 May 1961– 2 July 1970	2 July 1970– 27 June 1973	27 June 1973– 19 Sept 1974	19 Sept 1974– 26 Sept 1975	26 Sept 1975– 4 June 1976	4 June 1976– 6 June 1977	6 June 1977– 4 June 1978	4 June 1978– 3 July 1979	3 July 1979– 7 May 1980	7 May 1980– 20 Oct 1981	Variable Intervals: 1 May 1961– 19 Sept 1974	Variable Intervals: 2 July 1970– 19 Sept 1974	TOTALS
							North Bank							
1	318400	-	-	-	-	-	-	-	-	-	-	61900		380300
2	674500	123500	-	-	36500	7800	33100	-	-	-	-			675400
3a	7900	38900	-	-	4800	-	35800	29300	72800	9600	22700			221800
3b	-	5700	-	-	4000	-	8500	7600	18400	10500	3800			58500
3c	208700	82100	-	-	30900	-	-	6800	2900	22900	-			354300
3d	-	-	21100	-	-	9700	8900	-	25700	-	-			65400
4	1094200	1224900	379300	104000	-	-	-	-	-	-	-			2802400
							North Channel Islands							
5	•	220100	115000	-	-	-	-	-	-	-	-			335900
6	•	•	•	-	-	-	-	42200	15800	101100	60600			219700
13	307600	386400	25900	23800	-	-	-	-	-	96400	43700			883800
14	159700	318400	117900	35300	-	-	-	5900	-	-	-			637200
15	167000	271400	170800	-	-	-	-	-	-	-	-			609200
18	7600	32200	38400	52300	-	-	57800	-	21300	-	-			209600
19	80100	155600	-	-	-	85000	-	-	76500	-	-			395200
23a	•	-	-	17500	-	-	-	-	20500	12600	26100			76700
23b	•	-	-	-	-	-	-	-	35000	19500	106200			160700
24	•	-	-	-	-	-	11500	-	6500	-	-			18000
28	•	-	24800	20700	-	-	-	11500	-	-	5700			62700
							South Channel Islands							
12a	331500	42300	•	-	-	-	-	-	-	-	-			373800
12b	-	-	•	-	6900	-	-	-	-	-	-	174200		181100
12c	-	-	•	-	-	-	-	-	-	-	-		167400	167400
16a	•	•	-	28400	10600	2300	9600	8500	-	-	-			59400
16b	•	•	-	-	-	19700	-	7400	-	-	-			27100
17a	•	•	-	-	23100	17200	-	1900	12800	-	-			55000
17b	•	•	-	-	19000	-	-	-	-	-	-			19000
20	•	•	-	-	-	-	25400	-	41800	-	-			67200
21	•	•	•	32600	64900	-	-	-	52400	-	-			149900
22a	•	•	62200	-	50100	11100	22500	15800	24200	-	-			185900
22b	•	•	-	-	13800	23200	11800	-	12600	-	-			61400
25	•	•	-	-	71500	-	-	-	-	-	22500			94000
26	•	•	-	-	-	-	-	-	-	-	39300			39300
27	•	•	-	-	-	21200	75400	56900	53400	21600	-			228500
							South Bank							
7	•	•	95600	-	-	-	-	-	31100	22600	91800			241100
8a	•	•	-	-	-	-	-	-	-	-	21100			21100
8b	•	•	22500	8100	28900	-	8800	10300	9500	-	12400			100500
8c	•	•	7800	2100	22100	-	-	-	-	-	-			32000
8d	•	•	7900	8600	-	-	-	-	-	-	-			16500
8e	•	•	-	4000	-	-	6100	4500	-	-	3200			17800
9	•	•	•	24300	-	11400	118500	114200	98700	-	83300			450400
10a	•	•	•	23400	-	-	-	-	-	-	-			23400
10b	•	•	•	•	14700	-	12400	3700	16500	-	-			47300
10c	•	•	•	•	103700	29000	32000	40100	-	12100	-			216900
11	•	•	-	-	36900	-	2500	20000	-	-	-			59400
	3,157,700	2,901,500	1,090,000	385,100	542,400	235,600	480,600	386,600	648,400	328,900	542,400	236,100	167,400	11,102,200

- No Measurable Change
• No Photographic Coverage

Table A2. Land areas (sq. ft.) eroded upstream of the North Pole groin.

Sites	1 May 1961- 2 July 1970	2 July 1970- 26 Sept 1975	26 Sept 1975- 7 May 1980	Totals
		North Bank		
3b	144900	61000	4000	209900
		North Channel Islands		
1a	--	110700	90600	201300
1b	--	32400	23700	56100
2a	--	99200	--	99200
2b	--	46300	--	46300
3a	526100	60300	17000	603400
4	53300	57900	30600	141800
5	--	98600	--	98600
		South Channel Islands		
6b	--	87000	4200	91200
7	250600	662800	72700	986100
8	605900	410700	48100	1064700
9b	--	78600	7400	86000
13	293100	40100	235800	569000
		South Bank		
6a	--	13000	--	13000
9a	17800	11100	--	28900
10	491300	686600	238000	1415900
11	43800	3800	--	47600
12	940700	458000	197300	1596000
	3,367,509	3,018,100	969,400	7,355,000

-- No measurable change

Table A3. Land areas (sq. ft.) eroded near the floodway sill groin.

Sites	2 July 1970- 19 Sept 1974	19 Sept 1974- 4 June 1978	4 June 1978- 29 July 1979	29 July 1979- 7 May 1980	7 May 1980 20 Oct 1981	Totals
			North Bank			
2	418200	390600	--	--	--	808800
3	105000	--	--	--	--	105000
4	79400	235900	16700	--	--	332000
			North Channel Islands			
1	104200	256500	--	39900	10000	410600
9	265300	310300	51500	--	--	627100
10	34900	63000	41400	--	--	139300
11	--	--	64700	71500	103500	239700
16	55900	2900	151500	23300	132900	506500
			South Channel Islands			
7	75900	39800	47600	9100	53600	226000
8	203700	63600	35400	--	4400	307100
13	46000	111800	160400	58600	72600	449400
14	5500	46600	--	--	20500	72600
15	30900	20000	9500	--	47400	107800
			South Bank			
5	36100	65600	26500	40600	64200	233000
6	7400	242500	91100	48700	135400	525100
12	315400	73700	67500	40000	--	496600
	1,783,800	2,062,800	763,800	331,700	644,500	5,586,600

-- No measurable change

Table A4. Cumulative amount of land lost near the North Pole groin.

Interval	North Bank (sq ft)	North Bank (acres)	North Channel Islands (sq ft)	North Channel Islands (acres)	South Channel Islands (sq ft)	South Channel Islands (acres)	South Bank (sq ft)	South Bank (acres)
Pre-Construction								
1948-1961	2103700	48.3	722000	16.6	331500	7.6	*	*
1961-1970	362000†	83.1	2106100	48.4	492000††	11.3	*	*
1970-1973	403400†	92.6	2599700	59.7	704000††	16.2	133800	3.1
1973-1974	4152000†	95.3	2749300	63.1	862100††	19.8	222900	5.1
Post Construction								
1975-1976	4238800	97.3	2832300	65	1193300	27.4	451000	10.4
1976-1977	4325100	99.3	2901600	66.6	1338000	30.7	631300	14.5
1977-1978	4368800	100.3	2961200	68	1428500	32.8	824100	18.9
1978-1979	4488600	103	3136800	72	1625700	37.3	979900	22.5
1979-1980	4531600	104	3366400	77.3	1647300	37.8	1014600	23.3
1980-1981	4558100	104.6	3608700	82.8	1709100	39.2	1226400	28.2

† Includes amounts from the 1961-1974 interval (Table A1) distributed based on the number of effective erosion years per interval.

†† Includes amounts from the 1961-1974 and 1970-1974 intervals (Table A1) distributed based on the number of effective erosion years per interval.

Table A5. Cumulative amount of land lost upstream of the North Pole groin.

Interval	North Bank (sq ft)	North Bank (acres)	North Channel Islands (sq ft)	North Channel Islands (acres)	South Channel Islands (sq ft)	South Channel Islands (acres)	South Bank (sq ft)	South Bank (acres)
1961–1970	144900	3.3	579400	13.3	1149600	26.4	1493600	34.3
1970–1975	205900	4.7	1084800	24.9	2428800	55.8	2666100	61.2
1975–1980	209900	4.8	1246700	28.6	2797000	64.3	3101400	71.2

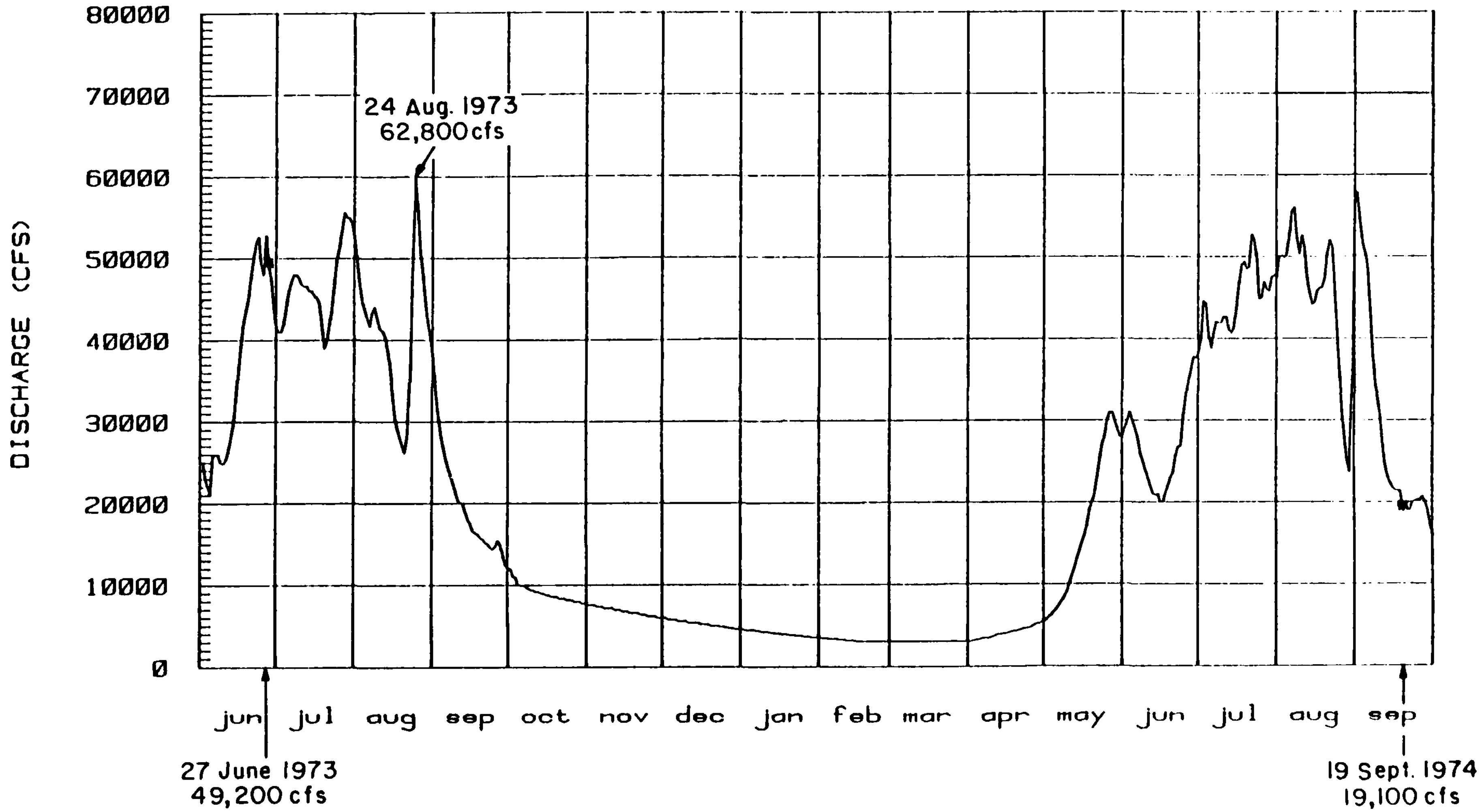
Table A6. Cumulative amount of land lost near the floodway sill groin.

