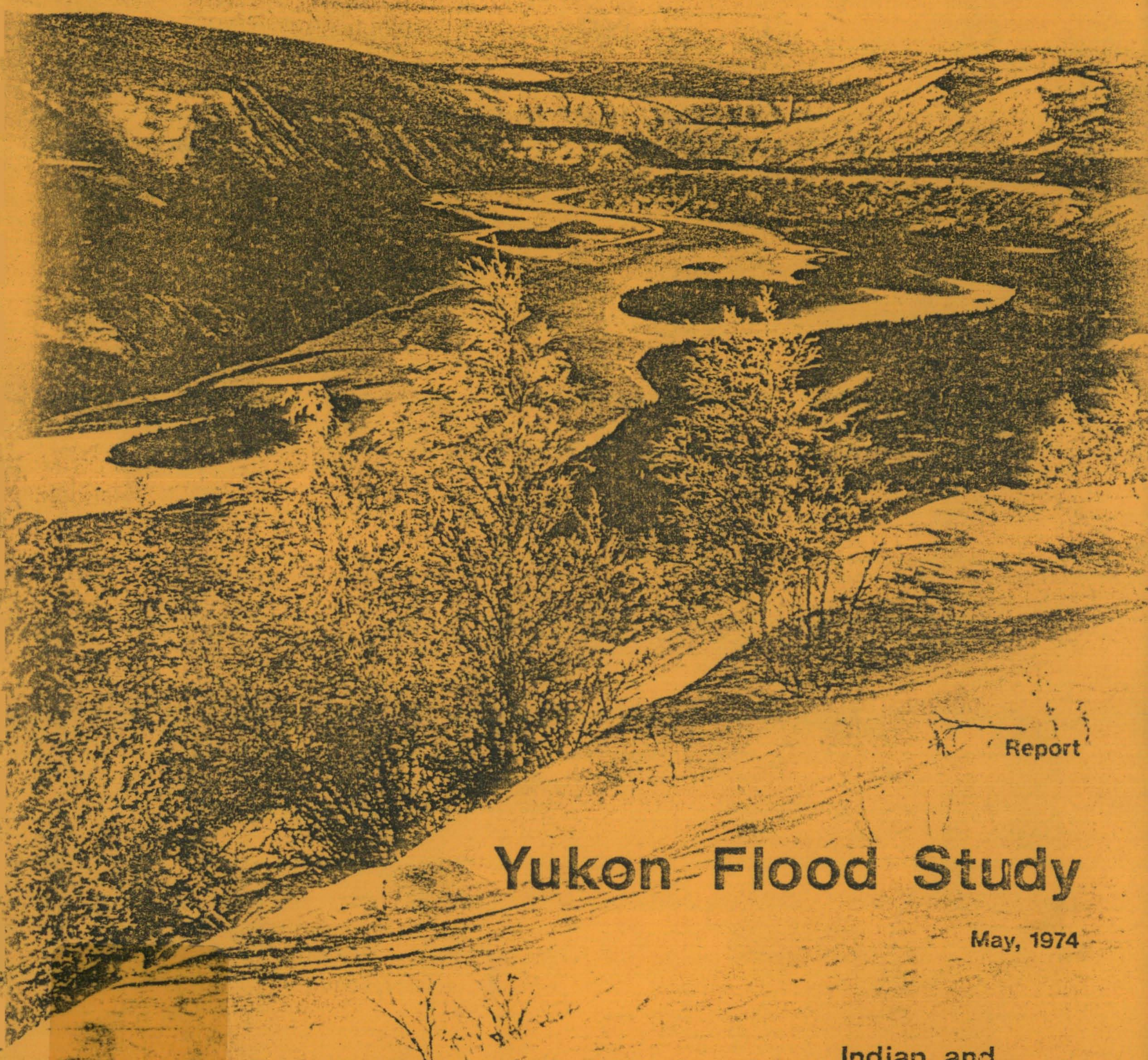
439



Report

Yukon Flood Study

May, 1974

Indian and
Northern Affairs

FENCO
Foundation of Canada Engineering Corporation Limited

REPORT

ON

YUKON FLOOD STUDY

SUBMITTED TO

NORTHERN NATURAL RESOURCES
AND ENVIRONMENT BRANCH
INDIAN AND NORTHERN AFFAIRS
WHITEHORSE, YUKON TERRITORY

MAY - 1974

FENCO

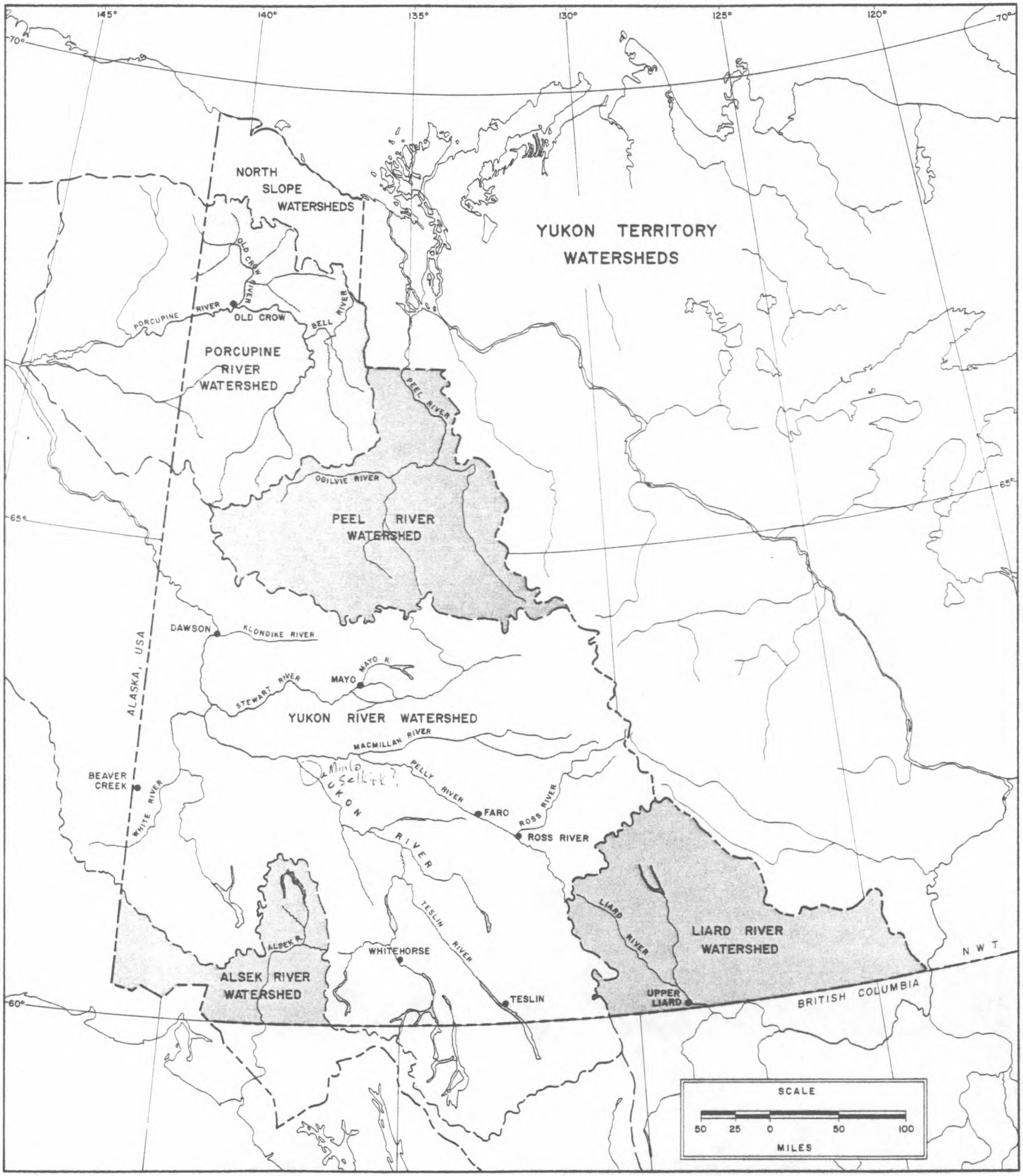
DISCLAIMER

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES


145°
140°
135°
130°
125°
120°
70°
65°
60°
NORTH SLOPE WATERSHEDS
YUKON TERRITORY WATERSHEDS
OLD CROW RIVER
PORCUPINE RIVER
OLD CROW
BELL RIVER
PORCUPINE RIVER WATERSHED
PEEL RIVER
OGILVIE RIVER
PEEL RIVER WATERSHED
DAWSON
KLONDIKE RIVER
ALASKA, USA
MAYO R.
MAYO
STEWART RIVER
YUKON RIVER WATERSHED
MACMILLAN RIVER
PELLY RIVER
YUKON RIVER
BEAVER CREEK
WHITE RIVER
FARO
ROSS RIVER
ROSS RIVER
TESLIN RIVER
LIARD RIVER
LIARD RIVER WATERSHED
ALSEK R.
WHITEHORSE
ALSEK RIVER WATERSHED
TESLIN
UPPER LIARD
N W T
BRITISH COLUMBIA
SCALE
50 25 0 50 100
MILES

I INTRODUCTION

The Northern Natural Resources and Environment Branch of the Department of Indian and Northern Affairs at Whitehorse, Yukon, has retained Foundation of Canada Engineering Corporation Limited (FENCO) to identify the flooding problems in the Yukon Territory and recommend future courses of action. (Terms of reference in Appendix VIII).

I.1 SCOPE OF THE WORK

An investigation of the past floods has been conducted for the communities of Dawson, Mayo, Ross River, Old Crow, Whitehorse and other areas subject to flood. Comments of the remedial actions undertaken in the past are presented.

Courses of action for future improvement are analyzed and detailed studies required for implementation of solutions are recommended.

A survey has been undertaken on the different types of flooding problems encountered along the highways. Comments are made on past remedial actions and on future highway maintenance improvements.

The possibilities of a flood warning system are discussed.

Finally, past flood expenditures are presented and final recommendations are made.

I.2 GENERAL HISTORY OF FLOODING IN THE YUKON

Almost all of the communities in the Yukon are located on river flats and have been exposed to floods in their past history. This is primarily due to the fact that towns grew up along the river bank, providing an easy access to the river network, which was the primary method of transportation across the Yukon.

Floods in the Yukon are of three types:

1. Water backing up behind ice jams at the time of break-up and in a few cases at the time of freeze-up. This is a common

type of flood on the Yukon River and on the Porcupine. Although these floods can be very harmful, they are usually confined to fairly short reaches of the river.

2. Heavy snowmelt runoff sometimes combines with rainfall runoff. These floods occur generally a few weeks after break-up (beginning of June). This is the type of flood found at Mayo and Ross River.

3. Heavy summer rainstorms will cause flash floods on small watersheds but will have little effect on major rivers.

These types of floods are not completely independent, in some instances heavy runoff can break an ice jam or, on the contrary, cause more serious flood conditions depending on the hydraulic conditions.

II DAWSON CITY

II.1 INTRODUCTION

1.1 Site Condition

The town of Dawson is located on an alluvial floodplain at the confluence of the Klondike River and the Yukon River. The area of the community is flat and bounded on the east and north side by steep mountains, on the west side by the Yukon River and on the south side by the Klondike River.

Most building lots in Dawson have been filled in with soil over the past years. Periodic application of gravel surfacing on the streets has resulted in the street levels being often above floor elevation of the older structures and unfilled lots. This situation has created serious drainage problems throughout most of the townsite.(1)

1.2 Soil Condition

The organic silt is found under a layer of 6 to 12 inches of peat or fill. The organic silt is thicker in the northern half of the town where it extends up to a depth of 15½ feet. It becomes considerably thinner in the south end of town where it is replaced by sand with a large proportion of silt.[(1)]

Permafrost is widespread throughout the northern and central part of the town in a discontinuous form. The absence of permafrost at the south end of town, combined with the presence of sandy ground allows for a serious seepage problem through the dike, into the basements of the houses. During the 1972 highwater of the Yukon River, the groundwater table was found to be 13 inches below ground level.

Moreover, there is an artesian groundwater source at a depth of 6 feet[(1)] , the effect of this on the town is beyond the scope of this report.

II.2 YUKON RIVER HYDROLOGY

The Yukon River at Dawson drains an area of 101,000 square miles.[(2)] The maximum discharge recorded at Dawson since 1944, was estimated at 526,000 C.F.S. on June 11, 1964.

The watershed of the Yukon at Dawson can be divided into 3 basins of different characteristics (Fig. 28).

1. White River watershed A = 25,000 sq. mi.
2. Upper Yukon Plateau watershed
   A = 33,600 sq. mi.
3. Pelly River, Stewart and Klondike
   A = 42,400 sq. mi.

The hydrographs for each watershed have been plotted for the years 1972 and 1971 (Fig. 29, 30). Each of these watersheds has a specific type of influence on the discharge of the Yukon at Dawson. Details of the computation are given in Appendix IV.

Watershed 1 (White River) represents 25% of the total catchment area of the Yukon at Dawson. Its headwaters are in the St. Elias Mountains in the southwest part of the Yukon Territory. Therefore, runoff is very late, first due to snowmelt, then occasional rainfall, and finally, glacier melting. Generally, discharge reaches a peak in July or August and, therefore, does not contribute to the peak flow at Dawson. Air temperature seems to be the governing factor in the glacier melting process.(2)

Watershed 2 (Upper Yukon Plateau, including Teslin River) lies largely at low altitude and is mainly controlled by lakes: Atlin, Tagish, Laberge and Marsh Lake control structure on the Yukon River, Teslin Lake on the Teslin River. Lake storage plays an important part by having a very strong delaying and damping action on the peak discharge. Although the Upper Yukon represents 33% of the total watershed, its influence is negligible on the peak flow at Dawson. It only provides the base flow during the early June peak flow and reaches a peak in the middle of July. It then provides more water than the other watershed during the dry periods of the summertime.

Watershed 3 (Pelly River, Stewart and Klondike) represents 42% of the total catchment area of the Yukon River at Dawson. The headwaters are in the Selwyn Mountains, on the eastern part of the Yukon Territory, where the snowfields are at a lower elevation than those of the St. Elias Mountians. As a consequence, peak flows come very early: in the beginning of June from snowmelt or in the middle of June from rainfall during the recession of the snowmelt runoff when the ground is still frozen. Because of an increase of the soil moisture retention later on in the season, summer rainfalls generate a lower peak flow.

A study has been conducted on Ross River hydrographs. (Ross River, a tributary of the Pelly River with a catchment area of 2800 square miles has the same type of watershed as the Pelly and Stewart Rivers.) Snowmelt and rainfall for Ross River at Ross River have been computed and recorded for the year 1967 (Fig. 31). Results show that snowmelt is the governing factor on the peak flow. Separation between rainfall and snowmelt has been made on the 1965 Ross River spring hydrograph (Fig. 32). It was found that the ratio between water equivalent of snow on the ground before snowmelt versus runoff volume was very high. This is due to the fact that the ground is still frozen in the early spring and so the soil retention is very low. This explains the sharp rise of water level during peak flow. In some cases rainfall during that early period can be of some importance on the peak flow, but it would be comparatively less important for the whole Yukon watershed than it is for a smaller basin.

The hydrographs for the Pelly and Stewart Rivers are very similar. Each catchment area covers an area of 19,700 square miles and represents 19.5% of the total drainage area of the Yukon at Dawson. The peak on the Stewart River occurs generally within three days of the peak on the Pelly River (Table 1).

The Klondike plays a special role as a trigger of the break-up of the Yukon although its importance becomes negligible later on during the summer. Curves have been drawn (Fig. 33) showing the percentage of total discharge per unit area for each river basin. It shows that the contribution of the Klondike, Pelly and Stewart Rivers in the middle of May (at break-up time) is much more important than its watershed area would indicate. The method and the results are explained in Appendix IV.

II.3 FLOODING PROBLEMS IN DAWSON

A complete record of the past floods in Dawson is presented in Appendix I, and only a brief chronological review is to be found in the following paragraph.

3.1 History of Floods in Dawson

1898 - First flood recorded.