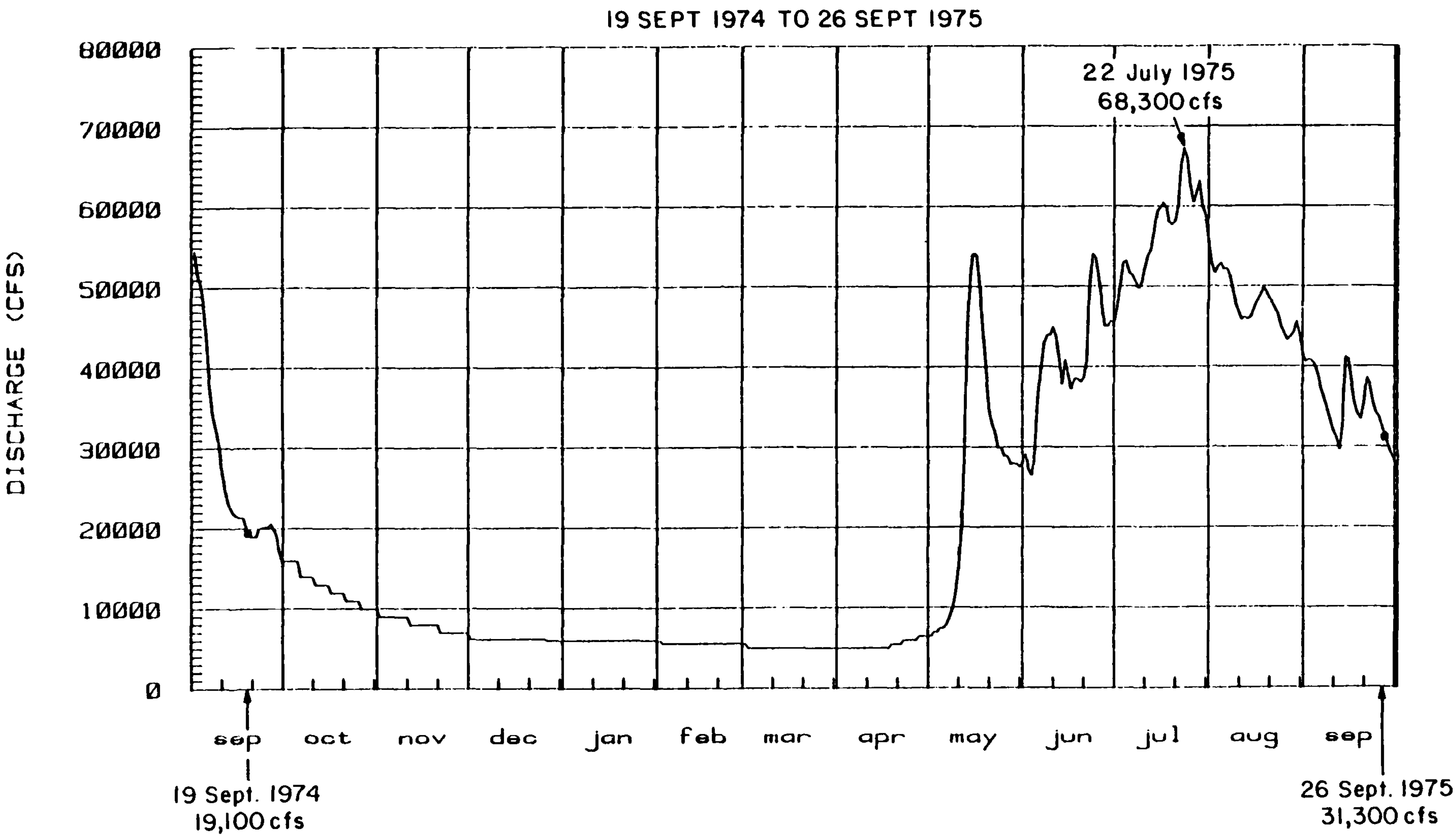
Interval	North Bank (sq ft)	North Bank (acres)	North Channel Islands (sq ft)	North Channel Islands (acres)	South Channel Islands (sq ft)	South Channel Islands (acres)	South Bank (sq ft)	South Bank (acres)
Pre-Construction								
1970-1974	602600	13.8	460300	10.6	362000	8.3	358900	8.2
1974-1978	1238600	28.4	1409500	32.4	787200	18.1	846400	19.4
Post-Construction								
1979-1980	1245800	28.5	1676800	38.5	963400	22.1	1055100	24.2
1980-1981	1245800	28.5	1923200	44.2	1161900	26.7	1254700	28.8

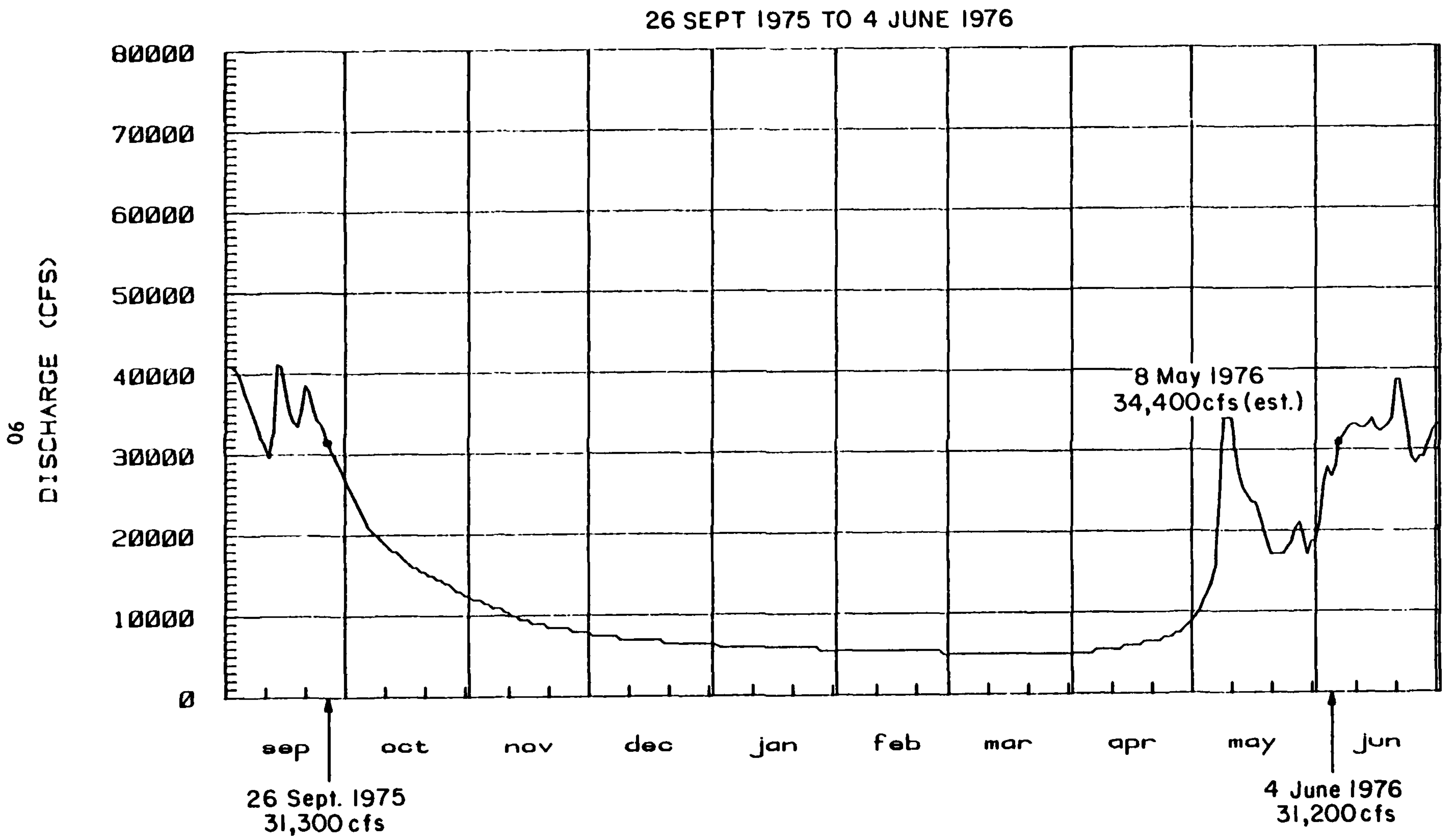
Appendix B

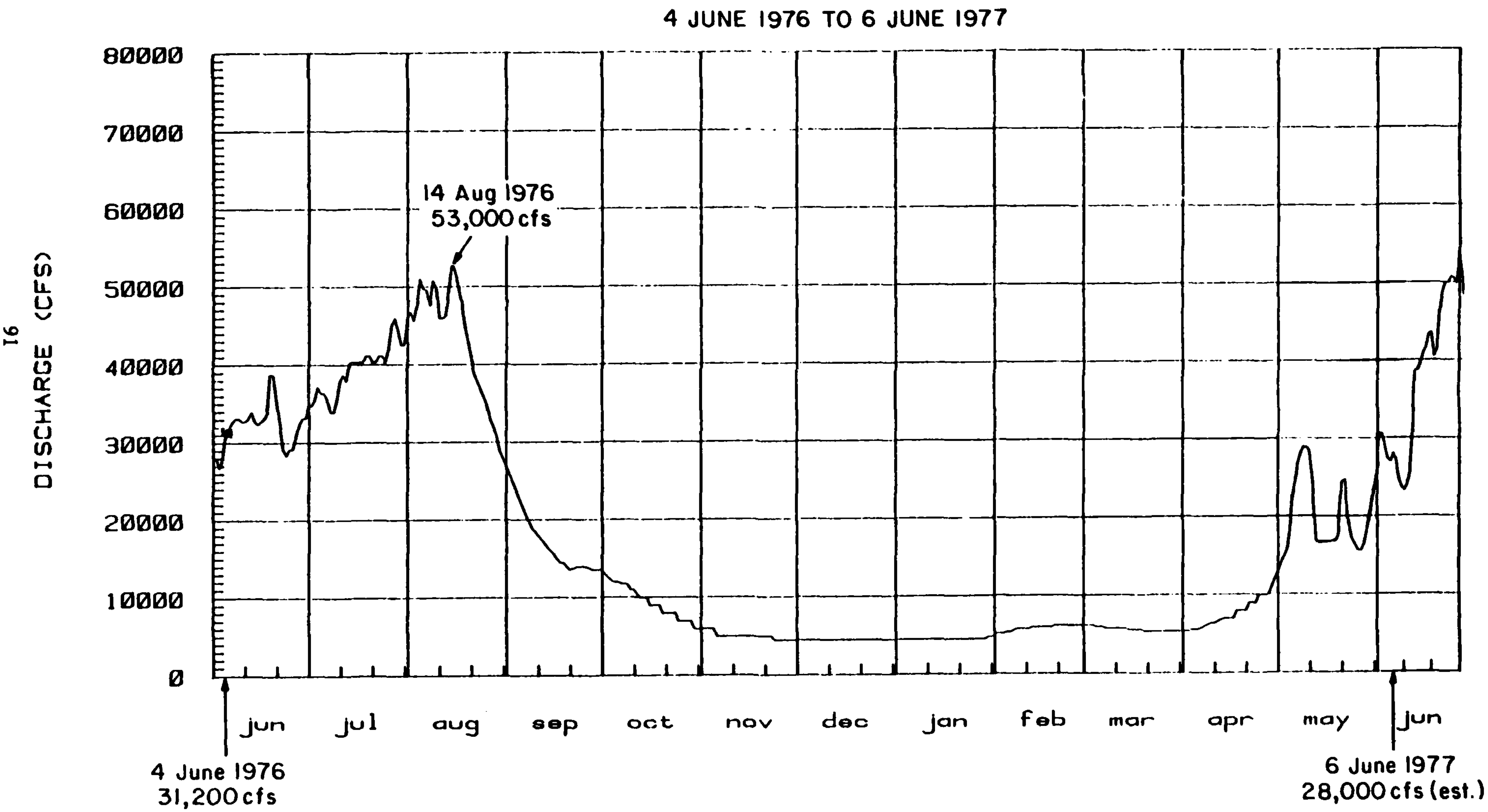
Hydrographs for the intervals between dates when aerial photographs were taken.