1925 - The Klondike overflowed its banks due to an ice jam on the Yukon. The water stayed high for a few days. A considerable amount of debris and mud was brought by the Klondike. The south end of the town was submerged by water and houses were carried away. Maximum water elevation - 1049.46 G.S.C.[3]

1944 - Ice jam 15 miles long downstream of Dawson. The water level was higher than in 1925. The south part of Dawson was under water, and ice floes caused damages along first Avenue. Flood lasted four days. Maximum water elevation - 1052.37 G.S.C.[3]

1957 - Water reached flood level due to heavy run-off in both Klondike and Yukon Rivers. Damage partly avoided with sand bags.

1959 - Construction of the dike around Dawson. Supposedly built 6 inches higher than the old high water marks of 1925 or 1944. Elevation of dike - 1050.50 on Harper St.
1052.10 at power plant
1052.6 at upper end
1050.1 at lower end.

1960 - Flood due probably to an ice jam from upstream. Ice cakes on First Street. Minto Park under water. Water came over dike in south part of town.

1964 - Flood due to heavy runoff two weeks after break-up. Maximum elevation - 1049.49 G.S.C. at level of Harper Street. Estimated discharge - 526,000 C.F.S.; largest discharge ever recorded in Dawson. See Figure 1 to 4 which show the same location during the flood and in its present state.

1966 - Ice jam on Klondike. Flash flood without warning left town without water and power for a day. Ice and water poured over the dike along First Street. Damage done to the dike. Maximum elevation:
1051.87 G.S.C. at level of Harper Street,
1051.98 G.S.C. at south end (Fig. 5).

1967 - Power house moved behind the dike.

1968 - The dike was raised -
1055.2 G.S.C. at upper end
1053.6 G.S.C. on Harper Street

1053.6 G.S.C. at N.C.P.C. Power Plant
1052.3 G.S.C. at lower end.
Pictures of the dike in its present state are shown in Figure 6.

NOTE: Some of the old high water elevations have been recorded directly or indirectly by different sources, sometimes with contradictory answers. A choice had to be made on the most probable value taking account of all the witnesses' recollections and of the newspaper clippings in the archives.

3.2 Frequency Analysis for Dawson

Three different frequency curves have been drawn on log-probability paper using:

1. The gauge height equivalent to the maximum daily discharge for every year (Fig. 34).
2. The maximum yearly gauge height due to ice conditions (with or without ice jams) (Fig. 35)
3. The highest yearly gauge height due to ice conditions or to high water (Fig. 36).

Twenty-four years of records were available from 1944 to 1972 with few years missing (Table 2).

Using a fragmentary historical flood data method[4] it was possible to extend the length of record to 65 years, knowing the elevation of the 1925 flood, which was the biggest between 1908 and 1944. The frequency analysis has been carried in gauge height to avoid extrapolation of the flow rating curve for the Yukon at Dawson.

For a 100 year return period the results for the 3 sets of data have been found to be:

1. H_{Max} = 1053.5 G.S.C.
2. H_{Max} = 1056 G.S.C.
3. H_{Max} = 1055 G.S.C.

Presently, the dike is at the elevation of 1053.6 G.S.C. at the level of Harper Street and, therefore, high enough to protect the town from a 100 year return period peak discharge (result number 1). It cannot prevent floodings in case of a 100 year return period ice jam (results number 2 and 3).

Result number 2 (ice condition only) is slightly higher than result number 3 (ice conditions and peak discharge). Results number 1 and number 2 are hydrologically more sound than result number 3 because they both relate, phenomena of the same type, in one case peak discharge and in the other case maximum water elevation due to ice conditions. In order to meet a 150 year average return period requirement, the dike should be raised by 3 feet, allowing 0.6 feet for freeboard and some channel constriction due to the dike. All the statistical computations were carried out for the Yukon River, the elevations were taken at the level of Harper Street, former location of the water survey gauge. It can be reasonably assumed that the grade of the dike should be of the same order as the slope of the Yukon River during high water, that is to say, approximately 1 foot per mile, this puts the lower end of the dike at the elevation 1055.5 G.S.C. and the elevation at the N.C.P.C. power station at 1056.6. As for the upper end of the dike, no elevation of high water on the Klondike along the south end of town has been taken in relation to the gauge height and therefore, only assumptions can be made. It seems that the actual grade of the dike can be kept. That will raise the upper end of the dike to an elevation of 1058.2 G.S.C.

Because of a possibility of misinterpretation of the term "100 year average return period" it should be stressed that it only means that the probability of exceeding the value within a year is 1% or, that, in a very long run, the event should come back an average of once every 100 years. A curve of the probability of not exceeding a given average return period during a certain number of years is drawn (Fig. 37). It shows that for a 100 year average return period design, the probability of the dike being overtopped is 26% withing the next 30 years, 36% within the next 50 years, and 60% within the next 100 years.

In case an increased safety is needed (200 year return period), an additional 1 foot raise of the dike is required. In such a case the total raise of the dike would be 4 feet above its present elevation.

II.4 ICE JAMMING PROBLEMS IN DAWSON

4.1 Location of Jams on the Yukon River

Fig. 38 shows the most common locations of the jams on the Yukon River in the vicinity of Dawson.

Ice jams in general tend to form on the shallow parts of the river where the ice can freeze solid to the bottom. This makes the movement of the ice more difficult during break-up. But far worse are the jams occurring in narrow deep bends of the river where the velocity is relatively small and the ice thick.[5]

The most frequent locations of the ice jams downstream of Dawson are at Cassiar Creek, some 15 miles from town, where the river is deep and narrow, and Rotten Creek, near the town (Fig. 38) Upstream of Dawson the most common place with a long history of jams is Coffee Creek, 112 miles away. These jams were well known by the river pilots who could see the ice piled up along the shores after break-up. When the jams at Coffee Creek gave way, usually a large quantity of ice floes were brought downstream to Dawson. As a result, the ferry across the river in Dawson is put into operation only after the ice from Coffee Creek has gone by Dawson.

Although ice jams occurred years before a winter ice bridge was built across the Yukon, the presence of ice 6 to 7 feet thick at the time of break-up might increase somehow the risks of ice jams.

Due to the enormous quantity of silt brought by the White River, the thalweg from Stewart to Dawson has changed almost entirely from what it was 50 years ago.[(6)] This constant shifting of the channels makes the prediction of some of the ice jamming locations even more difficult and unreliable.

4.2 Mechanism of Break-up at Dawson

Table 3 shows the days of break-up of the Yukon

River at Dawson since 1896 and of the Klondike River since 1956. Break-ups follow the same type of pattern every year.

First, the small creeks on the hill around Dawson start to flow. This triggers the break-up of the Klondike River, usually a day or two after. Then, an average of 5 days later, the Yukon starts to break-up. This time lag between both break-ups is crucial. It can allow the formation of an ice jam at the mouth of the Klondike because the ice sheet on the Yukon prevents the downstream movement of the heavy flow of ice and water of the Klondike. Several times in the past, this situation did result in the flooding of the southern part of Dawson and in the washout and flooding of the highway along the Klondike.

4.3 Ice Jams in Dawson

By analysing the past record of gauge height and discharge measured and computed by the Water Survey of Canada, and by comparing the result with the rating curves, it has been possible to determine the time and length of ice jams on the Yukon River at Dawson. This was complemented by imformation from the Water Survey data books, by material from the archives, and by personal recollections of Dawson residents. It shows that the ice jams on the Yukon are very frequent at break-up time. Analysis of past records show that out of 27 years of records there were 17 years of ice conditions and ice jams during break-up (Table 4). These ice jams last from a few hours up to 10 days, but only a small number of the jams reach flood level.

Ice jams are divided into two categories: static and dynamic jams.(7) A static jam is caused by the accumulation of ice floes in front of a solid cover. It is stable in a static manner and produces a regular increase in water level along its path. It becomes unstable with an increase in river discharge. This is the type of jam found at the mouth of the Klondike where the floes coming down from the Klondike meet the still solid ice sheet on the Yukon River. A dynamic jam is in an unstable state. The instability may produce a movement either within the mass of accumulated floes or in the solid ice core behind the jam. In this case, the water level will tend to fluctuate behind the jam. This type of jam is more unpredictable and, therefore, difficult to compute and forecast.

4.4 Analysis of Ice Jams

All the parameters that can be measured and that are possibly related to ice jamming have been computed and analyzed. These parameters are:

1. River ice thickness prior to break-up (Table 5).
2. Water elevation at time of freeze-up, as reported in Major Deacon's Report.[22]
3. Froude number at break-up time and evolution of the Froude number during ice jamming (Table 4).
4. Total number of degree days above 32°F up to the time of break-up and up to the last day of ice jamming. Computed average degree day per day above 32°F (Table 6).

The results show that:

1. Degree days are not a significant parameter

for break-up and ice jamming forecasting

2. The hydraulic considerations seem to be the governing factor for ice break-up and jamming. An upper limit of the Froude number is found in order to start a break-up (Fig. 39). This upper limit does not seem to depend on ice thickness. The Froude number varies from 0.04 to 0.12 for an ice thickness from 2 feet to 4 feet. Another upper limit is found for the break-up of ice jams. This limit is usually higher than the one to start a break-up, with a Froude number between 0.08 and 0.12. It shows that it takes a higher Froude number to break a jam than it takes to start the river break-up. It should be noted that the ice thickness used for this analysis was measured at time ranging from March 23 in 1946, to May 1 in 1967. During the only year when two ice thickness measurements were undertaken (on March 7 and April 23 in 1969), it was found that the ice thickness varied only 0.39 feet from 2.68 to 2.29. Whithin the scope of this study, ice thickness was assumed to stay almost constant during the last two months prior to break-up and no

adjustment of the thickness with climatic conditions was undertaken. The Froude numbers were computed following the procedure outline in Appendix II.

3. Water elevation at the time of freeze-up has been plotted on Figure 40 for the years 1946 to 1973. Results show that this has very little influence on ice jamming, although there seems to be a slightly higher frequency of ice jam when water level was low at freeze-up time. In this case ice will freeze solid to the bottom in the shallow reaches of the river and cause more jams to form during spring, although this type of jam is the mildest one and causes least danger of flooding.

III MAYO

III.1 SITE CONDITION

The community of Mayo is located on the east side of the Mayo River at the confluence with the Stewart River. The townsite is located on low land in a discontinuous permafrost zone. There are two types of soil conditions in the town; in the northwest area, the subsurface is sand and gravel with a groundwater level at 10 to 12 feet below the surface. In the southeast portion of the town, the soil is clay or silt permafrost.[8]

As an emergency measure during the most recent floods, a dike was built and then raised along the endangered part of the town. (Details in Appendix III). The total length of the dike from the east end of the town along the Stewart River to the highway is 1.5 miles, including 0.4 miles along the Stewart River. The dike is in fair condition, part of it is used as a road to facilitate maintenance. Very little protection is provided for erosion control, although weed growth should give some sort of natural protection. During the floods, protection was assured by sand bagging the top and the outside parts of the dike. Photographs of the dike are shown in Figures 7 to 15.

III.2 HYDROLOGY

The Stewart River rises in the Selwyn Mountains in the eastern part of the Yukon. It follows a general westerly course for over 400 miles to reach its confluence with the Yukon River some 65 miles upstream from Dawson. The Stewart River watershed measures 12,000 square miles at Mayo and the Mayo River watershed measures almost 1,000 square miles. An artificial dam was put into operation by N.C.P.C. in 1952 just upstream of Mayo on the Mayo River, and in 1957 a second unit was opened, doubling the production capacity.

The Stewart River peak flow comes mainly from snowmelt runoff with an addition of rainfall runoff in early June. Fairly steep average river slope and the presence of frozen ground allows for a fast runoff. The peak flow from snowmelt and rainfall run-off is usually followed by one or several other peaks from rainfall later in July.

III.3 MECHANISM OF BREAK-UP AND FLOOD AT MAYO

3.1 Break-Up

The Mayo River always breaks up first, due partly to an early release of water from the power station. There has always been a risk of ice jamming on the Mayo River since the ice is still solid at the time of the increase of water release. The break-up of the Mayo River is followed by the one on the Stewart River. There is no history of ice jams on the Stewart River in the vicinity of Mayo. Most of the past floods have come from heavy run-off, except the floods coming from the Mayo River where ice jams have occurred. A complete record of the past floods in Mayo is presented in Appendix III.

The high waters in Mayo seem to be partly explained by a special geophysical configuration:

below Mayo River there is a wide ridge 200 feet in height that crosses the Stewart Valley. The ridge is several miles in width along the river and is built of silt, sand and gravel alternating with layers of boulder-clay. A narrow depression bordered by steep banks has been cut through the ridge by the river. It acts as a control section to some extent, as the Stewart River is sluggish above the Mayo River.[9]

3.2 Frequency Analysis

From the Water Survey of Canada, 24 years of peak flow records were available. A frequency analysis for the Stewart River at Mayo has been conducted and checked with the results obtained by the Water Survey of Canada.[10] It shows (Fig. 41) that the 100 year return period flow is 155,000 C.F.S. which puts the 100 year return flood at a level of 1607.8 G.S.C. No survey of the dike elevation and grade has been taken, although from the 2 foot contour map it seems that the elevation of the dike along the Stewart River varies from 1608 to 1606 G.S.C. (Fig. 41A). A more precise survey should be done which could lead to raising the dike by approximately 1.5 feet with some freeboard allowed. Knowing the fact that for a water elevation of 1607.8 almost all the community will be flooded, special care has been taken to ensure that the dike can hold against the flood.

3.3 Land Use

After completion of the dike along the Stewart River in 1964, all the old warehouses and houses outside the dike were torn down and all the land leases along the river outside the dike were cancelled.

Since then three or four houses have been built outside the dike and a few holes have been cut through the dike to provide driveway accesses to the houses on the riverside (Fig. 16). Those gaps should be filled in order to obtain the greatest protection from the dike.

3.4 Bank Stability

Due to the location of Mayo at the outside of a very sharp bend, bank erosion has been a major problem in the past. In 1925 and 1936, parts of First Avenue were washed out during the floods. In recent times some bank erosion has occurred, particularly in the area just upstream of the seaplane base, but it is not considered to be serious.

III.4 DRAINAGE

Because of the type of soil and the lack of permafrost in the southwest part of the community, seepage through the ground tends to be more serious in the native village. Moreover, the only culvert draining the water out of the village is located in the western part of town, toward the Mayo River. (Picture of the culvert on Fig. 15.) Therefore, the water is prevented from draining out of the community except through that culvert. The culvert, about 3 feet in diameter can carry a maximum of 60 C.F.S. flowing full with a headwater of 4.5 feet. The area drained by the culvert is estimated at 0.5 square miles, and using the rational equation for a two year maximum rainfall, a culvert that can carry a minimum of 100 C.F.S. would be required. The water level upstream cannot be increased due to the flatness of the area, since any more pounding effect will flood more of the native village. It means that a 4.5 foot diameter culvert should be installed, running at full capacity with the same 4.5 foot headwater. A survey of the elevation at the base of the culvert should be undertaken in order to verify if a 4.5 foot headwater can be allowed without endangering some houses.

Flooding of minor nature occurs during the spring runoff when snowmelt from the north of the community runs into the town. The water levels in the Mayo and Stewart Rivers are too high to allow for gravity drainage. A pressure valve on the culvert prevents the water of the river from flowing back into the community. The use of pumps should help to remove the water from the low area in the western part of the town.

IV ROSS RIVER

IV.1 SITE CONDITION

The community of Ross River is located on the left bank of the Pelly River, less than a mile below the confluence of the Ross River where the Canol Highway crosses the Pelly River.

Most of the settlement is built on high ground overlooking a small arm of the Pelly River. The northern part of the community, with a low population density, is sloping down toward the Pelly River. The area of the community is of discontinuous permafrost.

The location of the community is such that no significant inundation occurred during the floods; although the entire north end was under water in 1972, including the Nursing Station with the exception of a few high spots such as the church and health center, most of the community was above water level, being built on the hill above the past flood levels. Only the general store and a few trailers are built on the flood plain, north of the community and so are very endangered by high water.

IV.2 HYDROLOGY

The Pelly River rises in the Selwyn Mountains at an elevation of about 6,500 feet and follows a 440 mile westerly course before it reaches the Yukon River near Fort Selkirk. Stream flow records of the Pelly River at Ross River are available from 1955 until now.

Study of available stream flow records shows that break-up of the Pelly River at Ross River occurs usually in the middle of May; peak flow follows one week later from snowmelt run-off, or up to 3 weeks later in case of rainfall during the recession of the snowmelt run-off. The watershed of the Pelly River at Ross River is 7,670 square miles, including the Ross River basin which is 2,800 square miles. The peak flow of both rivers occurs usually on the same day (Table 1) or sometimes the peak discharge for Ross River comes a few days after the one on the Pelly River. The run-off factor for both basins is of the same order.

IV.3 FLOOD PROBLEMS

3.1 History of Floods at Ross River

Maximum discharges for the Pelly River at Ross River have been gathered in Table 7. Since the water survey gauging station on the Pelly River at Ross River was installed in 1954, there have been records of two major floods, one in 1964, the other in 1972.

In 1964, the flood occurred on June 7 from snowmelt runoff combined with rainfall runoff. The maximum discharge was estimated at 71,000 C.F.S. and the elevation reached by the water was 2273.20 G.S.C.

The 1972 flood with an instantaneous peak flow of 62,100 C.F.S. was caused by a very heavy snowmelt runoff due to a high depth of snow at the end of the winter combined with heavy rain in the middle of May and above average temperature at the end of May. Water reached the elevation of 2273.37 G.S.C. on June 1st. (Pictures of the flood are presented in Figures 17 to 23).

In both floods the water stayed high for a few days and in 1972 the water level during the flood was within one inch of flooding into the well supplying the Y.T.G. water system.[11] The pump house was shut down for three or four days.

3.2 Past Flood Protection

As a flood protection measure, the construction of a dike was started during the third day of the flood, which was the day the water reached its maximum level. The dike was built on the east part of the community along the arm of the Pelly River, upstream from the foot bridge to buffer the main thrust of the stream flow. (A picture of the dike in its present state is shown in Figure 22.) As the water receded, the construction was stopped at the level of the foot bridge.

No survey was undertaken, although it seems, from the 5 foot contour map, that the elevation of the top of the dike in the vicinity of the water survey station is around 2275 G.S.C. Further downstream from the bridge is an area of low land where the general store is located, as well as a few trailers. This area is completely unprotected. Moreover, a hole 60 feet wide has been opened on the lowest part of the east dike and the gravel material has been removed, leaving the most exposed part of the east side unprotected.

3.3 Frequency Analysis and Recommendation

A frequency analysis for the Pelly River at Ross River has been plotted on log probability paper (Fig 42). It shows that the 100 year return water elevation is 2276 G.S.C. On Fig. 43, the flooded parts of the settlement are shown for the elevation of 2276. Comparatively few houses will be under water for that elevation. The aerial photo 17 taken during the 1972 flood shows, by comparison, the level of the 1972 high water. It outlines very clearly that the two areas with low or no protection (hole in the middle of the east dike and north end of the community) are the most exposed to the floods. The dike, in its present condition, is of little help against high water during the floods; it only helps to divert the main flow and so reduce the velocity of the current through the flooded areas, but not the water level.

A survey of the dike elevation, along with a water surface profile during high water should be undertaken in order to assure that the slope of the top of the dike is the same as the slope of the river during high water. Some parts of the dike might need consolidation or reconstruction, in particular the 60 foot wide hole on the east side of the dike.

As for the north side of the community, houses and stores should be removed from the low area or the dike should be extended downstream at the proper elevation, taking into account the slope of the river during high water.

IV.4 CHANNEL SILTING

During the past years, the sand bars in the main channel have been shifting in such a way that the channel has become constricted and shallow. It has been necessary to extend the berm of the ferry landing on the right bank into deeper water. This action itself caused more silting and the whole process became cyclic. The left bank has been eroded just upstream of the foot bridge, undermining the Canada Water Survey gauging station.[11]

Since 1959, the Water Survey of Canada has been conducting summer stream measurements from the foot bridge for calibration purposes. From those measurements it has been possible to draw a complete picture of the evolution of the bottom of the river during the past 14 years.

The results show that:

1. Ice conditions in the winter do not change the bottom profile (Fig. 44).

2. Spring floods tend to equalize the bottom

of the river and enlarge the river width. (Fig. 45)

3. Sand deposition and bar creation happen after the floods during late summer flow and tend to divide the river into two channels separated by a sand bar in the middle. (Fig. 46)
4. The constriction of the channel is very noticeable and happens during the summer months. (Fig. 47)
5. Silting is more important in the north channel than in the south channel with the main part of the river flowing along the south side. (Fig. 47)
6. The constriction of the channel has increased faster during the past few years. (Fig. 48)

A complete study of the river behavior should be undertaken in order to find a solution for the ferry landing and crossing. Possibly the most economical solution would be to move the crossing slightly downstream where currents seem to be more uniform than in its present location. However, this solution requires more study.

V OLD CROW

V.1 SITE CONDITION

Old Crow is located on the right bank of the Porcupine River, downstream of the junction with the Old Crow River. The top of the bank is 25 feet above the normal water level of the river. The village is bordered on the south by the Porcupine River and on the north by the airstrip. The land is flat in the vicinity of the airstrip and gradually rises half a mile to the toe of low mountains.

The community is within the continuous permafrost area. Permafrost is encountered at depths from 9 to 30 inches within the village and the immediate surrounding area. The permafrost is overlain by a layer of a mixture of gravel, sand and silt, topped by approximately 6 inches of organic material.[8]

V.2 HYDROLOGY

The Porcupine River rises in the northeast part of the Yukon and flows in a general westerly course until it reaches the Yukon River in Alaska.

The watershed area of the Porcupine at Old Crow is 20,900 square miles. Streamflow records are available from 1961 to 1973. Break-up usually occurs in the middle of May (Table 8) followed approximately a week later by the break-up of the Old Crow River. The peak discharge, from snowmelt run-off, of the Porcupine River occurs normally within a week of break-up. Other peaks may occur later during the summer from rainfall run-off. Those peaks can be higher than the snowmelt run-off peak flow. This was the case in 1969 when the August 7 peak of 55,800 C.F.S. was larger than the May 27 peak of 50,400 C.F.S. It should be noted, however, that both peak values are quite low when compared with the maximum daily discharge recorded at Old Crow on June 4, 1964, with a value of 237,000 C.F.S. which was mainly due to snowmelt.

V.3 FLOOD PROBLEMS

3.1 History of Floods

The most recent flood occurred on May 18, 1973. This was the second worst flood ever recorded at Old Crow. It was due to an ice jam twenty miles downstream of the village. The water rose to within three feet of the top of the bank. Water came around the town, flooding its western and northern parts. There was up to one foot of water in some houses. Almost half of the landing strip was covered with water and therefore only small aircraft were able to land. Water elevation was recorded at 30.16 (value adjusted to the old gauge, Appendix V); the top of the bank is at an elevation of 33 feet.

The maximum discharge recorded at Old Crow was in 1964, with a value of 237,000 C.F.S., which caused a minor flood. The gauge height reached 23.84 feet. That same year the gauge was moved further back on the banks as the bank of the river was gradually cutting out.

The worst flood of memory in the village happened in the 1930's (probably 1932) with up to 4 feet of water in one house, compared with only 1½ feet during the 1973 flood. The gauge reading for 1932 was estimated at 32.26 feet. (Appendix V)

3.2 Frequency Analysis

A frequency analysis of the Porcupine River at Old Crow has been conducted using the fragmentary historical flood method already described for Dawson City.[4] It was therefore possible to extend the length of the record to 60 years, knowing that the 1932 flood was the worst ever witnessed during the period of 1913 to 1973. The return period curve is plotted (Fig. 49) using elevations on the old gauge. The 100 year return period is found to be at an elevation of 33.75 feet. Knowing that the top of the river bank is at an elevation of 33 feet, the 100 year return period flood will rise over the banks and flood most of the village.

NOTE: An attempt was made at plotting a return curve for ice conditions only. The results were inconclusive due to the lack of reliable ice elevation data at Old Crow.

3.3 Flood Protection

Ice Jam Blasting

Results of tests conducted on ice jam blasting so far have been inconclusive. The ice pack of an ice jam is usually too loose to transfer the pressure wave from the explosion. Therefore, ice jam blasting as a flood protection measure must be viewed with a very limited confidence.

Village Protection

Although no contour map of the village of Old Crow is available, from the account of the last flood it appears that no adequate permanent flood protection can be built economically around the village, due to the flatness of the area.

If the present location for the village is retained, only emergency measures can be taken.

An emergency evacuation plan of the population should be reviewed, keeping in mind that the airstrip may be of no use, and that almost the whole village would be under water for a 100 year flood. At the present time, emergency evacuation is planned to Fort McPherson via Sikorsky Helicopters stationed at Inuvik. Lack of communication seems to have been a major problem during the 1973 flood.

V.4 DRAINAGE PROBELMS AND BANK EROSION

4.1 Drainage

After the completion of the airstrip in 1970, the drainage through town was altered. Every year after snowmelt, the water sits along the runway and in the back streets. A ditch, 11 feet wide and 3 feet deep was built along the airstrip in order to increase the drainage. No survey of the grade was undertaken although its grade seems inadequate.

Moreover, there are pools of water in front of the Co-op building and in the streets around. Because of the lack of adequate disposal of garbage, every spring debris is scattered around the village. This debris was partially washed out by the 1973 flood.

This poor drainage might have some side effect on the thermal balance of the top of the bank and therefore influence the bank stability.

4.2 Bank Erosion

According to people in the village, the bank started to erode in 1945. In the last few years, bank erosion has increased to its present rate of 7 feet per year.

Many memos have been written on the bank erosion problem and recently a complete report has been published.[12] The reasons for the increase of bank erosion are a combination of the following actions:[13]

1. Ice Erosion - When the ice break-up occurs, large ice jams are created. (In spring of 1971 a Water Survey Crew witnessed an ice jam which rose 22 feet in approximately 8 hours.) This ice jamming could be contributing to the bank being cut away.
2. Water Flow Erosion - At high flows the mean velocity is in excess of 6 feet per second.

3. Thermal Erosion - The physical cutting of the bank is exposing permafrost areas which are thawing out and collapsing.

The construction of the airstrip in 1970 may also have had some effect on the bank erosion because:

1. Local drainage has been altered.
2. The high water channel on the east side of the village has been obstructed by a causeway which connects the bar with the bank and carries a road which is used to transport gravel for construction and maintenance of the landing strip. The causeway has been breached by high flows each year since construction.[12]

4.3 <u>Bank Protection</u>

Bank protection measures have been studied several times.[12][14] Results of the studies show that:

1. Existing bank erosion of the Porcupine River at the village of Old Crow can be controlled

by providing a gravel embankment and protecting it with a layer of rock riprap at an estimated cost of $140,000. This cost may be reduced if sufficient large size gravel can be located.

2. Studies to finalize the design are required. Field investigations of material sources in the vicinity of Old Crow are necessary.

3. Regardless of the decision on whether or not the bank will be protected, the following action should be taken to reduce future bank erosion:

   a. Obstruction of the high water channel upstream of Old Crow should be completely removed prior to the period of peak discharge each year. Selective removal of gravel should be carried out to encourage flow in this channel.

   b. The drainage of the area between the bank and the landing strip should be improved to minimize the disturbance to the thermal regime of the area near the bank.

   c. Future development should be controlled to retain all vegetation near the bank and to minimize further disturbance to the thermal regime of the bank and the flood plain immediately adjacent to the river and particularly downstream of the existing problem.

VI WHITEHORSE

VI.1 SITE CONDITIONS AND HYDROLOGY

The Yukon River above Whitehorse is controlled by lakes which have a strong delaying and damping action on the peak flow. Further control has been added by the construction of two dams upstream of Whitehorse.

Marsh Lake Dam was built in 1951-52 and rebuilt in 1969-70. Its main purpose now is to provide greater winter discharge for the Whitehorse Rapids hydro-electric development.

Whitehorse Rapids Power development dam was built in 1957-58 with 2 units. A third unit was installed in 1969 considerably reducing the water coming over the spillway during the winter. Prior to 1969 an average of 1000 C.F.S. was released through the spillway.

VI.2 WINTER FLOODING

Winter flooding has come with almost an annual occurance in the Whiskey Flats, Mocasin Flats and Wells subdivision areas of Whitehorse. Various records indicate that these areas have been flooded as far back as 1903. The maximum recorded flood occurred November 14, 1935, and reached the elevation of 2080.6 feet G.S.C., as measured at the White Pass Depot.

Winter flooding is due to ice jamming at the time of freeze-up. The process involves an ice accumulation formed in the river when slush or ice cakes feed an ice cover in a regular fashion for a significant length of time. The accumulation freezes on top, which gives it a high resistance to hydraulic thrust. At certain places, thick ice covers are formed by accumulation of slush and ice cakes. At other places the ice pieces accumulate underneath the solid cover to form underhanging dams and, therefore, reduce the hydraulic section which results in flooding.

The former high spilling discharge at the Whitehorse Power Dam must have produced a substantial amount of frazil ice at the beginning of the winter. Because of its properties, active frazil ice accumulates underneath the solid ice cover, increases the underhanging dam, and raises the upstream water level. Since the opening of the third unit at the dam, it seems that the risks of jams have not been reduced: a flood occurred on October 25, 1970.

A report prepared by T. Blench in 1964 states[(15)] that the 100 year flood was found to be at an elevation of 1080 feet. This frequency curve does not take into effect the influence of the various dams built on the Yukon River above Whitehorse. The report presents different solutions to improve the situation, including flow regulation, river improvement and cost of diking. All the solutions seem to be expensive in view of the limited number of people endangered by the floods and the low property value.

VII OTHER FLOODED AREAS

VII.1 TESLIN LAKE

A frequency curve has been drawn for Teslin Lake at Teslin using the measurement done by the Water Survey of Canada from 1945 to 1973. (Fig. 50) The 100 year return period for water elevation is found at 2258.7 G.S.C. The 2259 contour line has been drawn on the Teslin Map. It shows that approximately 16 buildings along the lake would be flooded for that elevation. (Fig. 51) This area should be designated as a flood zone.

VII.2 MARSH LAKE

Some cottages along the lake have been flooded in the past. The level of the lake has been raised which might effect more cottages.

VII.3 FARO

Although the town of Faro itself is built on high ground, during the 1972 flood the Indian encampment by the Pelly River bridge was flooded and washed away.[16] Altogether, 25 people were involved and had to move away.

VII.4 BEAVER CREEK

There have been reports of the river flooding private property at Beaver Creek. No further investigation has been made due to the lack of gauging stations and contour maps.

VII.5 UPPER LIARD

Flooding of the highway close to the bridge access is described in Chapter VIII.1. Some houses were involved in the 1972 flood of the Liard River. (Photograph on Fig. 27.) An attempt has been made at drawing a return period curve for the Liard River at Upper Crossing, using the measurements done by the Water Survey of Canada. The results were inconclusive due to the insufficience of data.

VII.6 COFFEE CREEK

The worst flood ever experienced at Coffee Creek happened in 1936, due to an ice jam extending from the mouth of the White River to three miles south of Coffee Creek, a distance of 35 miles. The place had to be evacuated and never was settled again.[21]

VII.7 "40 MILES"

In 1973 there was a flood at the former village of "40 Miles". Presently, nobody lives there, but it is classified as an historical site.

VIII HIGHWAY FLOODING

VIII.1 DESCRIPTION

A brief survey of some of the flooding problems related to each highway is presented in Appendix VI. Those problems can be classified under a few general types:

1. Flooding of the highways along the rivers and bridge approaches due to high water level during the spring - case of the McQuesten Bridge and the Upper Liard Bridge.
2. Flooding of highways along the rivers due to ice jammings - case of the Stewart Crossing Dawson Road in its portion along the Klondike River. (Photograph on Fig. 24.)
3. Bridges washed out by ice floes or high waters - case of the McQuesten Bridge in 1960. (Photograph on Fig. 25.) The bridge had to be replaced.
4. Undersized culverts can be plugged by gravel during the spring run-off. This happened in several places along the highways. (Photograph on Fig. 26.)

The solution has been to replace or to increase the size of the culverts; in some instances relocation of the highway has been done.

5. Icing Problems - "The icing process is the emergence of water onto an iced surface at subfreezing temperatures and subsequent freezing in consecutive layers of water." Icings are of 2 types - groundwater icing and surface water icing.

   Groundwater icing creates dangerous icing conditions on the highways. The most common solution used against icing on the highways has been to raise the grade of the highway.

   Surface water icing can plug culverts and create flooding problems. A heated culvert has been used in the City of Whitehorse with success, to prevent ice plugging of culverts.

   Most of the icing problems occur on the Dempster Highway.

   The fact that some of the highways are closed during the winter, with no maintenance work done, makes icing problems worst during the spring.