27 JUNE 1973 TO 19 SEPT 1974

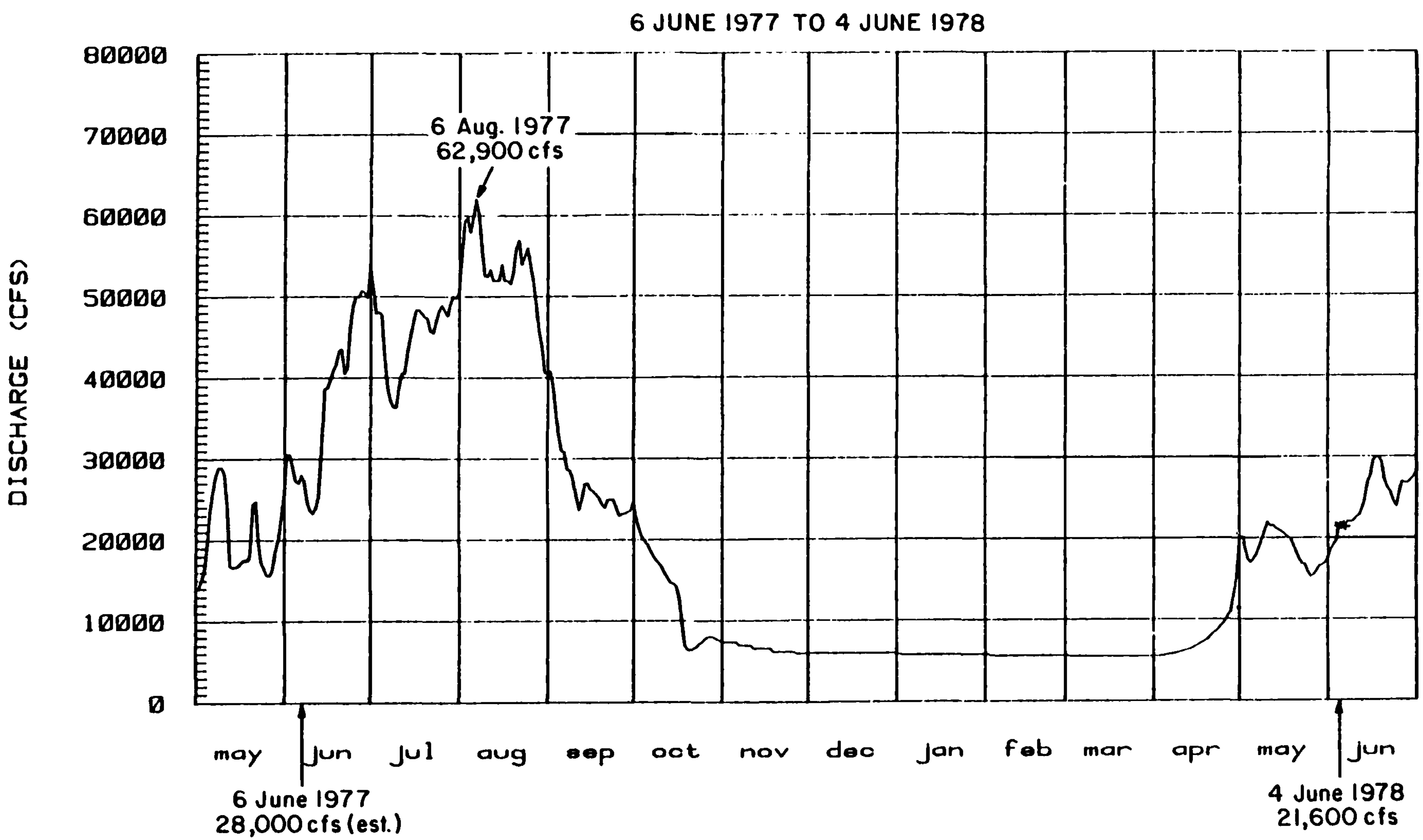


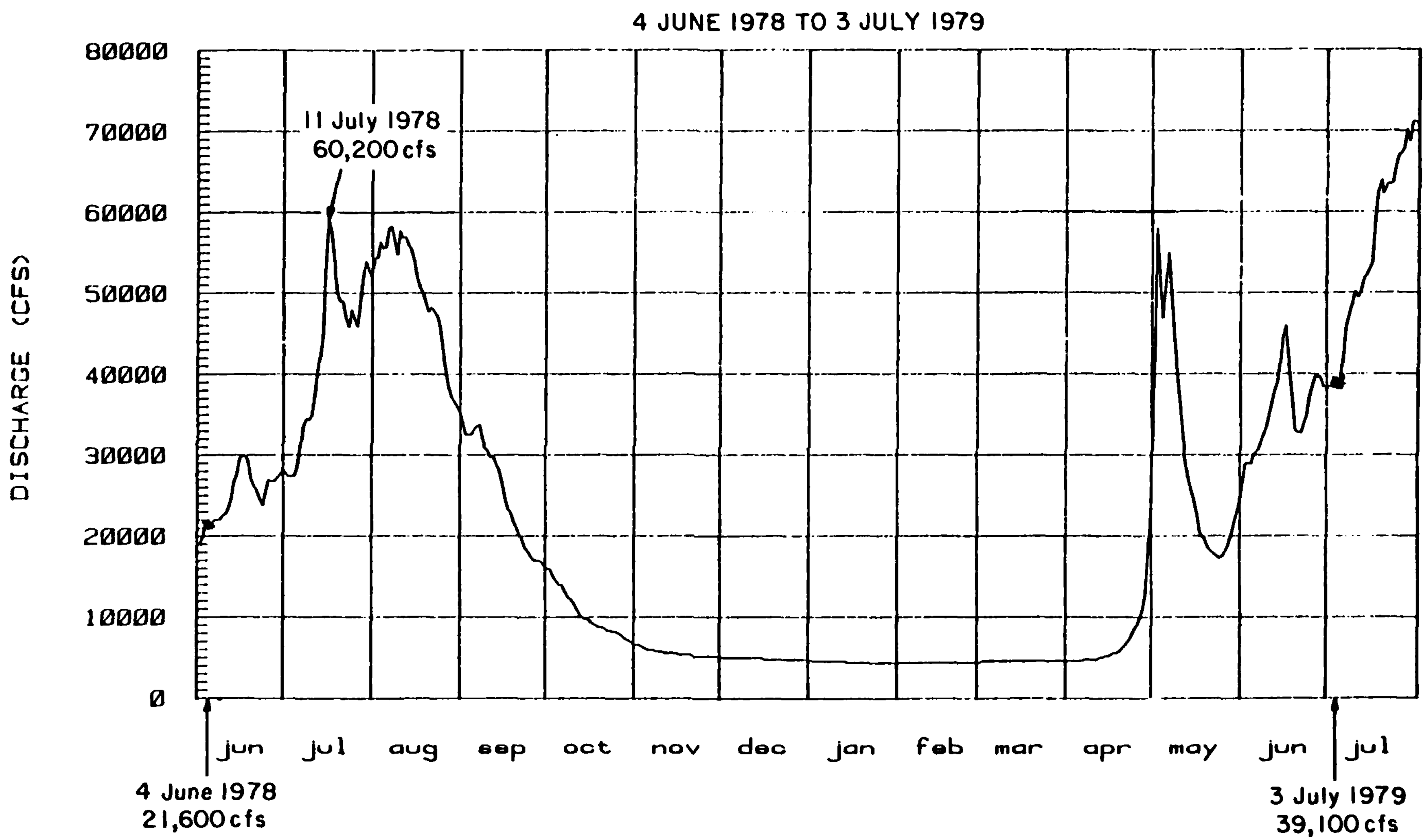

19 SEPT 1974 TO 26 SEPT 1975
DISCHARGE (CFS)
80000
70000
60000
50000
40000
30000
20000
10000
0
sep
oct
nov
dec
jan
feb
mar
apr
may
jun
jul
aug
sep
22 July 1975
68,300 cfs
19 Sept. 1974
19,100 cfs
26 Sept. 1975
31,300 cfs

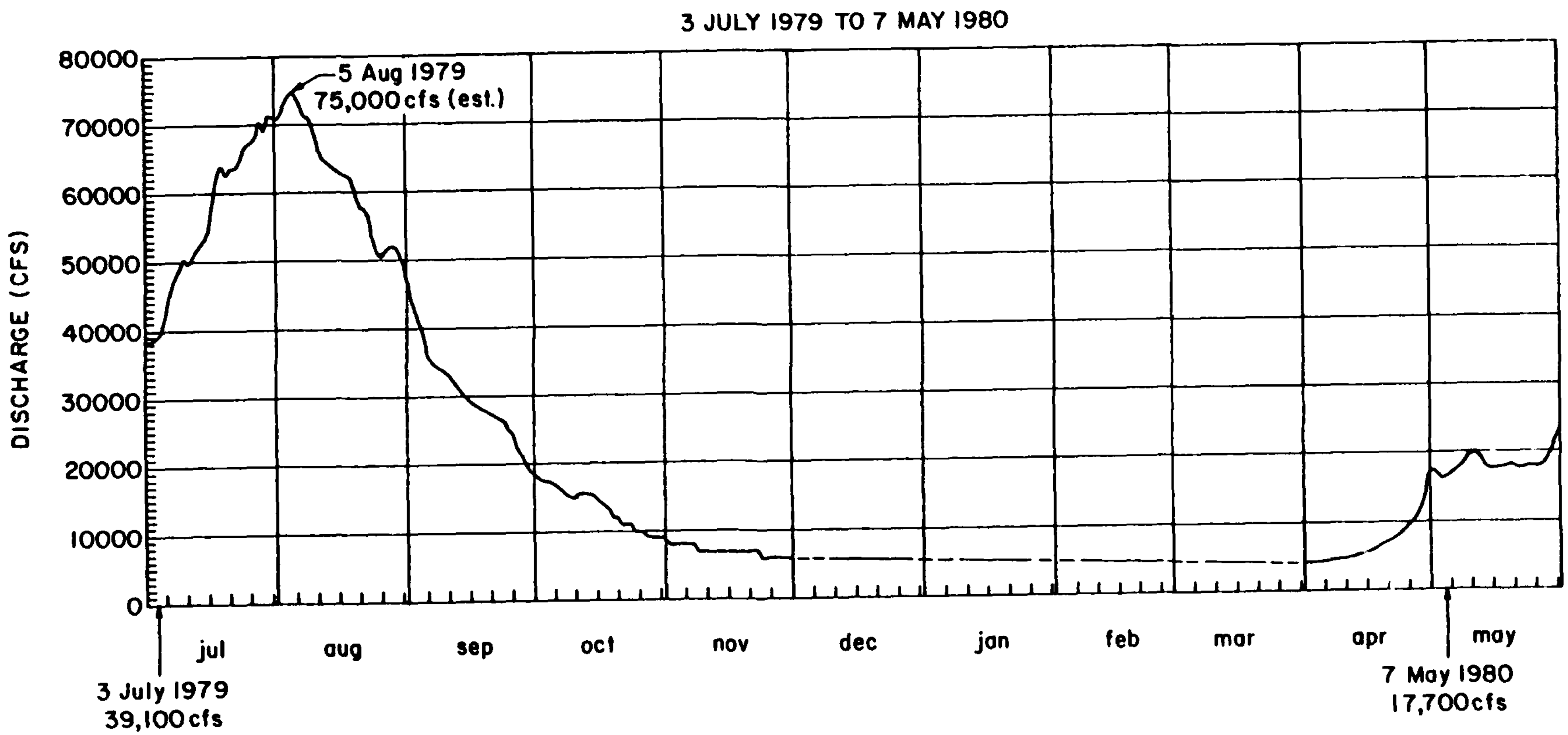

26 SEPT 1975 TO 4 JUNE 1976
DISCHARGE (CFS)
80000
70000
60000
50000
40000
30000
20000
10000
0
sep
oct
nov
dec
jan
feb
mar
apr
may
jun
26 Sept. 1975
31,300 cfs
8 May 1976
34,400 cfs (est.)
4 June 1976
31,200 cfs

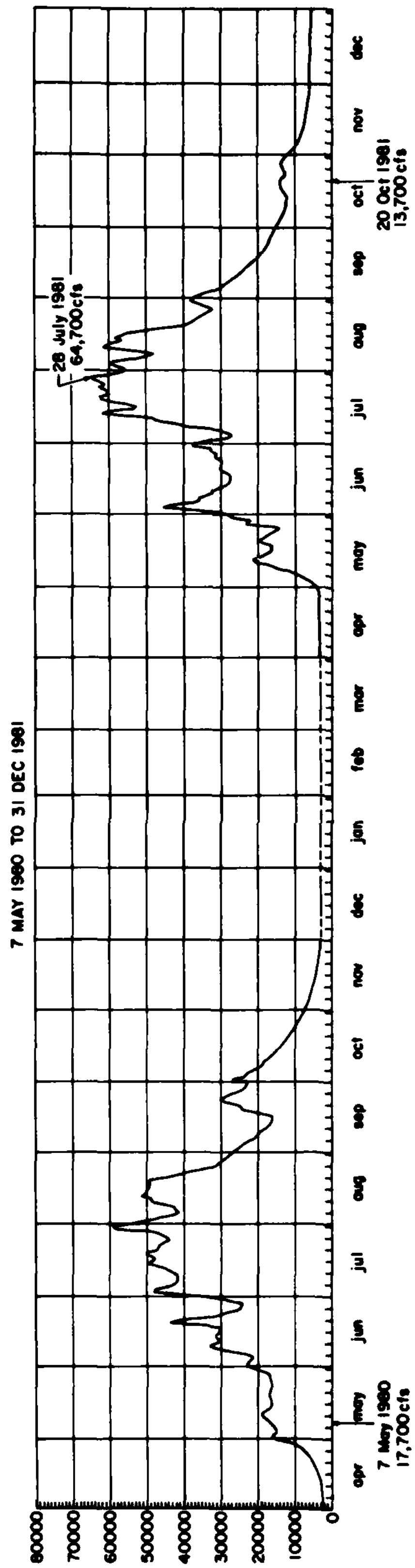


4 JUNE 1976 TO 6 JUNE 1977
DISCHARGE (CFS)
80000
70000
60000
50000
40000
30000
20000
10000
0
jun
jul
aug
sep
oct
nov
dec
jan
feb
mar
apr
may
jun
14 Aug 1976
53,000 cfs
4 June 1976
31,200 cfs
6 June 1977
28,000 cfs (est.)

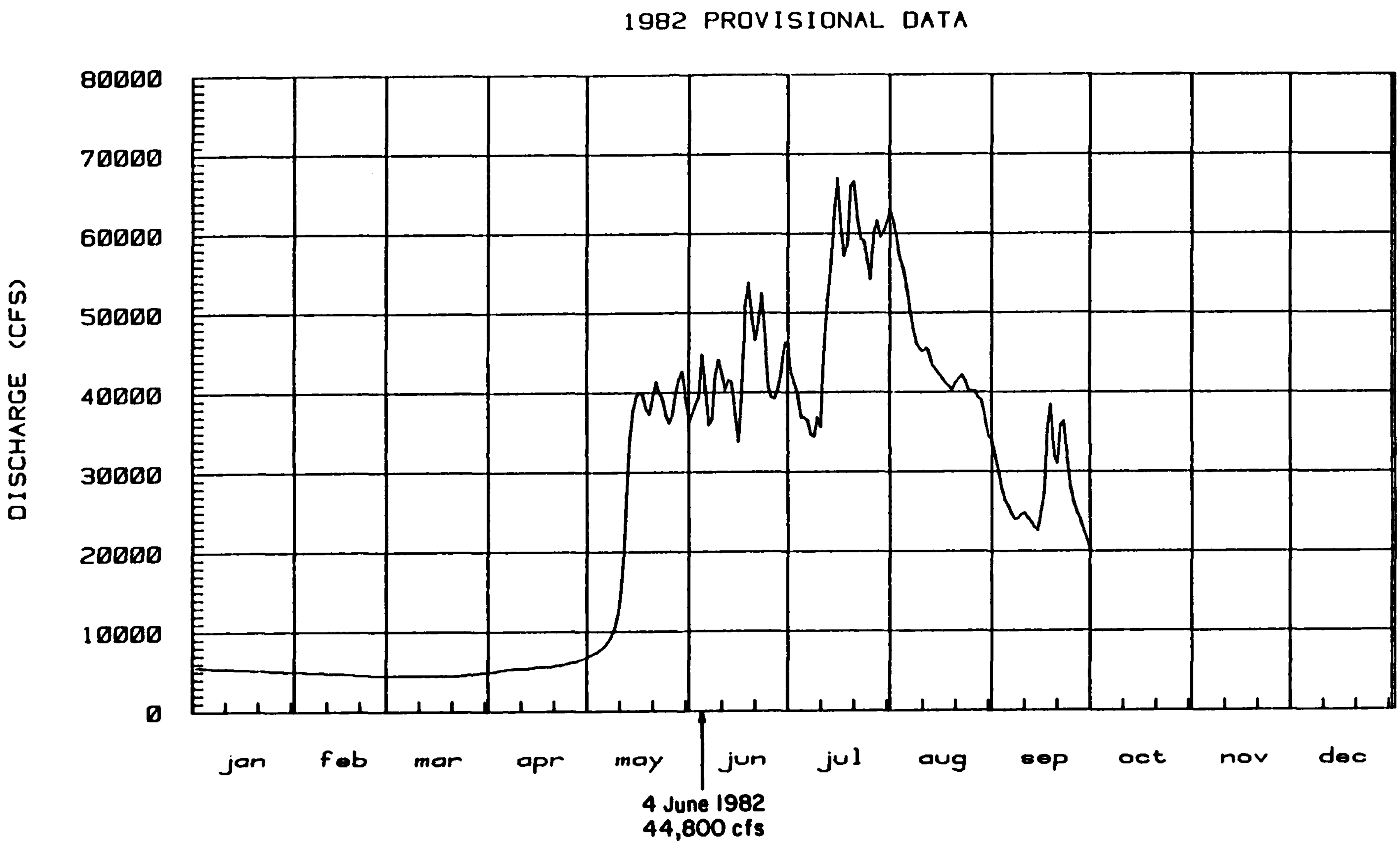

6 JUNE 1977 TO 4 JUNE 1978
DISCHARGE (CFS)
80000
70000
60000
50000
40000
30000
20000
10000
0
6 Aug. 1977
62,900 cfs
may
jun
jul
aug
sep
oct
nov
dec
jan
feb
mar
apr
may
jun
6 June 1977
28,000 cfs (est.)
4 June 1978
21,600 cfs


4 JUNE 1978 TO 3 JULY 1979
DISCHARGE (CFS)
80000
70000
60000
50000
40000
30000
20000
10000
0
jun
jul
aug
sep
oct
nov
dec
jan
feb
mar
apr
may
jun
jul
11 July 1978
60,200 cfs
4 June 1978
21,600 cfs
3 July 1979
39,100 cfs


3 JULY 1979 TO 7 MAY 1980
DISCHARGE (CFS)
80000
70000
60000
50000
40000
30000
20000
10000
0
5 Aug 1979
75,000 cfs (est.)
jul
aug
sep
oct
nov
dec
jan
feb
mar
apr
may
3 July 1979
39,100 cfs
7 May 1980
17,700 cfs

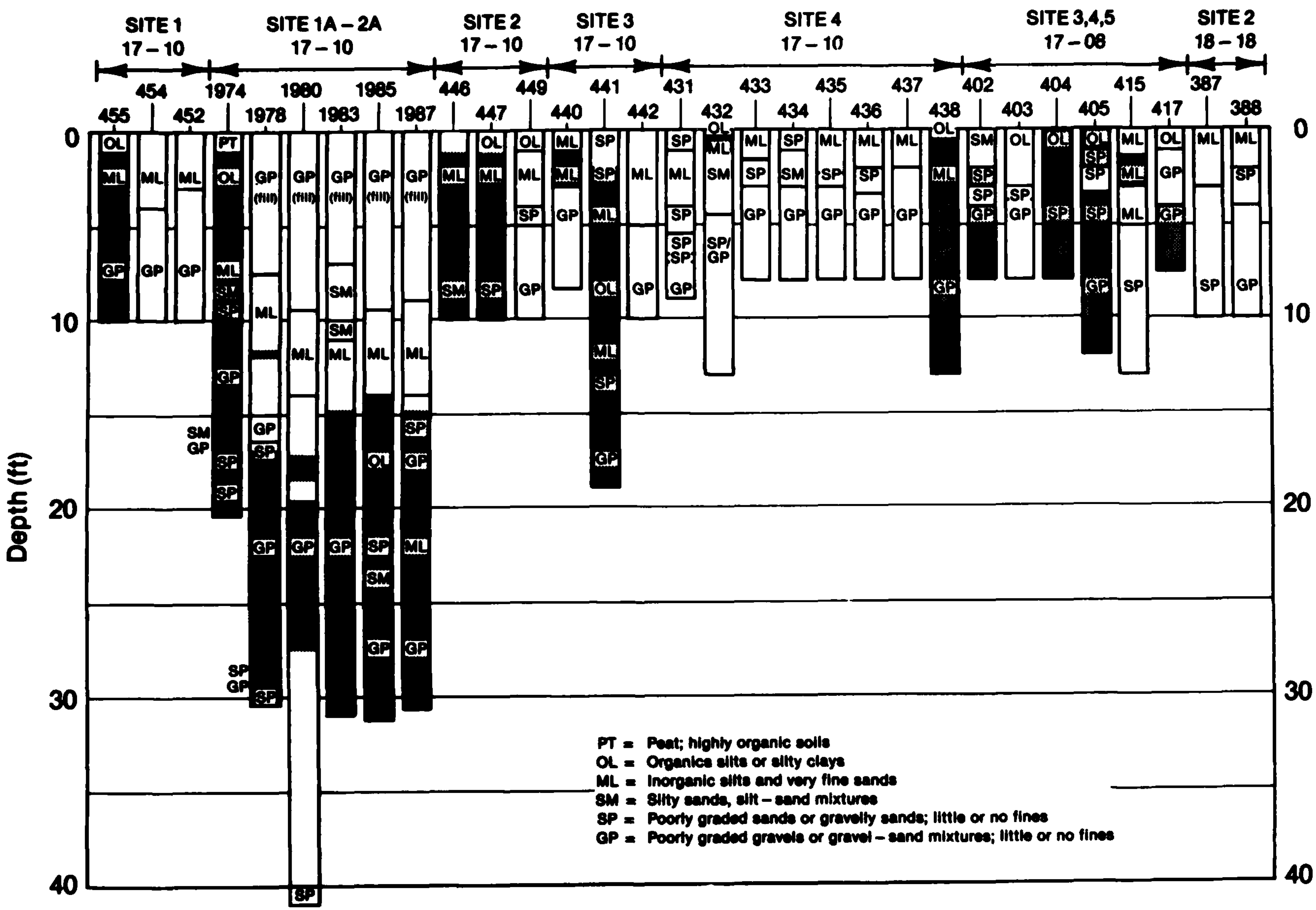


7 MAY 1980 TO 31 DEC 1981
80000
70000
60000
50000
40000
30000
20000
10000
0
apr
may
jun
jul
aug
sep
oct
nov
dec
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec
7 May 1980
17,700cfs
28 July 1981
64,700cfs
20 Oct 1981
13,700cfs


1982 PROVISIONAL DATA
DISCHARGE (CFS)
80000
70000
60000
50000
40000
30000
20000
10000
0
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec
4 June 1982
44,800 cfs

Appendix C

Alaska District soil logs.


SITE 1
17 – 10
SITE 1A – 2A
17 – 10
SITE 2
17 – 10
SITE 3
17 – 10
SITE 4
17 – 10
SITE 3,4,5
17 – 08
SITE 2
18 – 18
455
454
452
1974
1978
1980
1983
1985
1987
446
447
449
440
441
442
431
432
433
434
435
436
437
438
402
403
404
405
415
417
387
388
Depth (ft)
0
10
20
30
40
PT = Peat; highly organic soils
OL = Organics silts or silty clays
ML = Inorganic silts and very fine sands
SM = Silty sands, silt – sand mixtures
SP = Poorly graded sands or gravelly sands; little or no fines
GP = Poorly graded gravels or gravel – sand mixtures; little or no fines

APPENDIX D

EROSION ANALYSIS OF THE NORTH BANK OF THE TANANA RIVER, FIRST DEFERRED CONSTRUCTION AREA

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September 1982

Prepared for the
U.S. Army Engineer District, Alaska
as part of the
Tanana River Monitoring and Research Program

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ILLUSTRATIONS

TABLES

INTRODUCTION

This report is an analysis of a section of the Tanana River near Fairbanks, Alaska, with emphasis on erosion and bank recession rates of the north bank. The section of river analyzed in this report, referred to as the First Deferred Construction Area, is under active consideration for the placement of additional groins as part of the next construction phase of levee protection for the Tanana River Levee.

This analysis is being done as part of the Tanana River Monitoring and Research Program (TRMRP) for the Alaska District, Corps of Engineers, with the overall objective of determining long-term trends of river processes, and determining adverse impacts, if any, from the construction of the Tanana River levee and protective groin system.

The objectives of this analysis were to determine historic erosion patterns and bank recession rates along a section of the north bank of the Tanana River and to infer future bank recession and erosion that may be a threat to the existing Tanana River levee.

DESCRIPTION OF STUDY AREA

The two and a half mile section of river in the study area extends from just downstream of Goose Island to just upstream of groin No. 3, part of the Phase III levee construction (see reach of river between heavy lines, Figures 1 and 2). The river pattern in the study area consists of a major northern channel, a somewhat smaller southern channel, with connecting channels between the three major islands - from east to west, Goose Island, Haines Island, and a large unnamed island, along with numerous small islands.

A causeway was built between the north shore and Goose Island in November 1975, blocking off the north channel. A second, western causeway to Goose Island was built in early 1978 and extended to a small island southwest of Goose Island in the spring of 1979 for the purpose of gravel extraction. Effects of these changes in the river erosion pattern are discussed later.