6. Bank erosions are frequent on highways along rivers. They are due to inadequate rip-rap protection and to careless river training. Bank erosions occur mainly along the Klondike Highway.

VIII.2 COMMENTS ON REMEDIAL ACTIONS

1. In the past, remedial actions have been done mainly on an emergency basis. Very little has been done preventively against ice action and flood. Some of those actions have a permanent character, when a new bridge is installed or the grade of the road is raised. In other instances only emergency measures have been taken, in cases of flooding of highways due to high water and ice jams. No permanent solutions have been applied.
2. Icing problems are sometimes difficult to solve permanently. Different solutions have been proposed[17] to fight icing.

Each location where icing occurs has to be investigated separately and each solution is unique. Techniques for coping with icings fall into two categories which are called passive methods and active methods.[17]

Passive methods do not interfere substantially with icing formation, but attempt to minimize the ill effects of the icing.

Active methods attempt to eliminate icings or at least to shift their locations to remote points where they would do no harm.

3. Bank stability and river cut-offs have been treated in the past with mixed success. The basic rules for rip-rap protection and artificial cut-off have been detailed by C.N. Williams.[18]

   Bank protection should generally be extended downstream of the zone that is to be protected.

   Cut-off has to be undertaken with extreme care. There is a delicate balance in a river between sediment load, sediment size, stream slope, and stream discharge. They are related by the Lane formula which states that sediment load times sediment size is proportional to stream slope times stream discharge. This means that if one of the parameters is changed, one or several others should change in order to create a new equilibrium. A cut-off may change drastically the slope of the channel and create an unstable situation. In order to establish a new balance there must be a change in the sediment load, therefore, erosion will occur most probably upstream of the cut-off, and sedimentation will occur downstream. Eventually, the river will reach a new equilibrium.

VIII.3 DATA COLLECTION FOR FUTURE MAINTENANCE IMPROVEMENT

In order to improve the knowledge on icing problems, a suggested scheme for a survey is presented following K. Carey recommendations.[17]

The following information should be gathered:

1. Large-scale topographic map of the icing vicinity.
2. Map of the icing, indicating rates of variation and maximum extent.
3. Geologic map and cross sections of the icing vicinity.
4. Icing level related to road elevation.
5. Log of remedial actions undertaken and its results on icing.

IX COMMENTS ON WEATHER AND GAUGING STATIONS IN RELATION WITH A FLOOD WARNING SYSTEM

IX.1 INTRODUCTION

As seen previously, floods in the Yukon are of two types:

1. Floods due to ice jamming, cause of the worst floods in Dawson and Old Crow. The difficulty of ice jam forecasting (as seen in II.4.4) will make any type of ice jam warning system illusionary at the present time.
2. Floods due to heavy runoff. A mathematical model for high water level forecast should be attempted in the future. It has been seen in II.2 that peak flow occurs from snowmelt runoff. In order to build a mathematical model for maximum discharge forecasting, more data on snow depth is needed, knowing that the significant parameter is the water equivalent of the snow on the ground prior to snowmelt and the aerial distribution of snow cover. The other useful parameters are the number of days of snowmelt which can be computed

from degree days records and other meterological records. Snow, and if possible, water equivalent of snow should be measured in the headwaters of the Pelly and Stewart Rivers watershed.

IX.2 WARNING SYSTEM

A short term warning system is investigated by analysing data of gauging stations upstream of the area to protect. Maximum discharge and days of occurance have been gathered in Table 1 for all the gauging stations of the study area.

Investigation is to be carried for the years of floods. Very high discharges occurred in 1964 and 1972 for the Yukon watershed.

1. Pelly River - Both in 1972 and 1964, the maximum flow on the Pelly River occurred at Pelly Crossing three days after it occurred at Ross River. Therefore, it took the flood wave three days to travel approximately 200 miles. Which means that

the flood wave travels at an average speed of 4 feet/second. If a new gauging station were to be installed upstream of Ross River, the most practical location, close to the highway, would be some 50 miles upstream of Ross River and, therefore, would provide a flood warning approximately half a day before it reaches the town.

2. Stewart River - The time delay between the peak flood flows of the Stewart at Mayo and of the Stewart at mouth vary between 30 hours in 1972 to 2½ days in 1964. The distance between the gauging stations is approximately 130 miles, which means that the flood wave travels at a velocity varying from 3 to 6 feet/second. No pratical location for a gauging station on the Stewart River upstream of Mayo has been found.

3. Porcupine River - As seen from Table I very little relation exists between the peak flow of the Porcupine below Bell and the Porcupine at Old Crow. In some instances peaks occur on the same day

(1972), in other instances there is a month lag between peaks (1965), which shows that both peaks do not come from the same meterological parameters. Comparison of the hydrographs of the Porcupine River below Bell River and the Porcupine at Old Crow shows that the main contribution to the peak flow at Old Crow might come from the Old Crow River. Although this would not provide an accurate flood warning system because the worst floods are due to ice jamming, it is advisable to install a recording station on the Old Crow River for a better knowledge of the river behavior in front of Old Crow.

X FLOOD EXPENDITURE AND RESTORATION COST

X.1 COST OF FLOODS

Table 9 represents the flood expenditure for the major communities of the Yukon from 1960 to 1973 as recorded by the Yukon Territory Government. It should be noted that each year's flood expenditure is listed under the following fiscal year; for example the 1972 flood is under the 1973 budget.

Since 1967, the government has started to pay indemnities to flood victims. The total amount paid out during the past five years has been $70,969.00.

The total cost of construction and maintenance of the dikes has been:

$46,000.00 for the Dawson dike
$970.00 for the Mayo dike
$15,200.00 for the Ross River dike.

X.2 COST ANALYSIS FOR DAWSON

2.1 Cost of Restoration at Dawson

At the present time there are 17 buildings classified as "historic sites". Restoration is divided into two phases:

a. Stabilization and building foundation work.

b. Restoration after 1978.

An estimated 10 to 12 million dollars will be invested into restoration within the next 10 years - the Palace Grand reconstruction itself has cost $500,000.00.

2.2 Cost Analysis for the Dike

An annual average damage cost is computed for different dike elevations based on the probability of different depth of water on top of the dike and of the cost of raising the dike.

Sum of annual costs is presented on Table 11 for different dike elevations and various interest rates. Results are plotted on Fig. 52

and show that the most economical solution is to raise the dike by 3.5 to 4.5 feet, depending on the interest rate used. This corresponds approximately to a 200 year return period elevation.

A substantial amount of money has already been invested in Dawson and much more will be in the future. This added to the high cost of indemnification paid to flood victims and the priceless cultural heritage of Dawson contribute to the fact that protection should be built for a minimum of a 100 year return period and possibly a 200 year return period or more.

X.3 OLD CROW CASE

No special compensation was given after the 1973 flood.

The cost of bank stabilization is estimated to be around $140,000.00.[12] No permanent flood control can be established at the present time.

XI RECOMMENDATIONS

XI.1 SUMMARY

An investigation on the flooding has been conducted for the communities of Dawson, Mayo, Ross River, Old Crow, Whitehorse and other areas subject to flood. Recommendations are provided for each community as well as for highway flooding and icing problems. Future studies for implementation of solutions are recommended.

XI.2 RECOMMENDATION ON THE FLOODING OF COMMUNITIES

2.1 Dawson

a. Ice Jams

They created the worst flood at Dawson. Ice jams in general tend to form on the shallow parts of the river where the ice can freeze solid to the bottom; but far worse are jams occurring in narrow deep bends of the river.

Flow records show that ice jams in Dawson are extremely frequent at break-up time. These jams last from a few hours up to 10 days, but only a small number of the jams reach flood level.

Analysis of ice jams show that the hydraulic considerations are the governing factor for spring ice behavior. Break-up not followed by ice jam as well as ice jam breaking occur for Froude numbers ranging from 0.07 to 0.12.

The winter value of the Froude number is usually lower than 0.07. No ice obstruction is found for Froude number above 0.12.

b. Dike

The dike around Dawson was found in good condition. Drainage should be improved and sewers updated.

Results of the frequency analysis show that the dike, at an elevation of 1053.6 G.S.C. at the level of Harper Street, is high enough to protect the town from a 100 year return peak discharge (H_{Max} = 1053.5 G.S.C.), but it can only offer protection against a 60 year return period ice jam.

A substantial amount of money has already been invested in the restoration of Dawson and much more will be in the future. This added to the high cost of indemnification paid to flood victims and the priceless cultural heritage of Dawson contribute to the fact that further protection is needed.

In the light of the results of the frequency analysis and cost estimate study we recommend that the dike be raised by a minimum of 3 feet. This will offer a 150 year return period flood protection and allow for 0.6 feet of freeboard. That will put the dike at Harper Street at an elevation of 1056 G.S.C. In order to keep the grade of the dike of the same order as the slope of the Yukon River during high water, the elevation at the lower end of the dike should be 1055.5 G.S.C. and the elevation at the N.C.P.C. power station at 1056.6. For the stretch along the Klondike River, the present grade of the dike can be kept, this will raise the upper end of the dike to an elevation of 1058.2 G.S.C.

In case of emergency the 200 year return period flood (1 foot above the recommended elevation) can be met with sand bags.

c. Basic Study and Data Collection

Little information on the ice behavior downstream of Dawson is known. Ice jams are best known by their flooding consequences. Because the worst floods in Dawson are due to ice jamming, no accurate flood warning system can be installed at the present time.

Assessment of the effect of the winter ice bridge across the Yukon at Dawson on the probability of ice jams has to be established.

We therefore recommend that routine reconnaissance flights be undertaken during break-up time and that detailed observations of ice behavior be done, preferably by time lapse pictures. Location of ice jam, period of occurance, ice jam behavior and evolution should be recorded.

Ice thickness measurement prior to break-up should be undertaken.

2.2 Mayo

a. Dike

Floods at Mayo have always come from heavy runoff. As an emergency measure, during the most recent floods, a dike has been built and then raised along the endangered part of town. The dike was found to be in fair condition, part of it is used as a road to facilitate dike maintenance. Very little protection is allowed against erosion along the dike, although weed growth should give some natural protection.

Results of the frequency analysis show that the 100 year flood reaches an elevation of 1607.8 G.S.C. At the present time no survey of the dike elevation and grade has been undertaken, although from the 2 foot contour map, it seems that the elevation of the dike along the Stewart River varies from 1606 to 1608 G.S.C.

Knowing that for the 100 year flood elevation of 1607.8 almost all the community will be flooded, special care should be taken to ensure that the dike can hold against the flood. Therefore, we recommend that a survey of the dike elevation and grade be undertaken, and that the dike be raised approximately 1.5 feet, to elevation 1608.

A few houses have been built recently outside the dike and, therefore, are not protected against flooding. Moreover, a few holes have been cut through the dike to provide a driveway access to those houses. These gaps should be filled in order to obtain a most complete protection from the dike.

b. Drainage

Flooding of minor nature occurs during the spring runoff when snowmelt from the north of the community runs into the town; the water levels in the Mayo and Stewart Rivers are too high to allow for gravity drainage.

Moreover, drainage in town is entirely

through one culvert located in the west part of the village. The culvert at the present time is inadequate and we recommend that a survey of the elevation at the base of the culvert be undertaken in order to determine the maximum headwater that can be allowed without endangering houses in the native village. The result of this survey will help to select a proper size for the culvert.

c. Flood Zones

Areas outside the dike should be designated as flood zones and building construction should be completly restricted.

d. Flood Warning System

On the Stewart River, up stream of Mayo, no convenient location has been found for a flood warning gauging station. (It has to be of easy access in order to give a fast answer to water level changes).

Therefore a mathematical model for high water discharge forecasting should be carried out.

For this purpose, more data on snow depth and aerial distribution of snow cover will be needed, knowing that the most significant parameter is the water equivalent of the snow on the ground prior to snowmelt. We recommend the measurement of the water equivalent of the snow on the ground prior to snowmelt at the different meteorological stations where snow depth is already measured and possibly at several locations in the headwaters of the Stewart watershed.

2.3 Ross River

a. Flood

Floods at Ross River are due to heavy runoff. The location of the cummunity is such that no significant inundation has occurred during the floods. Although the entire north end was under water with the exception of a few high spots, such as the church and the health centre, most of the community was above water level. Only the general store and a few trailers are located on the flood plain, north of the community and therefore very endangered by high water.

The result of a frequency analysis shows that the 100 year flood is at an elevation of 2276 G.S.C. at the foot bridge. Comparatively few houses will be under water at that elevation.

b. Dike

Dike construction was started during the 1972 flood as a way to buffer the main thrust of the stream flow. As the water receded, the construction was stopped at the level of the foot bridge, therefore leaving the lower part of town unprotected. No survey of the dike was undertaken, although it seems from the 5 foot contour map that the elevation of the top of the dike is in the vicinity of 2275 G.S.C.

The dike, in its present state, is of little help against high water during the floods, it only helps to divert the main flow and, therefore reduce the velocity of the current through the flooded area, but it has no effect on the water level in the north end of town.

We recommend that a study be undertaken in order to determine if the extension of the dike downstream of the foot bridge can be economical. A survey of the left bank elevation downstream of the foot bridge should be undertaken along with a river slope measurement at high water in order to assess the cost of construction of a dike against a 100 year flood.

If construction of the lower part of the dike is uneconomical, steps should be taken in order to remove the General Store, designate the area as a flood zone and restrict development.

Moreover, a survey of the elevation of the existing dike should be undertaken, along with water surface profile during high water in order to assess the efficiency of the actual dike in case of a flood. Some gaps in the dike have to be closed, namely the 60 foot wide hole on the east side of the dike.

c. Flood Warning System

The most practical location, close to the highway, for a new gauging station would be some 50 miles upstream of Ross River. It would provide flood warning of approximately 12 hours. The establishment of an automatic recording station would cost $5,000.00 with an additional $1,000.00 annual operating cost.

In addition, the mathematical model for peak discharge forecast already mentioned for Mayo could be extended to Ross River and used in order to forecast flood danger. More data on snow depth, water equivalent of snow on the ground and aerial distribution of snow cover will be needed, especially in the headwaters of the Pelly watershed.

d. Channel Silting

A complete picture of the evolution of the bottom of the river has been drawn for the past 14 years.

The most important results are:

1. Silting is more important in the north channel than in the south channel with the

main part of the river flowing along the south side.

2. The constriction of the channel has increased faster during the past few years.

We feel that a complete study of the river behavior should be undertaken in order to find a solution for the ferry landing and crossing. Possibly the most economical solution would be to move the crossing slightly downstream where velocity seems to be more uniform than in its present location. However, this solution requires more study.

2.4 Old Crow

a. Flood

The worst floods ever recorded at Old Crow were due to ice jams.

Results of the frequency analysis show that the the 100 year flood due to ice jamming or high water is found at an elevation of 33.75 feet on the old gauge. Knowing that the top of the river bank is at an elevation of 33 feet, the 100 year flood will rise over the banks and flood most of the village. Only emergency measures can be taken to protect the village, no adequate permanent flood protection can be built economically around the village due to the flatness of the area. An emergency evacuation plan of the population should be established, keeping in mind that the airstrip may be of no use.

The area of Old Crow should be designated as improper for future development and flood - proofing of the existing and new buildings should be undertaken in order to reduce damage.

b. Drainage and Bank Erosion

The construction of the airstrip in 1970 seemed to have had some effect on the bank erosion because:

1. The high water channel on the east side of the village has been obstructed by a causeway which connects the bar with the bank and

carries a road which is used to transport gravel for construction and maintenance of the landing strip. The causeway has been breached by high flows each year since construction.

2. The drainage situation, already poor, seems to have been altered even more by the construction of the airstrip. A ditch was built along the landing strip in order to increase the drainage. A survey of the grade and elevation of the ditch is recommended in order to assess its efficiency.

2.5 Other Flooded Areas

a. Whitehorse

Winter flooding has come with almost an annual occurance in the Whiskey Flats, Mocasin Flats and Wells subdivision areas of Whitehorse. The maximum recorded flood occurred on November 14, 1935, and reached the elevation of 2080.6 G.S.C., which corresponds to the 100 year flood for the area. All flood control solutions seem to be expensive in view of the very limited number of people involved. These areas should be designated as flood zones and development should be restricted.

b. Teslin Lake

The 100 year flood was computed and found at an elevation of 2258.7 G.S.C. Approximately 16 buildings along the lake would be flooded at that elevation. The area along the lake should be designated as a flood zone.