Figure 1 is a 7 May 1980 photo mosaic of the study area of the river, showing Goose Island, the east and west causeways, the reach of the north bank studied, and the levee to just upstream of groin No. 3. The blocked off channel and gravel extraction area to the southwest of Goose Island is apparent.

Figure 2 is a 4 June 1982 photo of the study area. During August 1981, the river broke through into the previously blocked-off channel between Goose Island and the island to the southwest. Compare the blocked off channel and channel flow patterns between Figure 1 and 2.

PROCEDURE

A series of historical aerial photographs were used to map changes in the study area for each time period photography was available. Changes that were mapped included: north and south banklines, banklines of vegetated islands, intermittent and non-vegetated sand bars. Only changes of the north bank are analyzed in this report. Other changes, such as the south bank and islands, have not been analyzed as of yet, although they may be important in understanding the erosional trends of the river in this area.

Table 1 lists the dates of aerial photographs used for the study along with information on river discharge. The time periods bracketed by the aerial photo dates are defined in Table 2. The time period numbers are the same as in Buska et al. (1982) except that time period "9" has been expanded to 4 June 1982. Two earlier periods "P1" and "P2" were added as shown in Table 2. An exact time in years based on an effective six month erosion year of May through October was derived for each of the time periods. See Buska et al. (1981) for a more detailed discussion of effective erosion year concept.

A May 7, 1980 aerial photograph (Fig. 1) enlarged to a scale of 1:4700 (1" = 392 ft) was used as a photo base to map changes. A Bausch and Lomb Zoom Transfer Scope was used to project the image of each historical aerial photograph onto a transparent overlay registered to the 1980 photo base. Differences in river bank position, etc., could then be plotted easily onto the overlay. Once overlays for each year were made, some twelve in all, the north bank position for each of the years were then plotted together on a separate overlay as shown in Figure 3.

The area between banklines for each time period was digitized and the total erosional areas in square feet were calculated.

HISTORIC BANK EROSION

The river pattern in the study area consists of a northern and a southern channel with connecting channels between the three major islands. Along the north bank, the northern channel has two major areas of erosion marked by meander bends separated by a seemingly resistant point near the end of Peger Road (Fig. 1).

In late 1975, the channel north of Goose Island was blocked off by the construction of the eastern Goose Island Causeway. In-river gravel extraction did not began off the southern end of Goose Island until 1977.

The southern channel was not capable of handling all of the diverted flow so considerable flow continued into the north channel through the connecting channels between Goose Island, Haines Island, and the interviewing islands.

In the winter of 1977-78, another causeway (west) linked Goose Island to the north shore and the causeway was extended from Goose Island to the island to the southwest of Goose Island in the spring of 1979 to extract gravel from the smaller island.

The causeway extention between Goose Island and the gravel extraction area was breached in August 1981 causing renewed flow through the channel and increased erosion.

Table 3 lists the surface area erosion that has occurred along the north bank of the Tanana over the last thirty-four years. For each of the time periods the table lists the effective erosion period in years, based upon a six month erosion year from May through October, the total surface area eroded in square feet, and the erosion rate in square feet per effective erosion year. Erosion patterns during each of the time periods is discussed in greater detail below.

<u>Time Period: P2 (4 June 1948 - 1 May 1961)</u>

A total of 1,694,000 square feet eroded in 12.81 years. Much of the erosion occurs in the central portion of the study area an area of partially vegetated bars.

<u>P1 (1 May 1961 - 12 May 1970)</u>

During this period 1,044,000 square feet eroded during 9.06 years. The erosion occurred nearly uniformily over the eastern and western segments of the study area, with no erosion occurring in the central portion of the area.

1a (12 May 1970 - 27 June 1973)

Erosion in this period totaled 1,206,000 square feet over 3.25 years. The erosion in the most easterly section occurred in partly vegetated bars in front of the north bank. Erosion occurred over most of the rest of the study area with the greatest erosion on the outside of the western meander bend, in the western end of the study area. It is uncertain what caused the increased erosion rate during this period.

1b (27 June 1973 - 19 September 1974) A total of 99,000 square feet eroded in 1.46 years, much less than in previous periods. The erosion rate was significantly lower than the rate for the preceeding twenty-five years. All of erosion occurred in the western most bend, just downstream of the center of erosion activity in period 1a.

2 (19 September 1974 - 26 September 1975)

Erosion totaled 111,000 square feet over 1.04 years during this period. Most of the erosion occurred at the western end of the western bend.

3 (26 September 1975 - 4 June 1976)

Erosion totaled 324,000 square feet in only 0.38 years, with the majority of erosion occurring in the eastern bend during spring breakup. Some of it was in partly vegetated bars at the eastern end of the bend. It may be significant that this increased erosion followed the blocking of the north channel by the construction of the eastern Goose Island causeway.

4 (4 June 1976 - 17 May 1977)

Erosion increased again this period with 902,000 square feet of erosion during 0.90 years. Most of the area eroded was in the eastern end of the east bend. The erosion increased as the northern channel readjusted to the Goose Island causeway. Flow was directed almost due north around Goose Island and impacted on a low area of partially vegetated abandoned bars, which were easily erodable.

5 (17 May 1977 - 4 June 1978)

Erosion of 180,000 square feet in 1.10 years took place in scattered locations with most of it occurring in the eastern bend.

6 (4 June 1978 - 3 July 1979)

A total of 204,000 square feet over 1.16 years at scattered locations with the majority on the downstream end of the western bend.

7 (3 July 1979 - 7 May 1980)

Erosion totaling only 27,000 square feet over 0.69 years took place in the very upstream and downstream ends of the study area. The presence of the causeway extension from Goose Island to the island southwest of it, blocking off a major channel leading from the south channel to the north channel may have redirected flow or may have diverted enough flow from the north channel to reduce erosion.

8 (7 May 1980 - 29 May 1981)

Erosion of 181,000 square feet over 1.12 years occurred with the majority of erosion confined to the eastern end of the study area as flow re-established itself around the blocked channel.

9 (29 May 1981 - 4 June 1981)

Erosion of 130,000 square feet in 1.03 years in both bends but significantly increased erosion in western bend area. At this point, there is no noticable increase in the erosion in the eastern half, except at the extreme eastern end, due to the breakthrough of the channel block southwest of Goose Island in August 1981. Figure 2 shows the location of major erosion areas (heavy arrows) during time period 9.

EROSION TRENDS

Figure 4 is a graph of the cumulative erosion that has occurred on the north bank over the last thirty-four years. The sharp increases in erosion during periods 1 a and during period 3 and 4 are apparent. It is unclear what caused the increase erosion during period 1a except that part of it was in a less resistant, partially vegetated former bar area. However, a large amount of the erosion occurred in a heavily vegetated bank area in the westernbend. As pointed out before, periods 3 and 4 immediately follow the blocking off of the north channel behind Goose Island and may reflex the readjustment of channel patterns around Goose Island. Total erosion of 6,102,000 square feet has occurred over 34.00 years giving a long-term erosion rate of 179,000 square feet per year.

Figure 5 is a bar graph of the erosion rate of each time period. The rate of erosion and the duration of the erosion rate is apparent from the height and width of the individual time period bars.

BANK RECESSION RATES

Table 4 shows recent bank recession rates along the north bank of the Tanana River. Distances from the present (4 June 1982) bank position to center line of the levee are given for representative locations. Bank recession in feet, recession rates in feet per effective erosion year, and remaining distance to the levee are given.

During the last time period, up to 4 June 1982, the greatest bank recession of 65 feet took place at the levee sta 970+00. The area where the bankline is closest to the levee is from levee sta 945+00 to 952+50 (Fig. 3). For example, at 948+00 the bank receeded 30 feet, with 600 feet left from the riverbank to the center line of the level.

CONCLUSION

During the last time period (29 May 1981 - 4 June 1982) erosion has continued along the north bank at levels below that of the long term erosion rate.

Erosion is of concern in the western bend area where the bankline is within 600 feet of the levee centerline and bankline recession rates are on the order of 30 feet or more per year.

As of yet there is no noticible increase in erosion in the eastern bend area that is attributable to the August 1981 breakthrough of the channel block between Goose Island and the gravel extraction area to the southwest.

REFERENCE CITED

Buska, J.S., et al. (1982) The Effects of Phase III Construction of the Chena Flood Control Project on the Tanana River Near Fairbanks, Alaska, A Preliminary Analysis. Prepared for the U.S. Army Engineer District, Alaska by USACRREL.

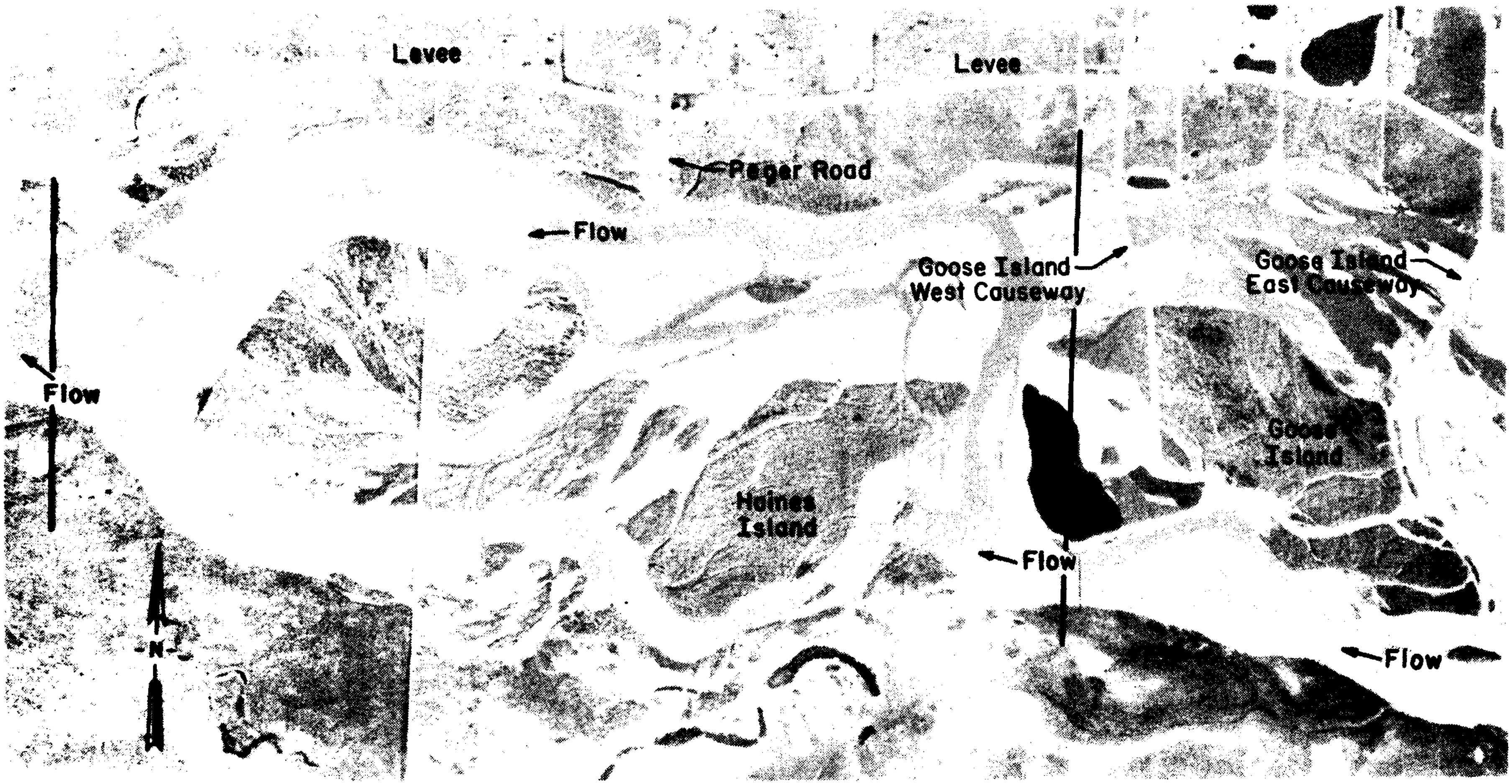


Figure 1. 7 May 1980 aerial photograph of study area.

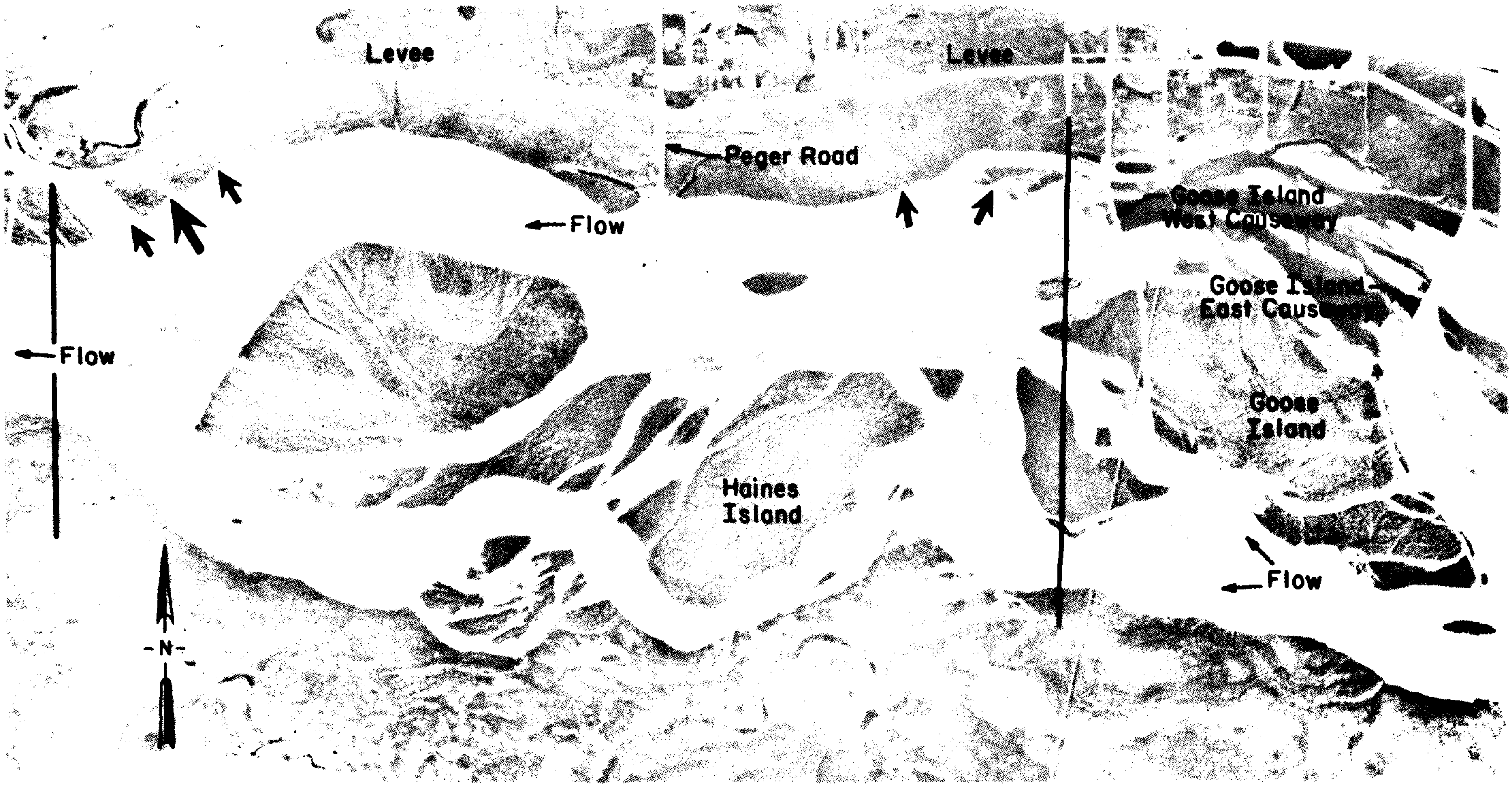
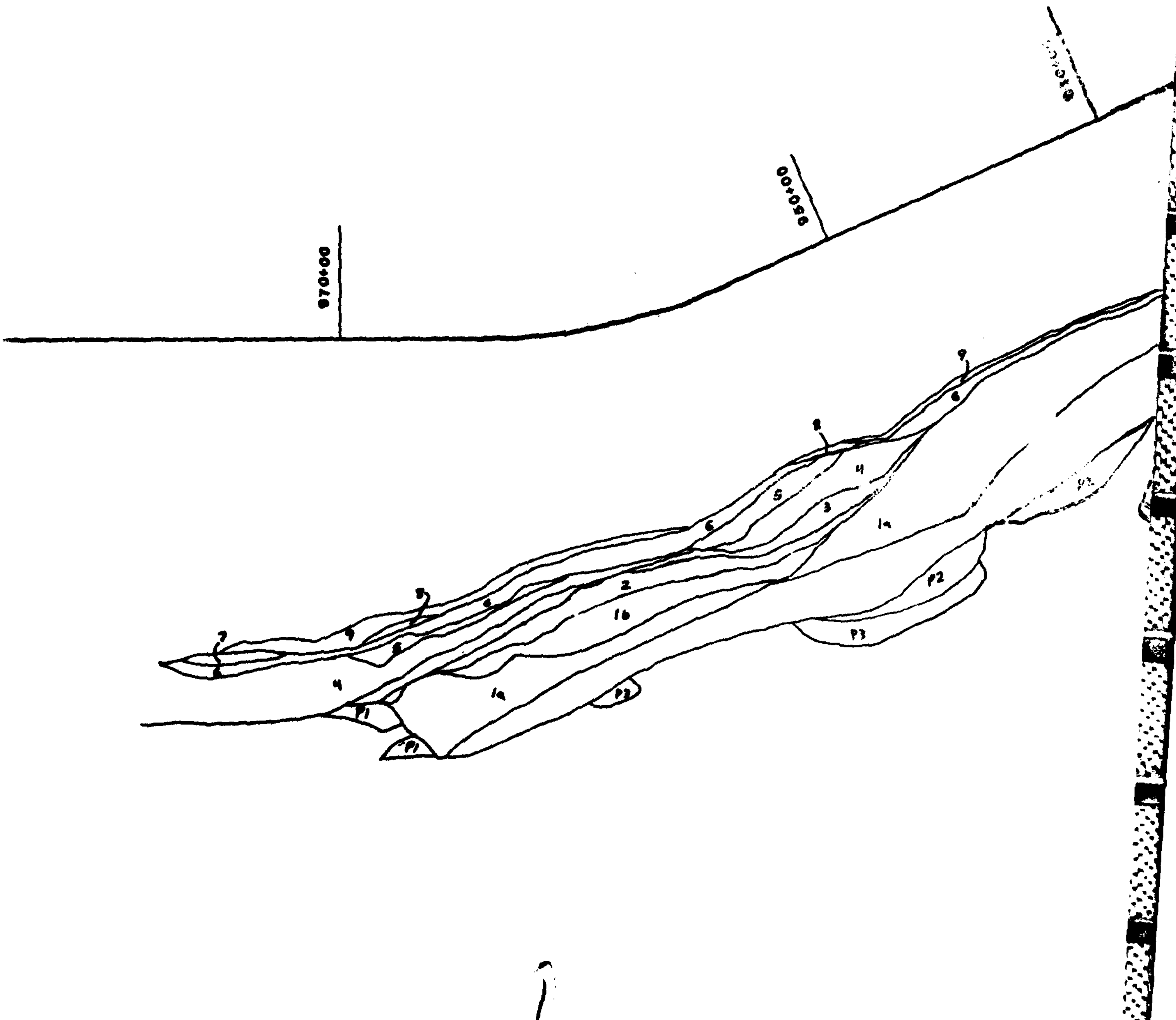
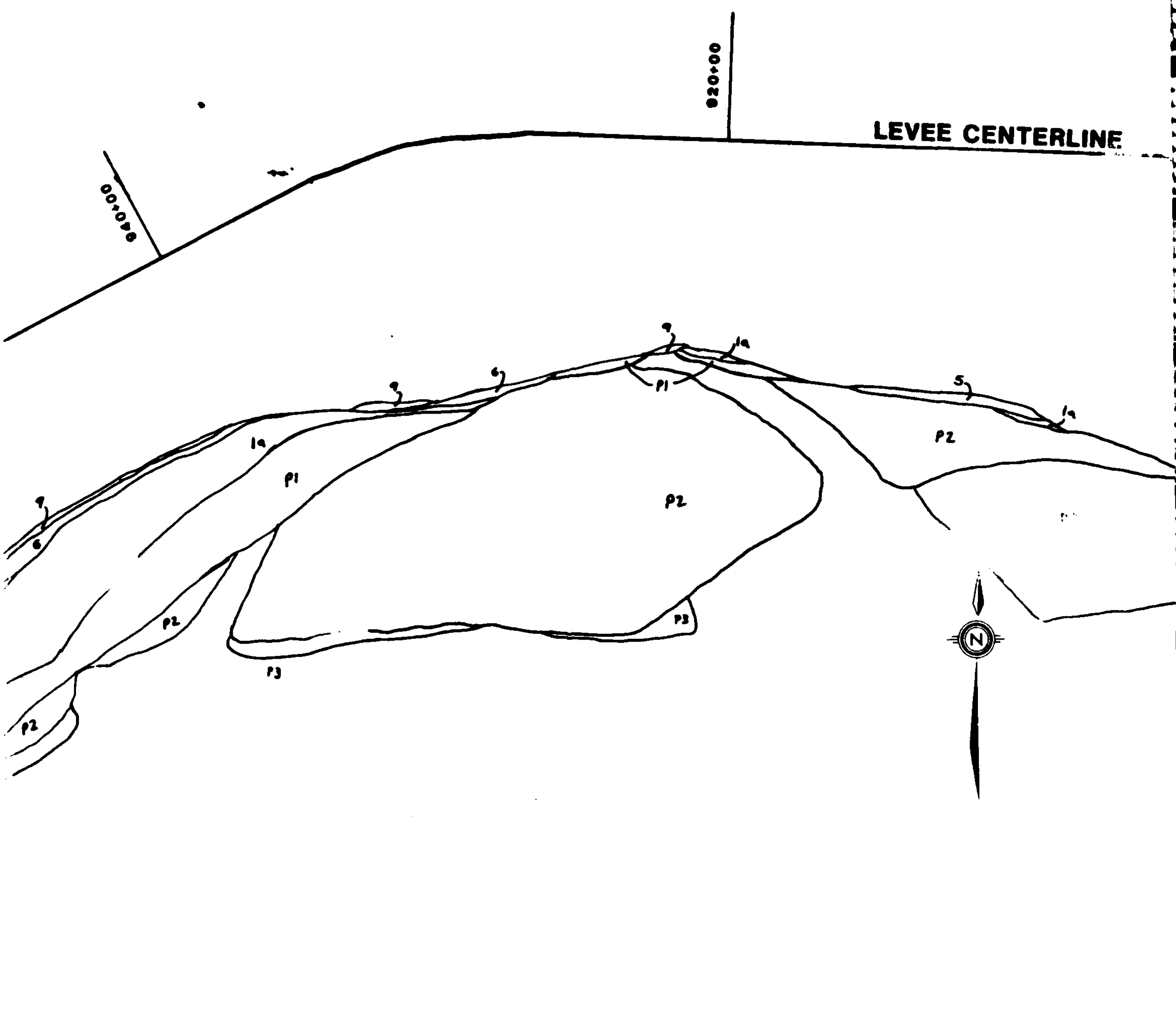
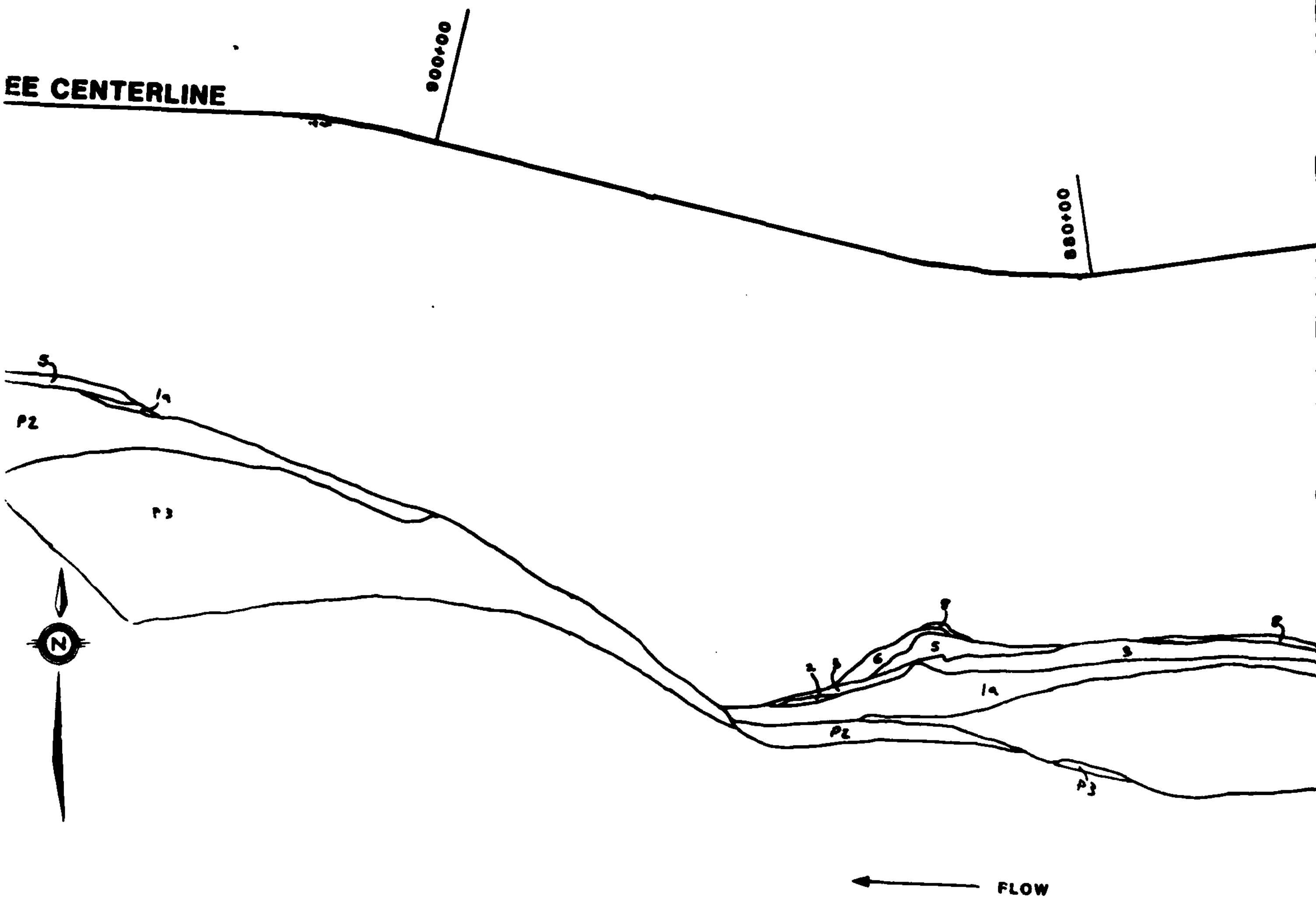