XI.3 RECOMMENDATION ON HIGHWAY FLOODING

3.1 Causes of Highway Problems

Flooding problems related to highways can be classified under a few general types:

a. Flooding of the highways along the rivers and bridge approaches due to high water level during the spring.

b. Flooding of highways along the rivers due to ice jams.

c. Bridges washed out by ice floes or high water.

d. Undersized culverts being plugged by gravel during the spring runoff in numerous places along the highways.

e. Icing problems - Ground water icing creates dangerous icing conditions on the highways. Surface water icing can plug culverts and create flooding problems.

f. Bank erosions on highways along rivers.

3.2 Comments and Recommendations

a. In the past, little has been done preventively against ice action and flood. Remedial actions have been done mainly on an emergency basis.

b. Icing problems are sometimes difficult to solve permanently so each location where icing occurs has to be investigated separately since each solution is unique.

c. Bank stability and river cut-offs have been treated in the past with mixed success. Bank protection should generally be extended downstream of the zone that is to be protected and cut-offs have to be undertaken with extreme care.

d. In order to improve the knowledge on icing problems a general inventory has to be undertaken.

e. Gauging stations on selected small streams are required in order to assess the hydrological behavior of the culverts along the highway.

APPENDIX I

Floods in Dawson City

In Dawson, floods are of two types: floods due to ice jams and floods due to heavy run-off.

Records of floods go back to the founding of the town. The first flood was recorded in 1898[19] followed by another one shortly after the turn of the century.

The first flood of real importance occurred in 1925. At that time it was considered to be the worst flood known in Dawson. The main channel of the Klondike overflowed its banks due to an ice jam on the Yukon. The water stayed high for several days and a considerable amount of debris was brought by the water from the Klondike (Dawson News and recollection of Miss Faulkner). A considerable amount of debris and mud was left after the flood. The maximum water elevation was 1049.46 G.S.C.[3]

The worst flood known in Dawson occurred in 1944 due to an ice jam 15 miles downstream of Dawson. The water came up over the high water marks of the flood of 1925 by 18 inches causing considerable property damage.[20] The Yukon River overflowed its banks, carrying packed ice and causing damage on First Avenue. This was followed by a sharp rise of the level of the Klondike River flooding the southern part of the town. The whole flood lasted four days causing much damage because it combined ice jam and heavy run-off from snowmelt on the Yukon and Klondike Rivers. As usual in the case of ice jams, the water dropped very quickly when the jam gave way. The maximum elevation reached by the water was 1052.37 G.S.C.

In 1957, the water again reached flood level due to heavy run-off in both the Klondike and Yukon Rivers (373,000 C.F.S.). Families in the south end of town had to move out but damage was partly avoided with sand bags.

In 1959, the dike around Dawson was first built at an elevation of 1050.50 G.S.C. at the level of Harper Street. The grade was approximately even, although no survey of the elevation had been undertaken.

The dike elevation chosen was supposedly 6 inches higher than the old flood marks on the White Pass Buildings and the Power Station.

A year later, in 1960, due probably to an ice jam from upstream, huge ice cakes rammed the old White Pass Dock. The water came over the dike in the southern part of town and on several places along First Street. Several parts of town were under water.

In 1964, the biggest flood from run-off happened 2 weeks after break-up with a discharge estimated at 526,000 C.F.S. and the elevation reaching 1045.45 G.S.C. Sewage backed up along the streets and poured into the low area of the city, although the dike prevented any real flooding.

In 1966, due to ice jams on the Klondike and below Moosehide on the Yukon, water came up and down very fast without warning. The power plant was flooded and the town left without water and power for a day. Ice and water poured over the dike along First Street. Some damage was done to the dike.

The water reached the elevation of 1051.87 G.S.C. According to some witnesses,[6] if the jam had lasted another four hours, the entire front street would have been demolished, including the steamer Keno and large areas of the community would have been damaged, including some historic buildings.

In 1967, the power house was moved behind the dike and in 1968, the dike was raised to its present elevation of 1053.6 G.S.C. at the level of Harper Street and 1055.2 at the upper end.

In 1972, the river was very high due to heavy run-off. Some fissures appeared on the outer edge of the road along the dike. There was no flood, but sewage backed up into basements. The maximum elevation reached was 1046.44 G.S.C. for a discharge of Q = 426,000 C.F.S. Moreover, almost every spring, during peak flow, water seeps under the dike rather than through it,[11] and often comes up through the sewers, bypassing the check valves which are inadequate. In the past the sewer outlets had to be sand bagged and it has been necessary to dump gravel into the manholes a few times.

APPENDIX II

Computation of the Froude Number during Break-up

$$F = \frac{V}{\sqrt{gH}} = \frac{Q}{W\sqrt{g}\,H^{1.5}}$$

where:

Q - discharge in C.F.S.

H - average depth of the river

W - width of the river = 1100 feet

$g = 32.2$ feet/second^2

$$F = \frac{Q}{62.42\,H^{1.5}}$$

$$\frac{Q}{6242.\,H^{1.5}}$$

The soundings done by the water survey crew during the summer at Dawson allow for the development of a relation between the water depth (H) and the gauge height (GH) assuming that a certain increase of the gauge height induces the same increase of the average depth.

The relation is found to be:

$H = GH + 14.02$

It shows that the Froude number during break-up is a function of the discharge and the gauge height.

During the free flow period of summer, discharge and gauge height are related by the rating curve, which is no longer true during a period of ice jamming.

APPENDIX III

History of Floods in Mayo

1925 - Very high water level washed out the river bank and part of First Avenue.

1936 - Stewart River overflowed its banks - the flood cut away 25 feet of bank. The church and the native village suffered most. The water was 3 feet high in the village.

1937 - Mayo River overflowed its banks, the north end of Third Avenue was under water. The Stewart River came to the level of the front road. Nothing as bad as the 1936 flood.

1957 - Because of too much water release from the newly opened second unit at the dam on the Mayo River, a flash flood occurred in the village during the winter. A dike was built along the Mayo River for further protection.

1961 - The water came in low areas by seepage and it flooded houses. The level was slightly lower than in 1957. No spilling over the dike.

1964 - The water reached flood level. The dike broke at the level of the culvert along the Mayo River and allowed water to flood parts of the town. The dike was built along the Stewart River during the flood and was raised along the Mayo River. Consolidation of the dike was done with sand bags. This flood was due to an especially high snowfall in April and May. Fig. 8 to Fig. 11 show pictures taken during the construction of the dike and pictures of the dike in its present state. Sand bagging is illustrated on Fig. 13.

1972 - Extension of the dike along the left bank of the Mayo River, upstream from the bridge crossing, after an ice jam on the Mayo River.

APPENDIX IV

Yukon River and Tributaries

From the Water Survey of Canada it was possible to obtain discharge records from the following stations:

Station n° 9AH-1	Yukon at Carmacks (Upper Yukon watershed)
Station n° 9BC-1	Pelly River at Pelly Crossing
Station n° 9CD-1	Yukon above White River
Station n° 9DD-3	Stewart River at mouth
Station n° 9EA-3	Klondike River
Station n° 9EB-1	Yukon at Dawson.

The discharge of the White River at the mouth could be computed knowing that:

$$Q_{\substack{\text{White}\\\text{River}}} = Q_{\substack{\text{Yukon at}\\\text{Dawson}}} - \left[Q_{\substack{\text{Yukon above}\\\text{White River}}} + Q_{\substack{\text{Stewart}\\\text{River}}}\right]$$

$$= (9EB\text{-}1) - \left[(9CD\text{-}1) + (9DD\text{-}3)\right]$$

	Watershed Area mi^2	% of Total Area
Q_1, Upper Yukon	33,600	33
Q_2, White River	25,000	25
Q_3, Pelly River	19,700	19.5
Q_4, Stewart River	19,700	19.5

	Watershed Area mi^2	% of Total Area
Q_5, Klondike River	3,000	3
QT, Yukon River at Dawson	101,000 mi^2	100

The daily values, $x_i = \frac{Qi}{QT}$, have been computed for each of the five watersheds for the months of May, June and July.

The coefficient of discharges per unit area has been computed:

$z_1 = x_1 / 33/100$

$z_2 = x_2 / 25/100$

$z_3 = x_3 / 19.5/100$

$z_4 = x_4 / 19.5/100$

$z_5 = x_5 / 3/100$

The results are plotted on Fig. 33 for the year 1972. They show that:

In the middle of May the contribution of the Klondike, Pelly and Stewart Rivers is very high and decreases slightly by the end of the month. This contribution stays above "average" until the beginning of July, when the response is only to rainfall.

The Upper Yukon contribution is important before break-up (winter base flow), decreases considerably after break-up and increases up to an "average" value by the middle of June.

The White River discharge starts with a sharp increase due to late snowmelt at the end of May. The discharge then becomes below "average" until a new increase in July due to glacier melting.

APPENDIX V

Flood Gauge Height at Old Crow

There is no geodetic datum at Old Crow. In July, 1972 the gauging station was relocated and a relation between the old and new gauge readings had to be found. This was done by comparing similar discharges on the respective stage discharge rating curves and thus obtaining the difference between the gauge readings.

Discharge 1973 Curve	Ga. Ht. 1973	Discharge Table No. 4	Ga. Ht. No. 4	Difference
213,000	37.2	213,000	27.6	9.6
117,000	34.5	117,000	24.9	9.6
59,000	23.5	59,000	13.9	9.6

Converting the 1973 flood gauge height back to the gauge readings prior to July 1972, gives:
39.6 feet - 9.6 feet = 27.76 feet.

Niel MacDonald claims that the flood in 1932 was up to 4 feet in his house, it was also the largest flood since his arrival in Old Crow in 1913. In 1973 the water was up to 1½ feet in his house. This indicates that the flood in 1932 had a gauge reading of $4 - 1.5 + 29.76 = 32.26$ feet.

APPENDIX VI

Highway Problems

A brief survey of some of the flooding problems related to highways is presented. This survey does not pretend to be complete; its purpose is to show the major problems along each highway.

1. Alaska Highway - The Alaska Highway was built in 1942 and has been improved since then.
    a. Upper Liard - MP 642 - In 1972 flooding of the highway and a few houses along the Upper Liard River close to the bridge crossing took place. Traffic was interrupted on the highway for 2 to 3 days.
       This type of flood has happened before. As a remedial action, the grade was raised.
    b. Burwash Creek (on northwest end of the Kluane Lake) - The culverts are plugged by gravel carried by the creeks at the end of June and during July. Nothing has been done at the present time.
    c. Beaver Creek - Beaver Creek has some highway maintenance problems.

d. Silver Creek - MP 1053 - The culverts have been plugged every year by boulders and rocks. The road will be relocated in 1974 and the crossing equipped with 2 multi-plate culverts.

e. Gordon River - MP 1152 - There has been high water at the approach of the bridge.

2. Canol Highway - The south Canol was rebuilt in 1958 and the north Canol in 1965.

   a. Rose River Crossing - In 1961 the river overtopped the highway and the road was washed out. This was due to an especially high run-off and it was considered to be a 10 year flood. Very little of the road was lost. Washout happened at numerous locations. In winter the highway is closed and therefore there is no winter maintenance.

3. Whitehorse - Keno Road

   a. MP 72 - Had some glaciation problems. The grade was raised and there has been no more problems.

   b. MP 183 - Willow Creek. In 1964 the creek took away 40 feet of road, up to 12 feet deep in some places.

      A bridge was installed, eliminating the problem.

c. MP 205 - In 1964 was washed out at Crooked Creek.

4. Stewart Crossing - Dawson Road (built in 1953) - Because of the proximity of the Klondike River, more problems have developed along this highway than along the others. A report prepared by the Northern Economic Development Branch[18] presents some of the problems.

   a. MP 29 - McQuesten Bridge - The bridge has been changed 3 times since it was first built.

      1957 - The bridge ramp was overtopped by water.

      1960 - The bridge was washed out by an ice jam.

      1961 - A new bridge was installed with a 240 foot span.

      1964 - The road was washed out.

   b. MP 63.7 - French Creek - The bridge was replaced by a culvert.

   c. MP 82.4 - Flat Creek -

      1960 - The bridge was pulled out.

      1964 - The creek flooded the highway.

d. MP 85 and MP 102 - In 1964 the road was overtopped by water due to an ice jam on the Klondike.

e. MP 120 - Serious ice jam on Klondike that flooded the road (4 feet of water for 3 days) with many wash outs along the road.

5. Dempster Highway (built in 1960) - The most significant problems encountered along the Dempster Highway are presented in the report.[18] The problems are mainly icing problems connected to highway construction on permafrost.

6. Robert Campbell Highway (built in 1960) - Past problems have been mainly icing problems, erosion problems and culvert wash outs due to inadequate sizing. No major structures have been lost.

APPENDIX VII

List of People Contacted

1. Department of Indian Affairs and Northern Development:

   Dr. A.B. Hollingshead - Controller of Water Rights

   C.N. Williams - Water Rights Engineer

   B. Lymburner - Land Administration Officer

   G. McIntyre - Flood Controller at Mayo in 1964

   A. Moffat - Indian Affairs Branch

   A. Cunningham - Indian Affairs - Vancouver

   V.P. Rolfson - Superintendent, Kluane National Park

   B. Harvey - Area Superintendent, National Historic Sites - Yukon

   J. Gould - Custodian - Historic Sites - Dawson

   T. Koscielecki - Restoration Architect - Ottawa

2. Department of Environment - Federal Government

   Water Survey of Canada:

   M. Alford - Officer in Charge - Whitehorse, Yukon

   F. Braybrooks - Vancouver

   Mr. R.E. Brawn - Vancouver

   O.L. Nagy - Vancouver

   Atmospheric Environment Service:

   H. Wahl - Whitehorse

3. Department of Public Works - Federal Government:

Y.C. Quong - Technical Service Engineer

4. Department of Local Government - Government of the Yukon Territory - Whitehorse:

W. Bilawich - Director

J. Maddison - Local Government Advisor

G. Livingston - Local Government Advisor

T. Nairn - Fire Marshall - E.M.O. Officer

5. Department of Highways and Public Works - Government of the Yukon Territory:

Chess Campion - Senior Highway Superintendent

Eugene Kotyk - Municipal Engineer

W.A. Cyr - Mechanical Superintendent

Art Christenson - Project Manager

Charlie Profeit - Dawson

Jack Fraser - Surveyor - Dawson

Ron Edzerza - Highway Maintenance - Ross River

Mr. VanBibber - Foreman - Territorial Garage - Mayo

6. Northern Canada Power Commission:

Joe Long - Assistant General Manager - Technical Services - Edmonton

Gerry Pedhora - N.C.P.C Operation - Mayo

7. Others:

Wes Williams - City Manager Engineering - Assistant

A. Miller - Assistant Commissioner

Lio Murphy - Northwest Survey - Edmonton

Major Stu Deacon - Canadian Armed Forces - Whitehorse

G.E. Cameron - Former R.C.M.P.

Miss Faulkner - Former Secretary of the Commissioner in Dawson

Brian Speirs - Provincial Archives - Whitehorse

Diane Johnston - Provincial Archives - Whitehorse

Roy Minter - Historian White Pass - Vancouver

Walter Israel - Carmacks

Tom MacGinty - Pelly Crossing

Ralph Troberg - Dawson

Mrs. Butterworth - Dawson

Joe Hanulik - Dawson

Fred Caley - Dawson

Elmat Gondron - Dawson

Alan Innes-Taylor - Former River Pilot - Whitehorse

Benny Warnsby - Former River Pilot - Dawson

Mr. Charlie - Old Crow

Peter Benjamin - R.C.M.P. - Old Crow

Edith Josie - Old Crow

Niel MacDonald - Old Crow

Bill Carsen - Ross River

Con Klippert - Mayo

Marie McDiarmid - Mayo

APPENDIX VIII

Terms of Reference

July 31, 1973.

Dr. A. B. Hollingshead, P. Eng.,
Controller of Water Rights,
Northern Natural Resources and
Environment Branch,
Indian and Northern Affairs,
Room 211, Federal Building,
WHITEHORSE, Y.T.

Dear Doctor Hollingshead:

FLOODING PROBLEMS - YUKON TERRITORY

Further to our discussion in Whitehorse on Friday, 27 July, 1973, we are pleased to submit to you the following proposal to carry out the preliminary study to identify flooding problems in the Yukon Territory.

Objectives

As stated by you in your letter of 10 July, 1973, our study would have the following objectives:

(i) Identify problem areas.

(ii) Identify the problem and its cause.

(iii) Present alternative solutions to each problem with costs and benefits (relocation, zoning, warning systems, river training, etc.).

(iv) Recommend detail studies required for implementation of the solutions and priorities.

Scope of work

We propose to carry out the following investigations to achieve the above mentioned objectives:

1. Survey of damage attributed to floods.

   1.1 Review of flooding risks in Yukon Territory:

      1.11 Investigation of damage to buildings, highways and bridges and settled areas in general.

      1.12 Assessment of flooding risks on existing and planned river crossings based on high water marks and other evidence.

      1.13 Assessment of flooding risks to existing and planned communities and villages.

   1.2 Determination of the relationship of damage to actual causes from eye witness reports, observation and from other sources:

      1.21 Overflow and icing of flat areas.

      1.22 Floods in river valleys and from ice backup.

      1.23 Direct damage from ice pile-ups and ice thrust.

      1.24 Scour and silting caused by floods, ice and existing facilities.

2. Investigation of flood causes.

   2.1 Review of flood causes which are of hydrologic character:

      2.11 Runoff from melting including ablation of ice sheets on lakes.

      2.12 Seasonal freezing of underground arteries and blockage by embankments.

      2.13 Effects of operation of control structures and plants on rivers.

2.2 Review of ice formations on rivers which are an obvious cause of many floods:

2.21 Steep water level slopes in ice covered rivers.

2.22 Floods in small creeks as caused by spring flow over frozen sills or over completely frozen creeks.

2.23 Aufeis formations in larger rivers.

2.24 Hanging ice dams in major rivers as causes of winter floods.

2.25 Ice jamming as related to causes of major floods in Yukon.

2.3 Survey of secondary damage from scour:

2.31 Increased velocity from flow under ice cover in relation to possible causes of erosion.

2.32 Effect of structures which can cause scour or other problems during break-up.

2.4 Survey of direct ice effects:

2.41 Ice pileups and mounds

2.42 If predominant, a rough assessment of the effects of freezing and thawing of permafrost.

3. A review of alternative solutions to the problems. Basically the following main schemes will be considered with indication of cost and benefit where applicable:

3.1 Relocation as a definite possibility for the many shoreline villages if safer areas are available in the vicinity.

3.2 Outline of zoning possibilities:

3.21 Zoning for settlement to define areas where building in future should be concentrated without requiring costly protection.

3.22 Zoning possibility for other uses in general outline.

3.3 The usefulness of upstream gauging stations on the river as a basis for a warning system which could be established.

3.4 River training as a means of eliminating the major causes of damage on the river.

3.5 Design and operating criteria for future engineering work to minimize future flood problems. These would specifically apply to:

3.51 River control structures and plants.

3.52 Location of buildings.

3.53 Suitability of location for highways, pipelines and bridges.

3.54 Crossing spans and clearance of sluices and bridges.

4. Recommendation of further studies and indication of priorities as related to item No. 3 above. In particular the following would be considered:

4.1 Determination of danger areas by more detailed topography and hydrography.

4.11 Detailed mapping of specific areas necessary.

4.12 River elevation measured over a number of years and correlated to findings considered relevant.

4.2 Potential uses of hydrologic studies.

4.21 Correlation for flows, ice formation and water surface related to hydrologic parameters.

4.22 Stream measurements where it is necessary to augment available hydrologic data.

4.23 To relate ice floods on large rivers to hydrology, math models would be suggested relating ice movements, accumulation and floods to flow considerations and the amount of ice formed.

4.24 Parametric correlation between flow, floods and climatic conditions to be established, from which frequency analyses can be developed.

4.25 From the correlation between flow and hydrological data, extension of findings to other areas in the Yukon, possibly covering the whole Yukon.

4.3 Studies for future planning guidelines:

4.31 Requirements of definite design criteria applicable to construction of highways, bridges and pipelines.

4.32 Requirements to ensure optimum operation of hydroelectric plant and control works on rivers for all affected parties.

4.33 Zoning requirements.

REFERENCES

1. Elmer W. Brooker & Associates Ltd. - Ground Temperature Study of Dawson - September 14, 1972
2. Yukon River Basin Report - Department of Northern Affairs and National Resources - Water Resources Branch
3. R.B. Brown - Memorandum to file - 3248 - Yukon River at Dawson - Water Survey of Canada - Vancouver - June 2, 1966
4. Hydrology Handbook - A.S.C.E. - Manual 28 - p.p. 102-104 - 1949
5. J.B. Nuttall - River Modification and Channel Improvements - Seminar on Ice Jams in Canada - Associate Committee on Geotechnical Research Technical Memorandum 107 - July, 1973
6. Alan Innes-Taylor - Account of Floods
7. B. Michel - Theory and Simulation of Ice Jams at Break-up - Seminar on Ice Jams in Canada - Associate Committee on Geotechnical Research Technical Memorandum 107 - July, 1973
8. Stanley Associate Engineering Ltd. - Quality of Life Study - September 7, 1973 - Government of the Yukon Territory
9. H.S. Bostock - p.p. 28-29 - G.S. of Canada - Memoir 284 - Yukon Territory
10. R.S. McAully - Planning and Studies Section - Magnitude of Floods - Yukon Territory - Water Survey of Canada - Vancouver - November, 1973

11. Eugene Kotyk - Internal Memorandum - Department of Highways and Public Works - Government of the Yukon Territory
- Flood Control at Dawson
- Flooding and Bank Stability at Mayo
- Flooding and Bank Stability at Ross River
- Flooding and Erosion at Old Crow

12. Dr. A.B. Hollingshead - Bank Erosion Protection on the Porcupine River at Old Crow - April, 1973

13. Cliff Williams - Bank Protection - Old Crow - March 14, 1971

14. R. Howe - River Bank Protection - Old Crow - Department of Highways and Public Works - Yukon Territorial Government - January 6, 1972

15. T. Blench and Associate Ltd. - Report to the Government of the Yukon Territory regarding Erosion and Flooding Problems on the Yukon River near Whitehorse, Yukon

16. Whitehorse Star - June 12, 1972 - p.p. 6a

17. Kelvin L. Carey - Icings Developed from Surface Water and Groundwater - CRREL - May, 1973

18. C.N. Williams - Road Embankment Protection - Klondike and Dempster Highways - Northern Economic Development Branch - Department of Indian Affairs and Northern Development - October, 1972

19. Pierre Burton - "Klondike"

20. Dawson News - Tuesday, May 9, 1944 - Yukon Archives - Whitehorse, Yukon

21. Whitehorse Star - May 15, 1936 - No. 20 - p.p. 1

22. Major Stu Deacon - Assistant to Civil Authorities
Fire and Flood in the Yukon - October 16, 1970

Fig. 1 - Flood, 1964 - Between 2nd and 1st Avenue looking south.

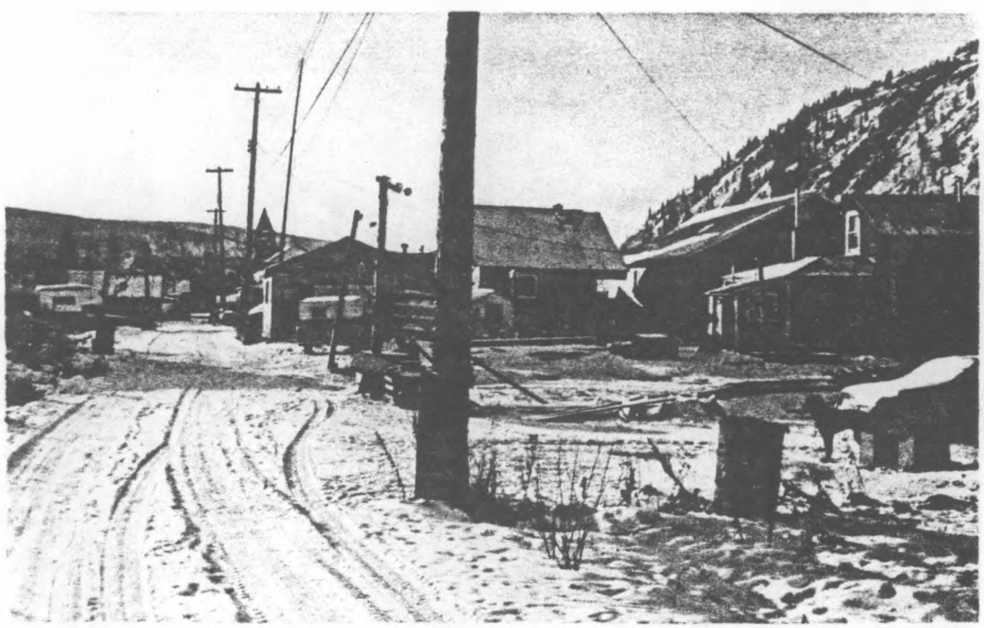


Fig. 2 - Same view - November, 1973.

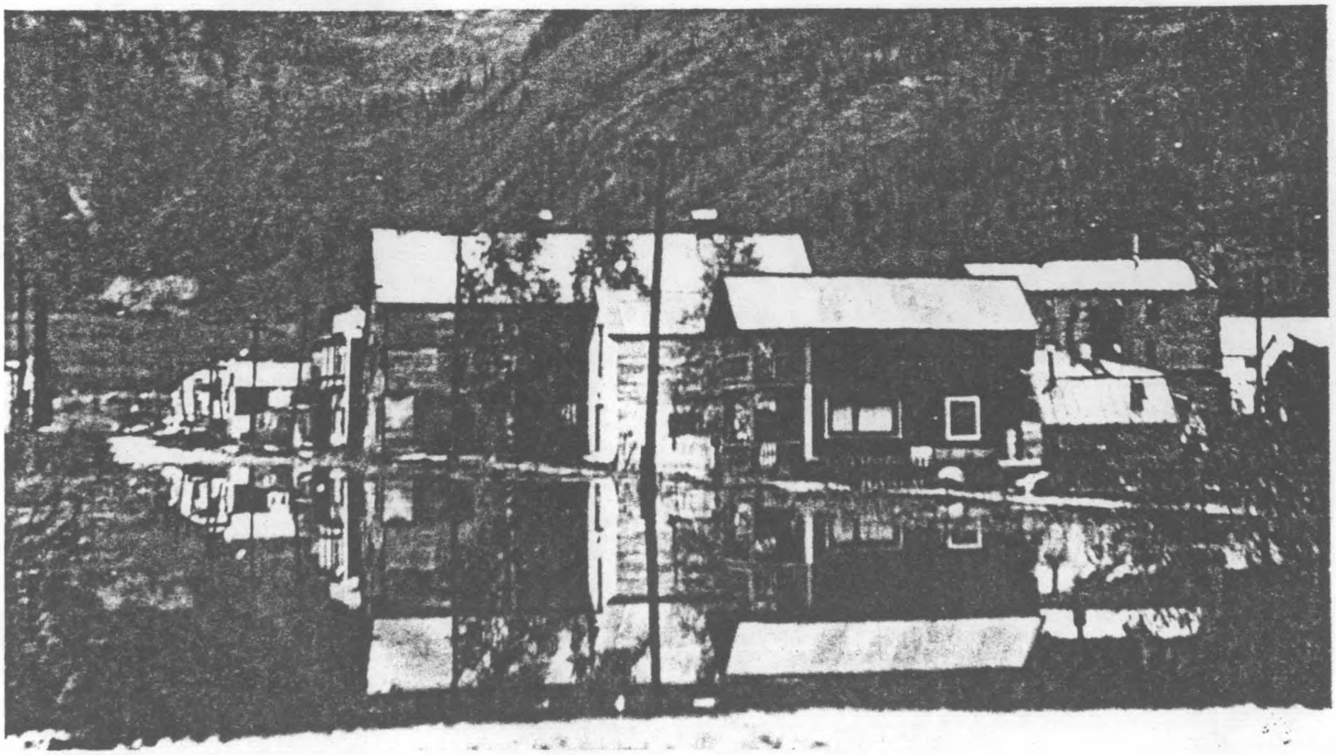


Fig. 3 - 1964 Flood - 2nd Avenue looking north.

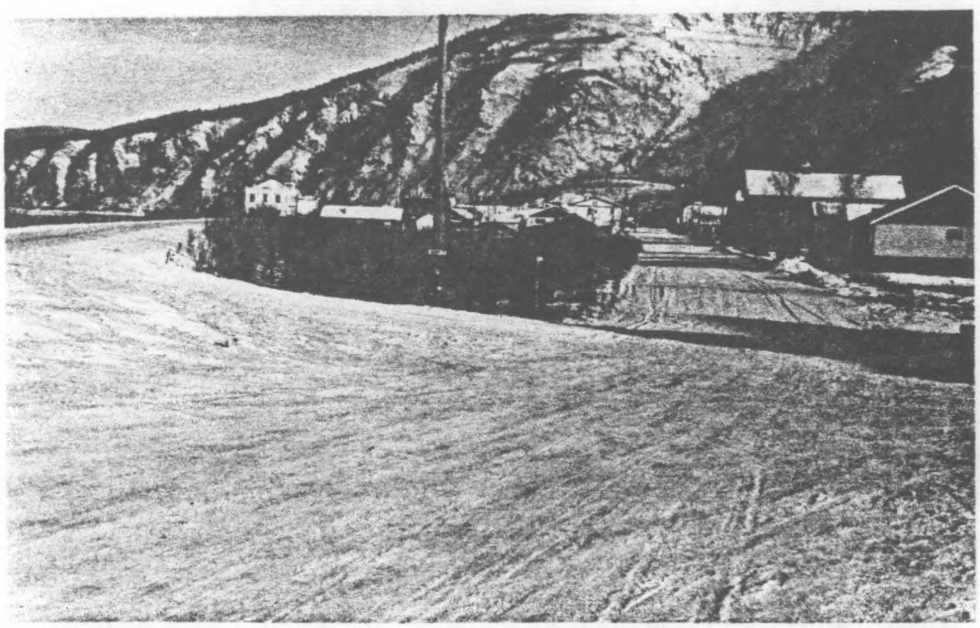


Fig. 4 - November 1973 view - 2nd Avenue with dike on the left.

Fig. 5 - Ice floes left after the 1966 Flood.

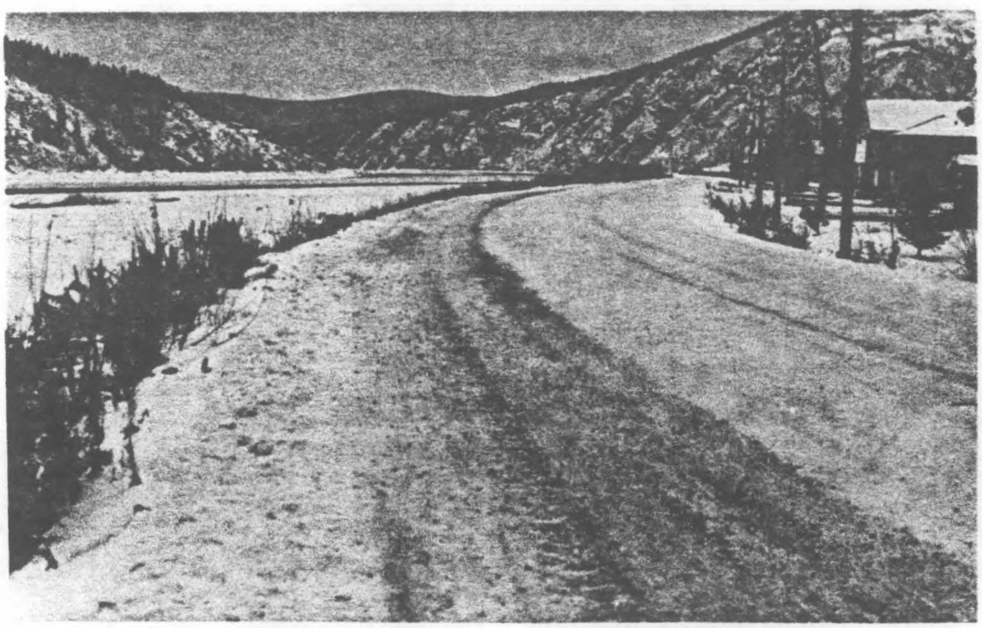


Fig. 6 - 1973 view of the dike at Dawson.