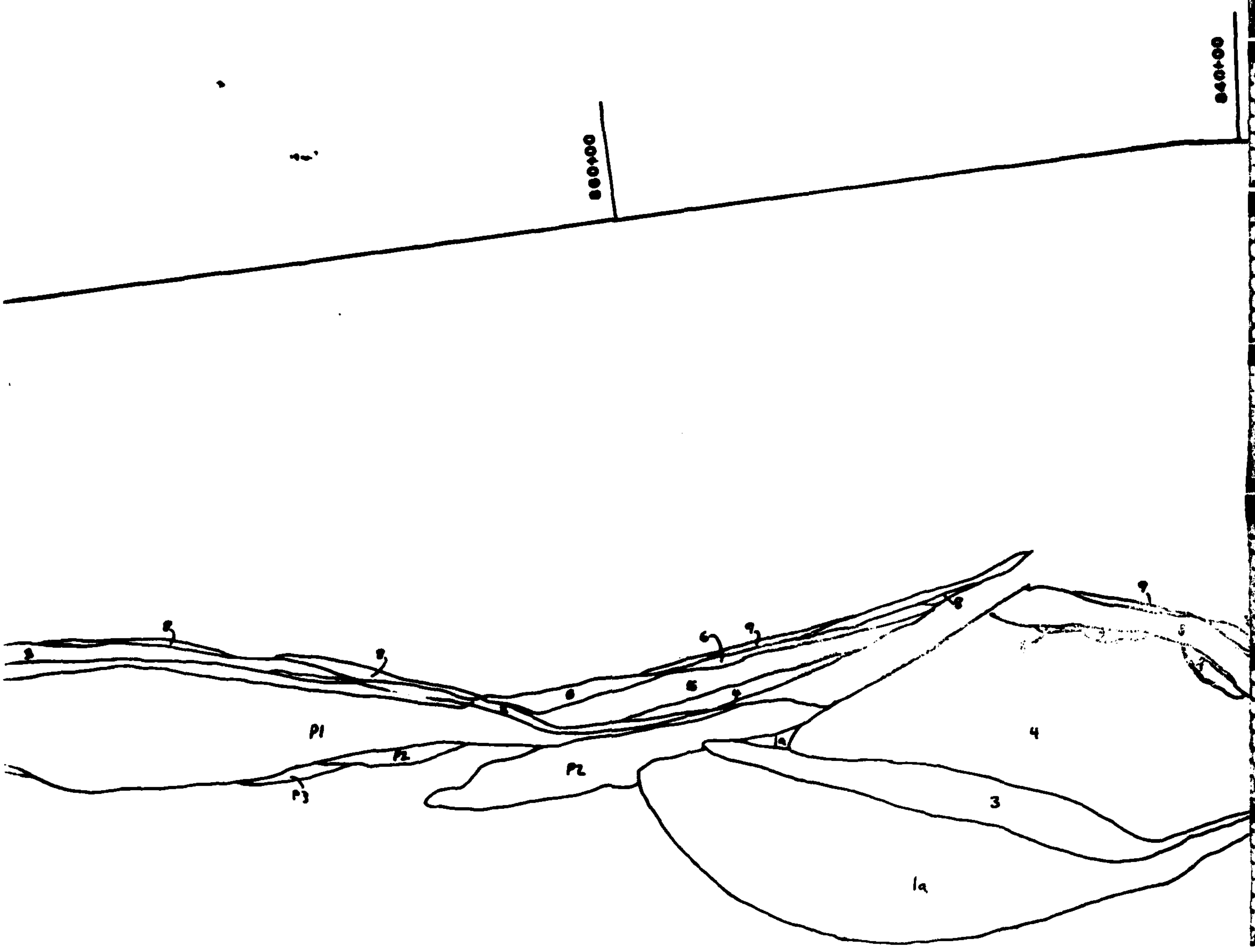
Figure 2. 4 June 1982 aerial photograph of study area.

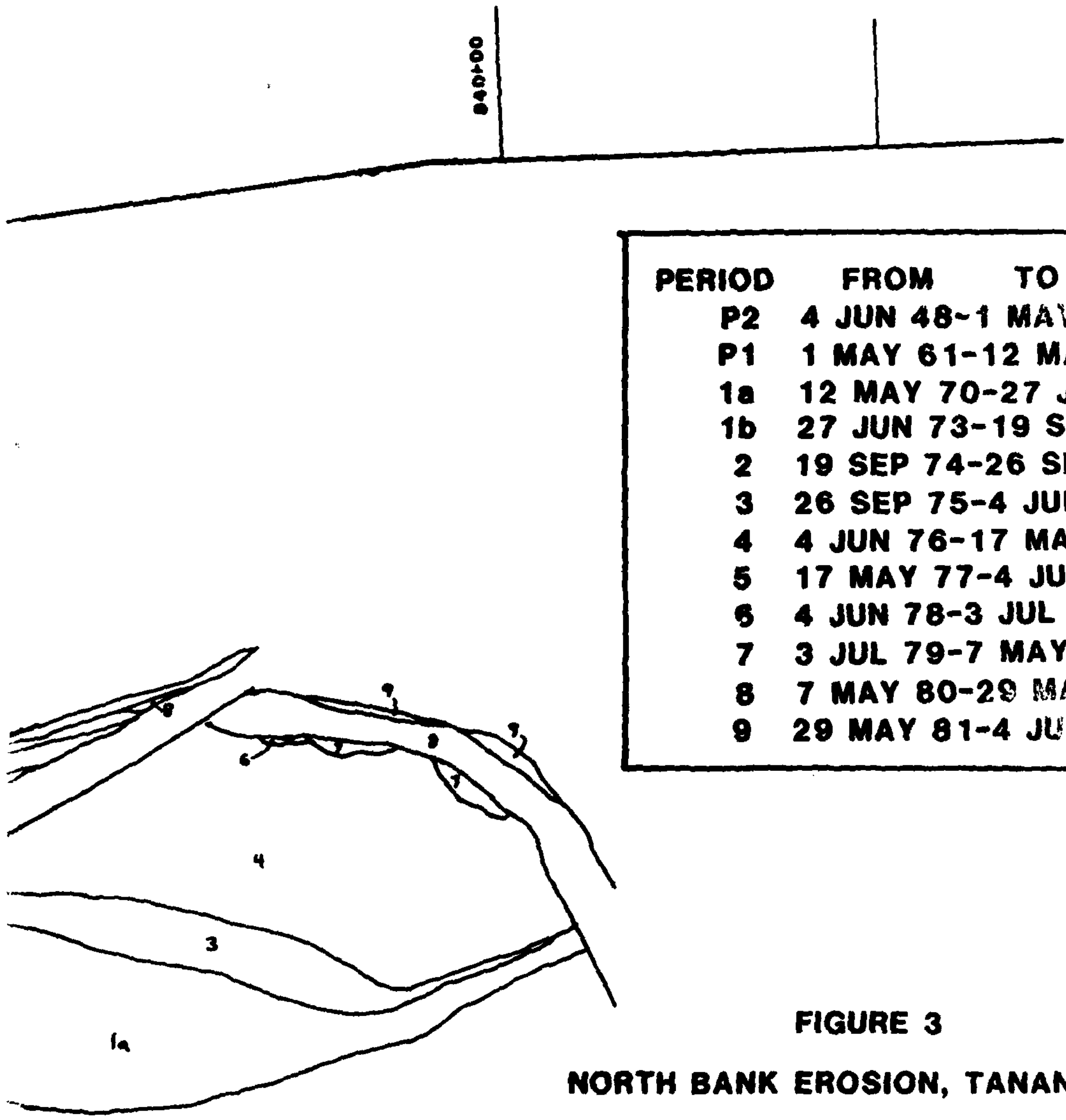

970+00
1a
1b
2
3
4
5
6
7
8
9
P1
P2
P3



(2


EE CENTERLINE
900+00
880+00
5
1a
P2
P3
N
2
3
6
5
8
3
1a
P2
P3
5
FLOW


P1
P2
P2
P3
4
3
1a



PERIOD	FROM	TO
P2	4 JUN 48	1 MAY 61
P1	1 MAY 61	12 MAY 70
1a	12 MAY 70	27 JUN 73
1b	27 JUN 73	19 SEP 74
2	19 SEP 74	26 SEP 75
3	26 SEP 75	4 JUN 76
4	4 JUN 76	17 MAY 77
5	17 MAY 77	4 JUN 78
6	4 JUN 78	3 JUL 79
7	3 JUL 79	7 MAY 80
8	7 MAY 80	29 MAY 81
9	29 MAY 81	4 JUN 82