Fig. 7 - 1964 Flood - Aerial view of Mayo

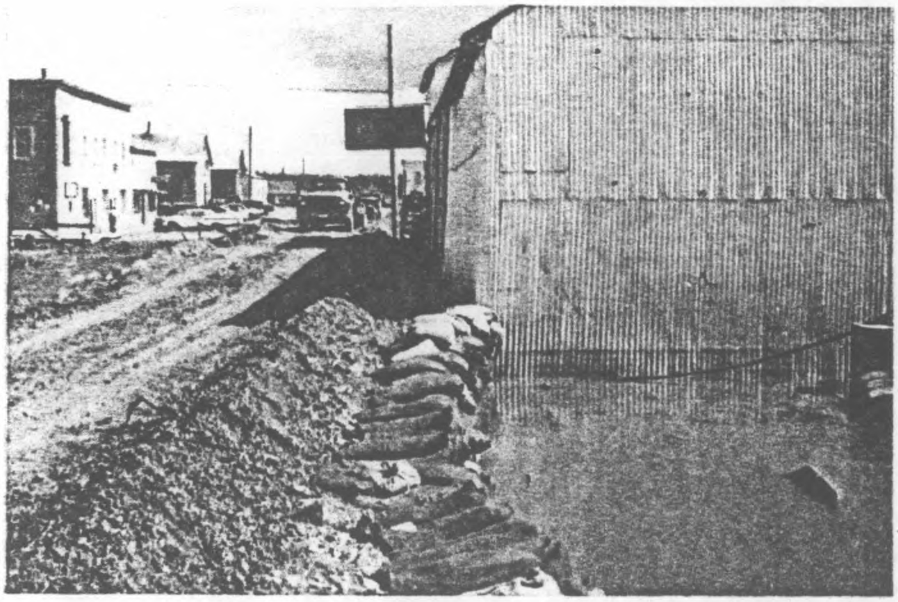


Fig. 8 - 1964 Flood Dike Construction.

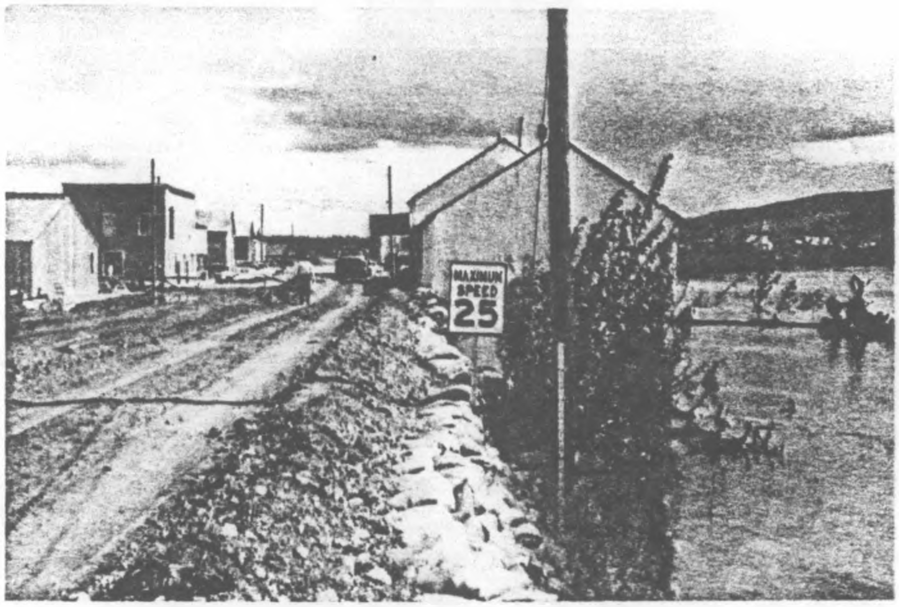


Fig. 9 - 1964 Flood Dike Construction.

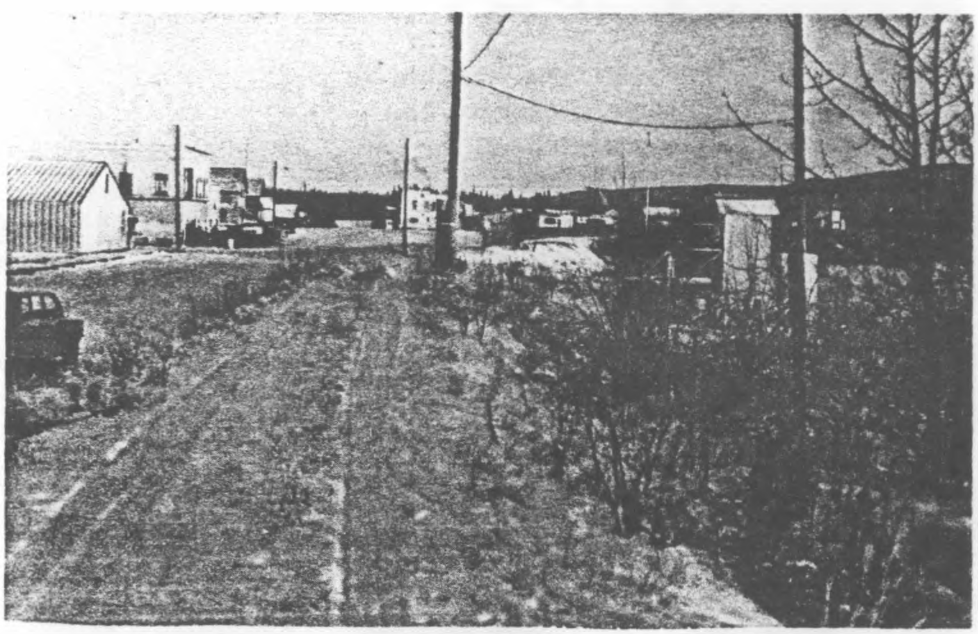


Fig. 10 - Same view 1973

Note that bldgs on right have been removed.

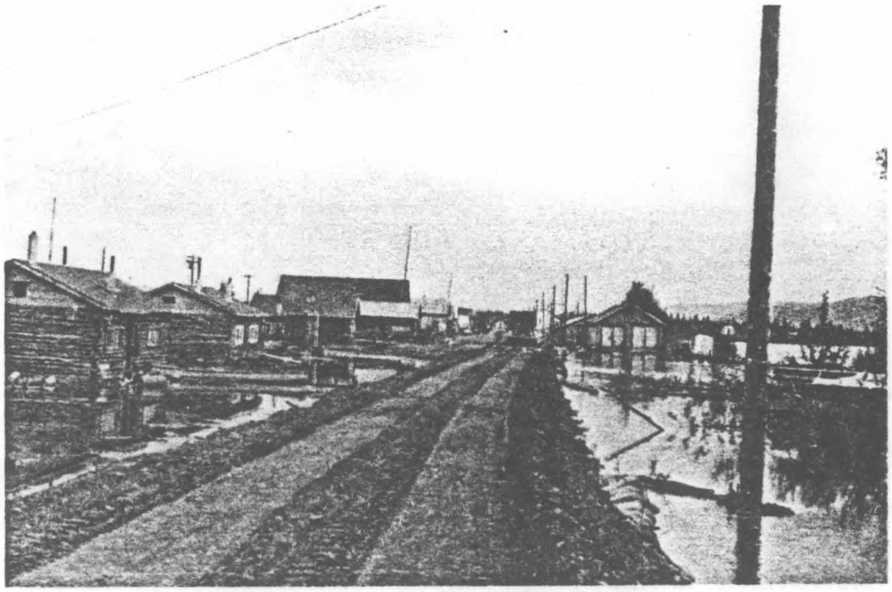


Fig. 11 - Construction of the dike during the 1964 Flood.

Fig. 12 - Dike and Native Village - November 1973.

Fig. 13 - Construction of the dike along the Mayo River 1964 Flood.

Fig. 14 - 1973 view of the dike.

Fig. 15 - Drainage culvert through dike.

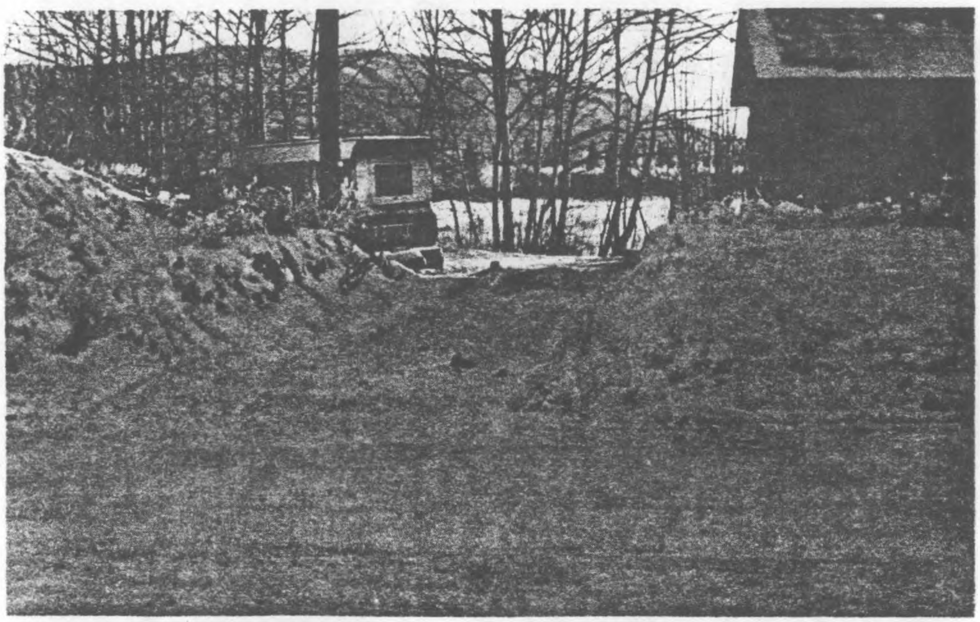
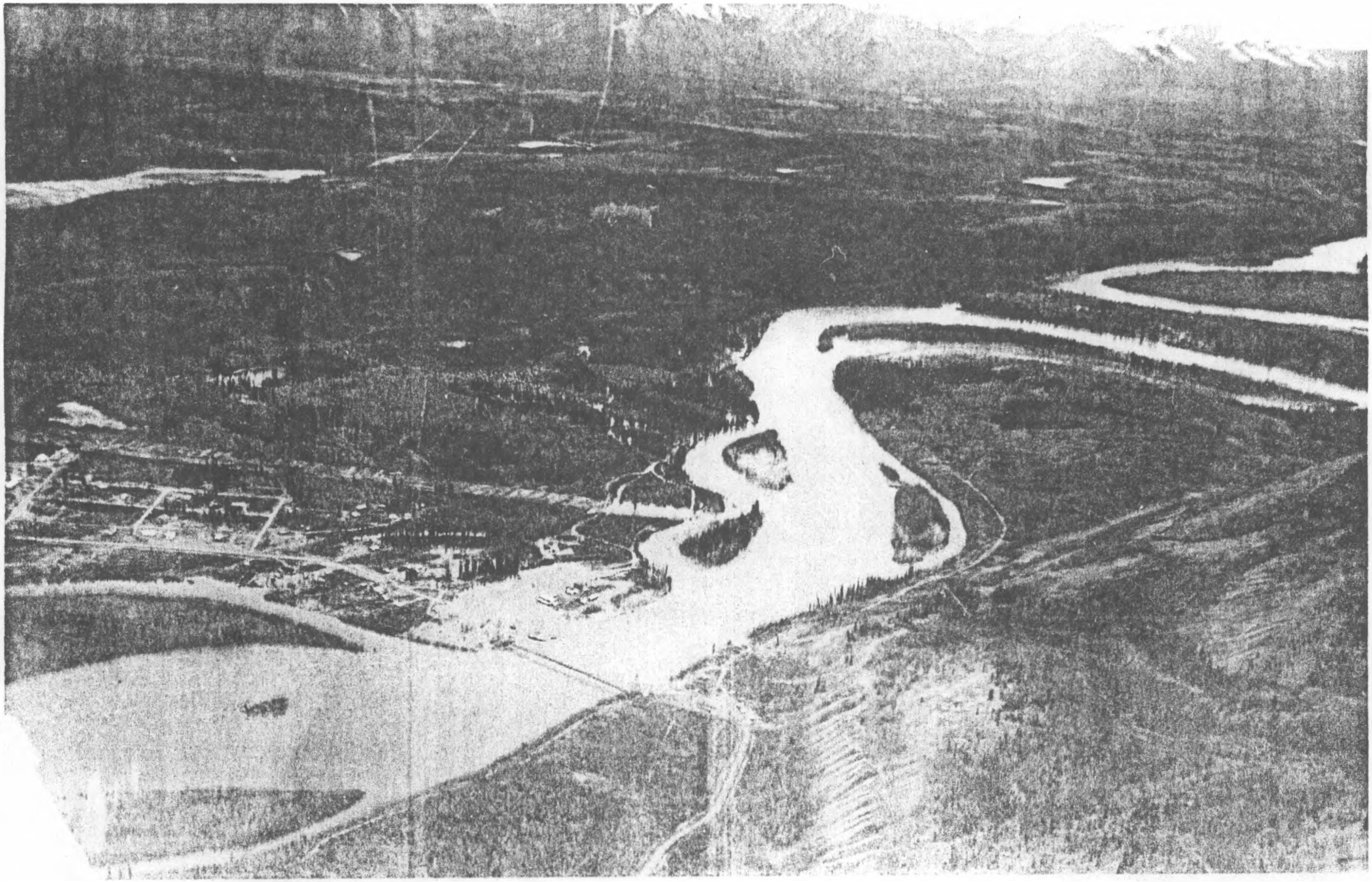


Fig. 16 - Opening through dike - November, 1973.

Fig. 17 - Ross River - 1972 Flood



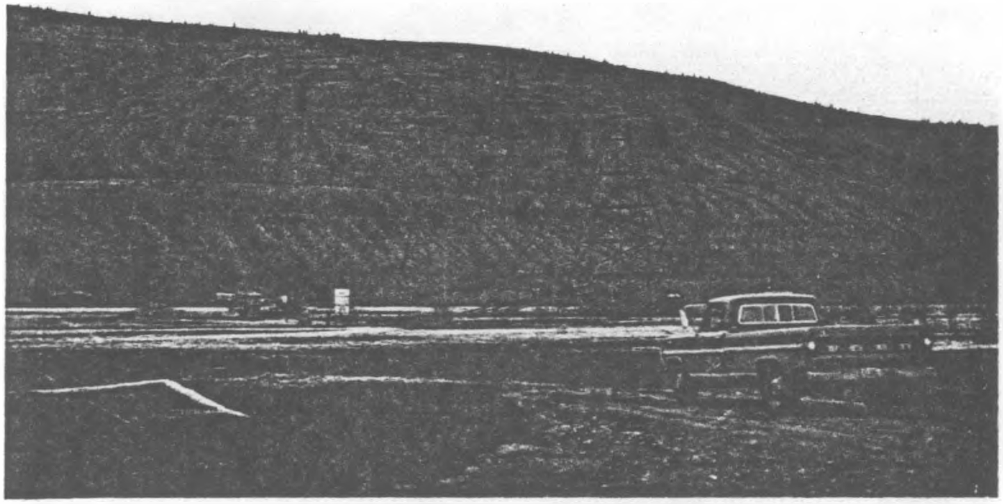


Fig. 18 - 1972 Flood - View of the foot bridge.

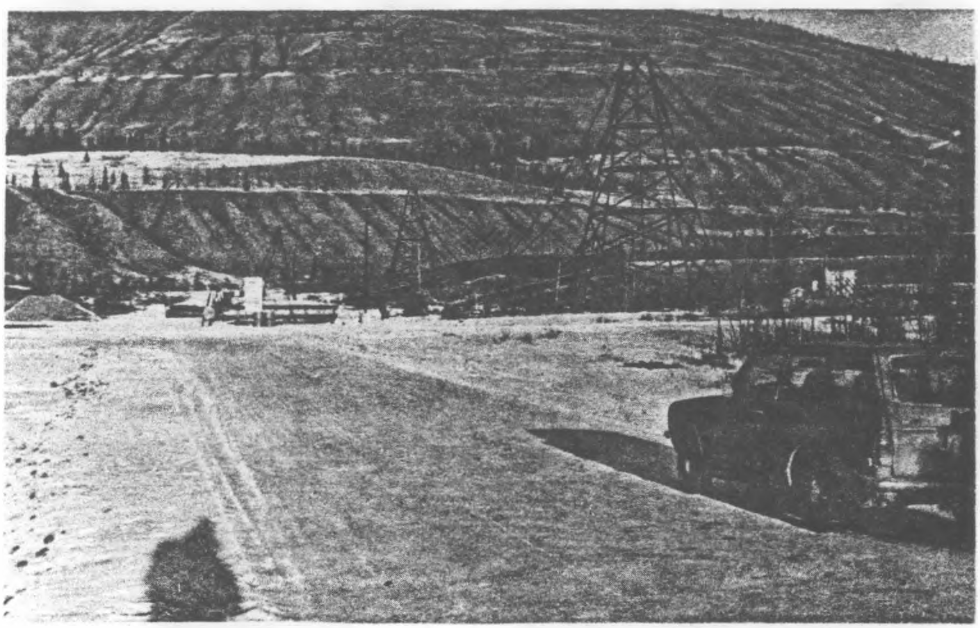


Fig. 19 - November, 1973 - Similar view.