FIGURE 3

NORTH BANK EROSION, TANANA RIVER
FIRST DEFERRED CONSTRUCTION AREA

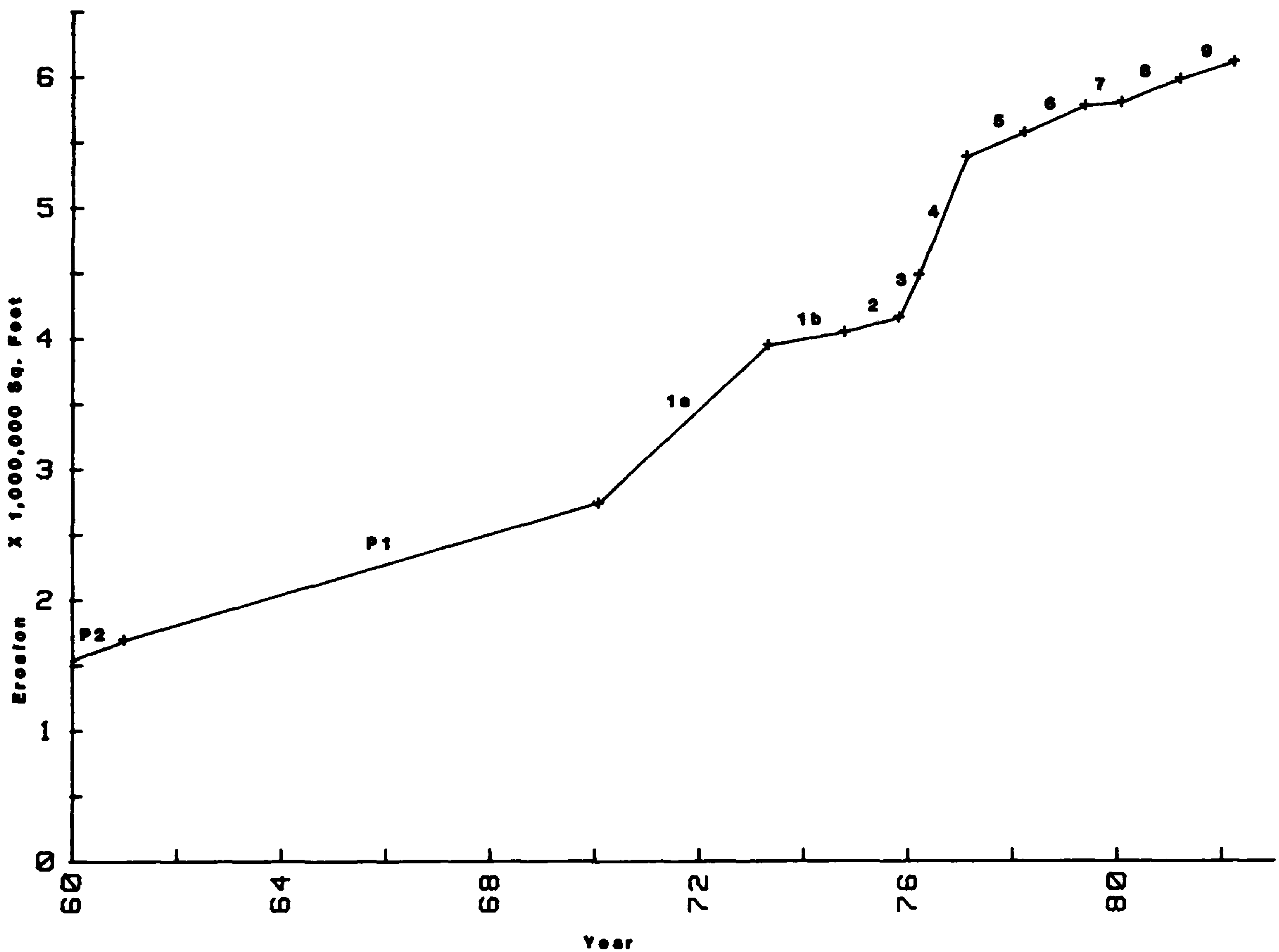


Figure 4. North bank cumulative erosion.

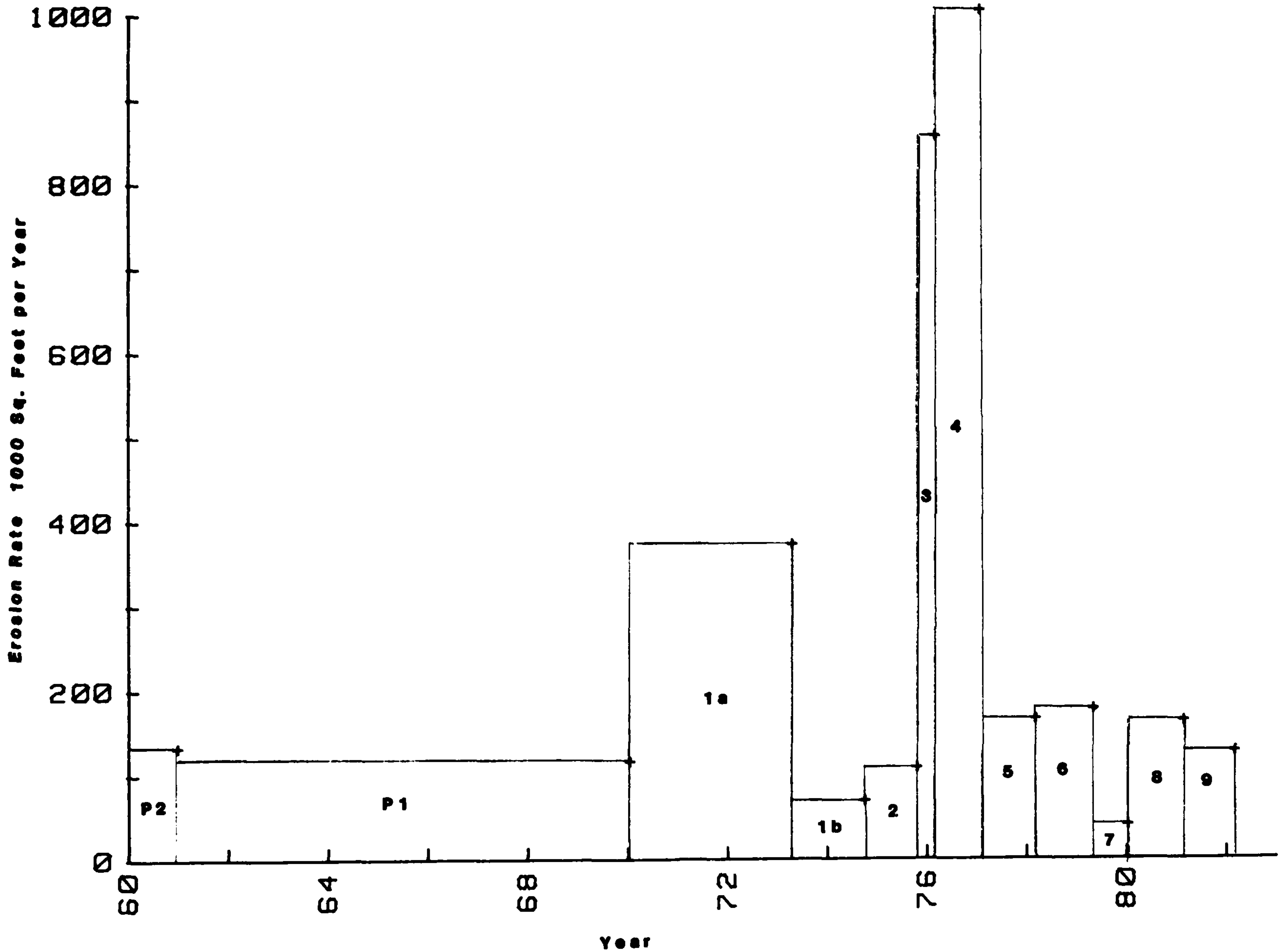


Figure 5. North bank erosion rates.

TABLE 1. Aerial photography used in analysis.

Date	Discharge (cf)	Date	Discharge (cfs)
4 Jun 1948	est. 17,000	17 May 1977	17,090
1 May 1961	est. 18,000	4 Jun 1978	21,600
12 May 1970	est. 21,200	3 Jul 1979	39,100
27 Jun 1973	49,200	7 May 1980	17,700
19 Sep 1974	19,100	29 May 1981	23,000
26 Sep 1975	31,300	4 Jun 1982	est. 44,800
4 Jun 1976	31,200		

TABLE 2. Time periods used in analysis.

Time period	Aerial Photo Dates From	To	Time interval-years*
P2	4 Jun 48	1 May 61	12.81
P1	1 May 61	12 May 70	9.06
1a	12 May 70	27 Jun 73	3.25
1b	27 Jun 73	19 Sep 74	1.46
2	19 Sep 74	26 Sep 75	1.04
3	26 Sep 75	4 Jun 76	0.38
4	4 Jun 76	17 May 77	0.90
5	17 May 77	4 Jun 78	1.10
6	4 Jun 78	3 Jul 79	1.16
7	3 Jul 79	7 May 80	0.69
8	7 May 80	29 May 81	1.12
9	29 May 81	4 Jun 82	1.03

* Based upon a six month, May-Oct, effective erosion year.

TABLE 3. North Bank erosion rates first deferred construction area.

Time Period	Effective time (years)	Erosion ft^2	Erosion rate ft^2/yr
P2	12.81	1,694,000	132,000
P1	9.06	1,044,000	115,000
1a	3.25	1,206,000	371,000
1b	1.46	99,000	68,000
2	1.04	111,000	107,000
3	0.38	324,000	853,000
4	0.90	902,000	1,002,000
5	1.10	180,000	164,000
6	1.16	204,000	176,000
7	0.69	27,000	39,000
8	1.12	181,000	162,000
9	1.03	130,000	126,000

TABLE 4. Recent bank recession rates in relation to the Tanana River levee.

Levee Sta.	Distance remaining from riverbank to centerline levee	Time periods 9	8	7	6	5	4	Avg. 9-4 6.0 yr
		Dist. (ft) (Rate) (ft/yr)						
850+00	1250	20 (20)	--	--	--	--	--	20 (3)
853+00	1050	25 (24)	--	--	25 (22)	15 (14)	--	65 (11)
860+00	1400	20 (20)	--	--	--	--	--	20 (3)
922+00	690	25 (24)	--	--	--	--	--	25 (4)
940+00	620	--	--	--	10 (9)	--	--	10 (2)
945+00	590	15 (15)	--	--	--	--	--	15 (3)
948+00	600	30 (30)	--	--	65 (56)	--	--	95 (16)
950+00	640	25 (24)	--	--	45 (39)	--	25 (28)	95 (16)
952+00	625	--	30 (27)	--	--	40 (36)	85 (94)	155 (26)
960+00	705	20 (20)	--	--	55 (47)	--	--	75 (13)
970+00	965	65 (63)	--	--	--	--	--	65 (11)

APPENDIX E

COMPUTATION OF BED-LOAD TRANSPORT BY MEYER-PETER AND MULLER FORMULA

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as part of the
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COMPUTATION OF BED-LOAD TRANSPORT BY MEYER-PETER AND MULLER FORMULA

Meyer-Peter and Muller Formula (1948)

The formula was originally published in the proceedings of the IAHR Second Meeting, Stockholm 1948, and has been quoted in numerous later publications. For the present study it was taken from the ASCE Sedimentation Manual (ASCE, 1975). Various apparently different versions of the formula can be found, depending on whether hydraulic roughness is characterized by Strickler k or Manning n, on whether a side-wall correction factor is included, and on whether bed-load transport is expressed as submerged weight or dry weight. (Cross-checking is advisable to check that the particular source used does not include numerical errors in the coefficients.) The formula was based on extensive laboratory flume experiments in Switzerland and replaced an earlier Meyer-Peter formula of 1934. Source data included the classical USGS experiments by Gilbert of 1914.

The ASCE version of the formula is:

$$\left(\frac{k_r}{k_r'}\right)^{3/2} \gamma r_b S = 0.047\ (\gamma_s - \gamma)\ d_m + 0.25 \left(\frac{\gamma}{g}\right)^{1/3} \left(\frac{\gamma_s - \gamma}{\gamma_s}\right)^{2/3} g_s^{\ 2/3}$$

where r_b = hydraulic radius of bed* (essentially mean depth for a wide channel

k_r = Strickler coefficient defined by: mean velocity

$$V = k_r r_b^{\ 2/3}\ S^{1/2}$$

*Differs from hydraulic radius of cross-section in case of narrow channels, by a correction for side-wall friction.

k_r' = partial Strickler coefficient associated with grain roughness only, as defined below

S = total channel slope

γ = specific weight of fluid

γ_s = specific weight of sediment (dry)

d_m = effective diameter of sediment, as defined by a fraction summation procedure

g = gravitation acceleration

g_s = sediment discharge per unit width, dry weight.

For purposes of this calculation, linear dimensions were expressed in metres, specific weights in metric tons (force)/m^3, g in m/s^2, and transport g_s in metric tons/m/s. All three terms in the formula are then in stress units of metric tons (force)/m^2. The formula could be more logically arranged by writing the last (transport) term as equal to the first (total shear stress) term minus the second (threshold shear stress) term.

A procedure for applying the formula may be summarized as follows:

1. Select effective grain-size for roughness recommended as d_{90}, and for the case of fully rough conditions, compute Stricker $k_r' = 26/d_{90}^{1/6}$.

2. Compute $k_r = V/r_b^{2/3}\ S^{1/2}$.

3. Apply formula to obtain g_s in t/m/s.

4. Multiply by assumed effective bed width and convert to tons/day.

Assumptions that were used in deriving the curves shown on Figures 4.5 and 4.6 are listed in Section 4.3 of the report. Table E.1 shows the calculations used to derive the curves. These were applied to a section more or less equivalent to the Fairbanks discharge-measuring section GSX2 (or 6A). The section was treated as a whole and not divided laterally into strips, in view of the relative crudity of the basic information and assumptions.

TABLE E.1

COMPUTATION OF BED-LOAD TRANSPORT BY MEYER-PETER AND MULLER FORMULA

Discharge (m^3/s)	Mean depth (m)	Mean vel. (V)	K_r	g_s (t/m/s)	Eff. bed width (m)	Total transport G_s (t/day)	Bed-load concentration (ppm by wt.)
400	1.8	1.5	44.1	0.000033	100	280	8
700	2.0	1.6	43.8	0.000088	125	950	16
1000	2.2	1.7	43.7	0.000166	150	2150	25
1500	2.4	1.8	43.7	0.000259	175	3920	30
2000	2.6	1.9	43.7	0.000366	200	6320	37

For input assumptions, see Section 4.3 of report.
For formula and procedure, see preceding test, Appendix E.

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