Fig. 20 - 1972 Flood - View of the department store.

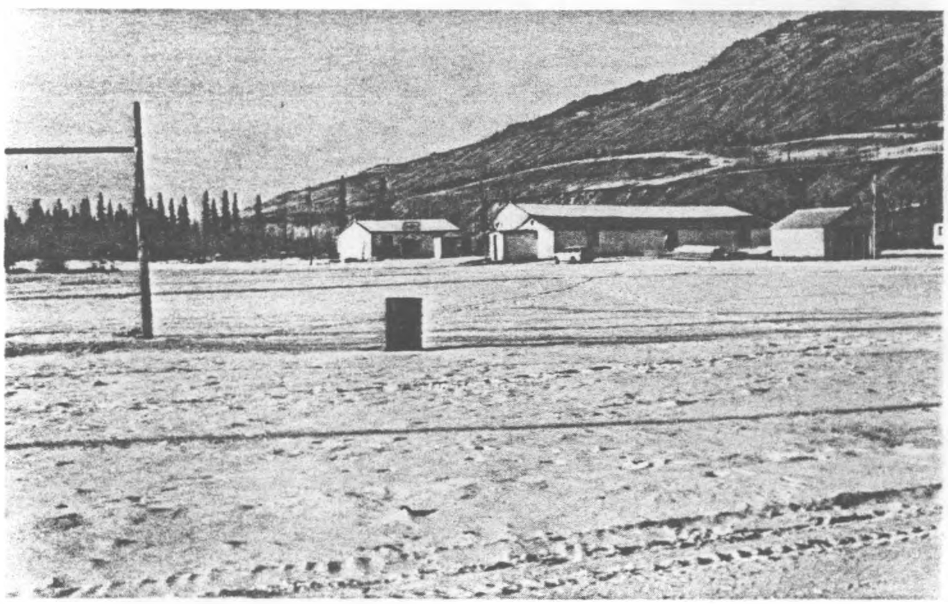


Fig. 21 - Similar view - November, 1973.

Fig. 22 - 1973 view of the dike.

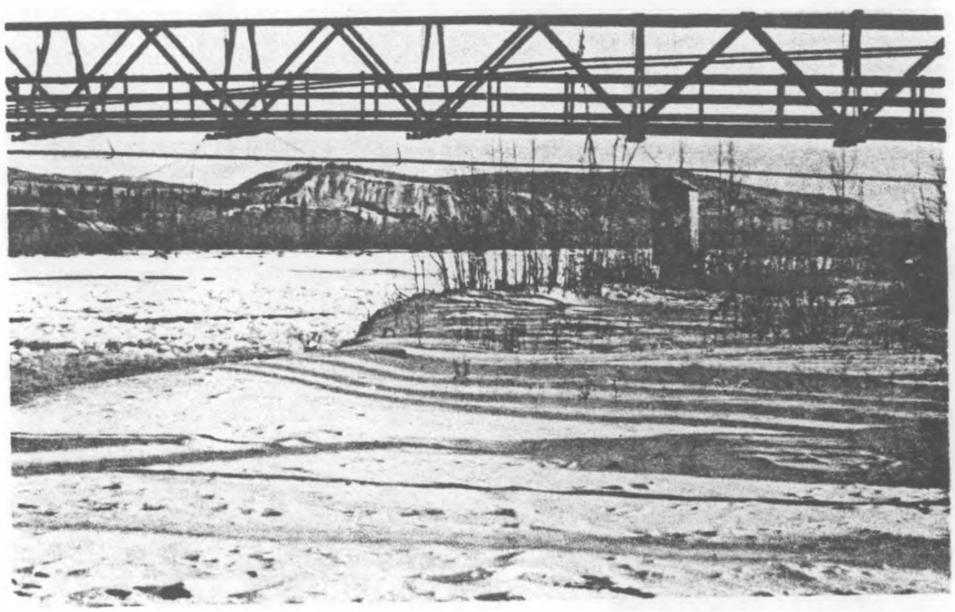


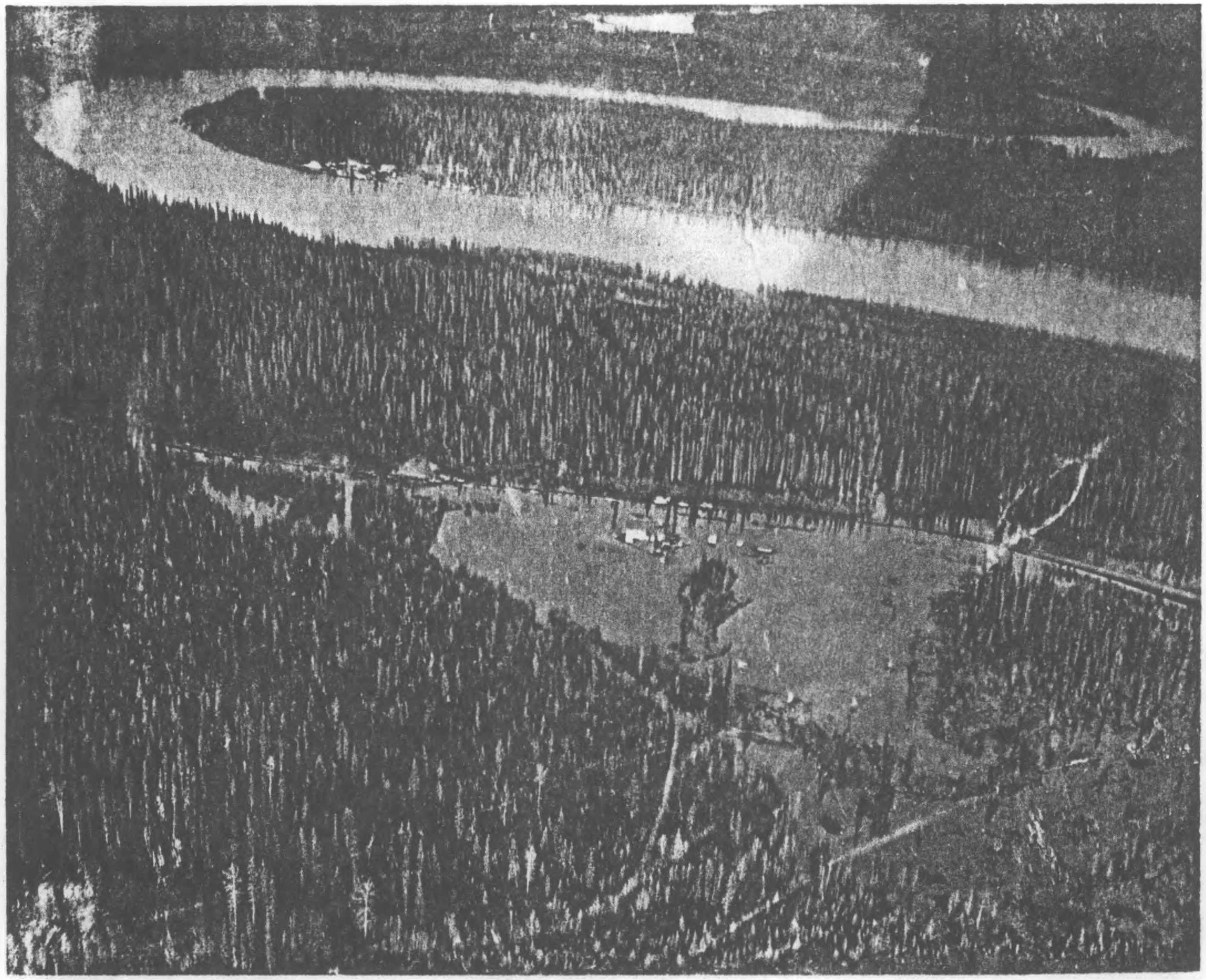
Fig. 23 - Pelly River and Water Survey Station - November, 1973.

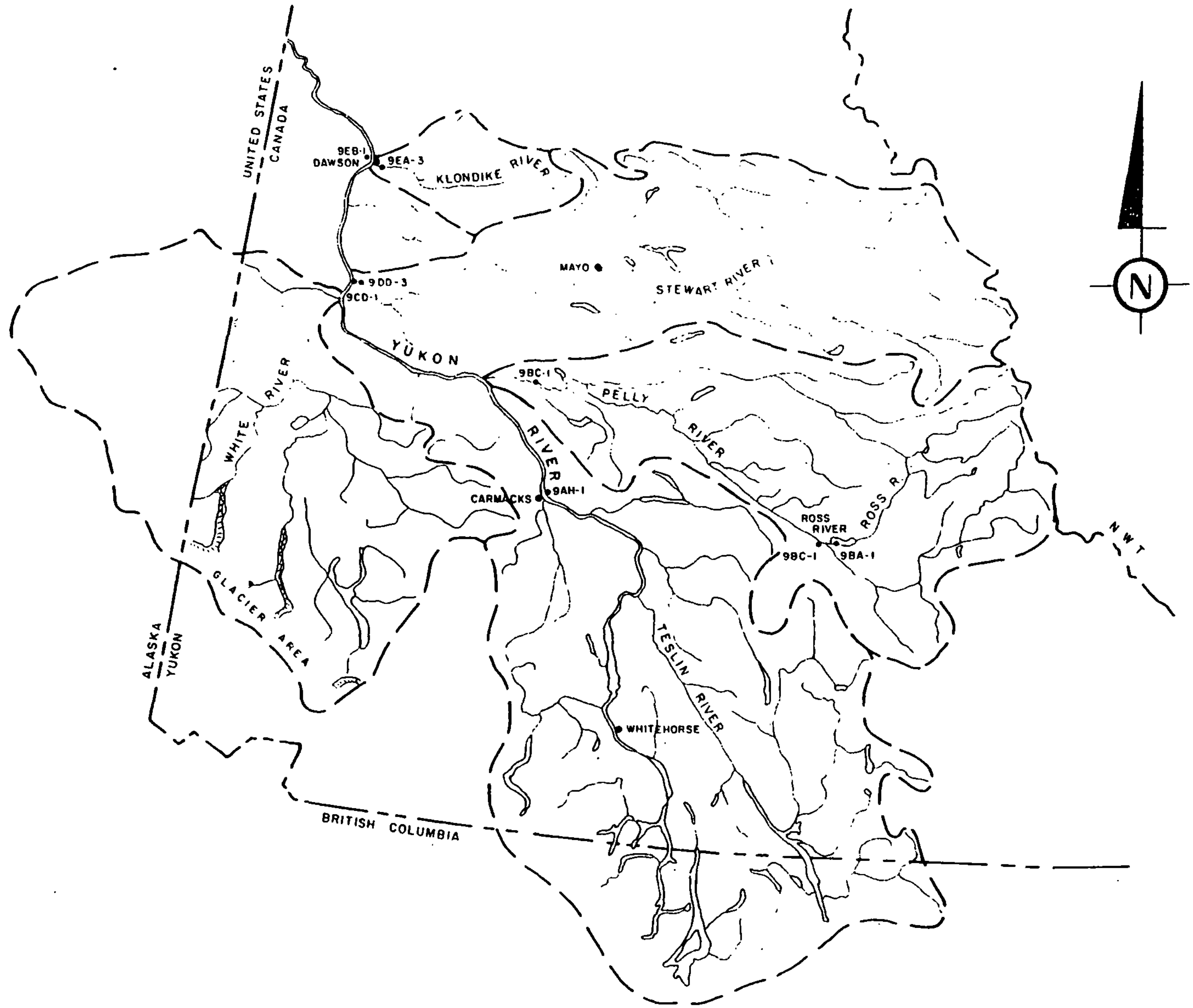
Fig. 24 -
Ice jam on
Klondike.

Fig. 25 - Flood of bridge
approach -
McQuesten River
May 23, 1957.

Fig. 26 - Culvert
plugging at Flat
French Creek.

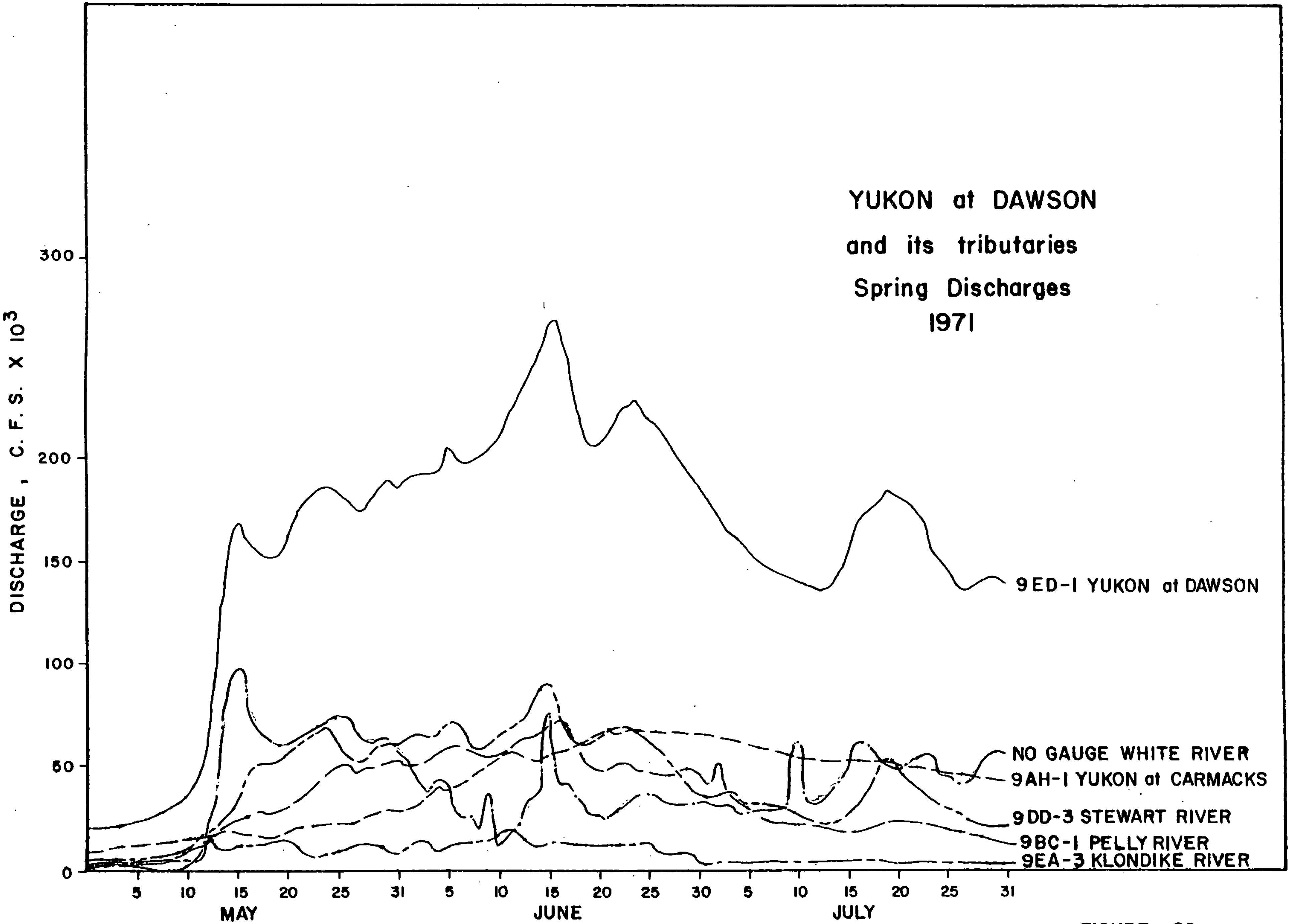
Fig. 27 - Upper Liard - 1972 Flood





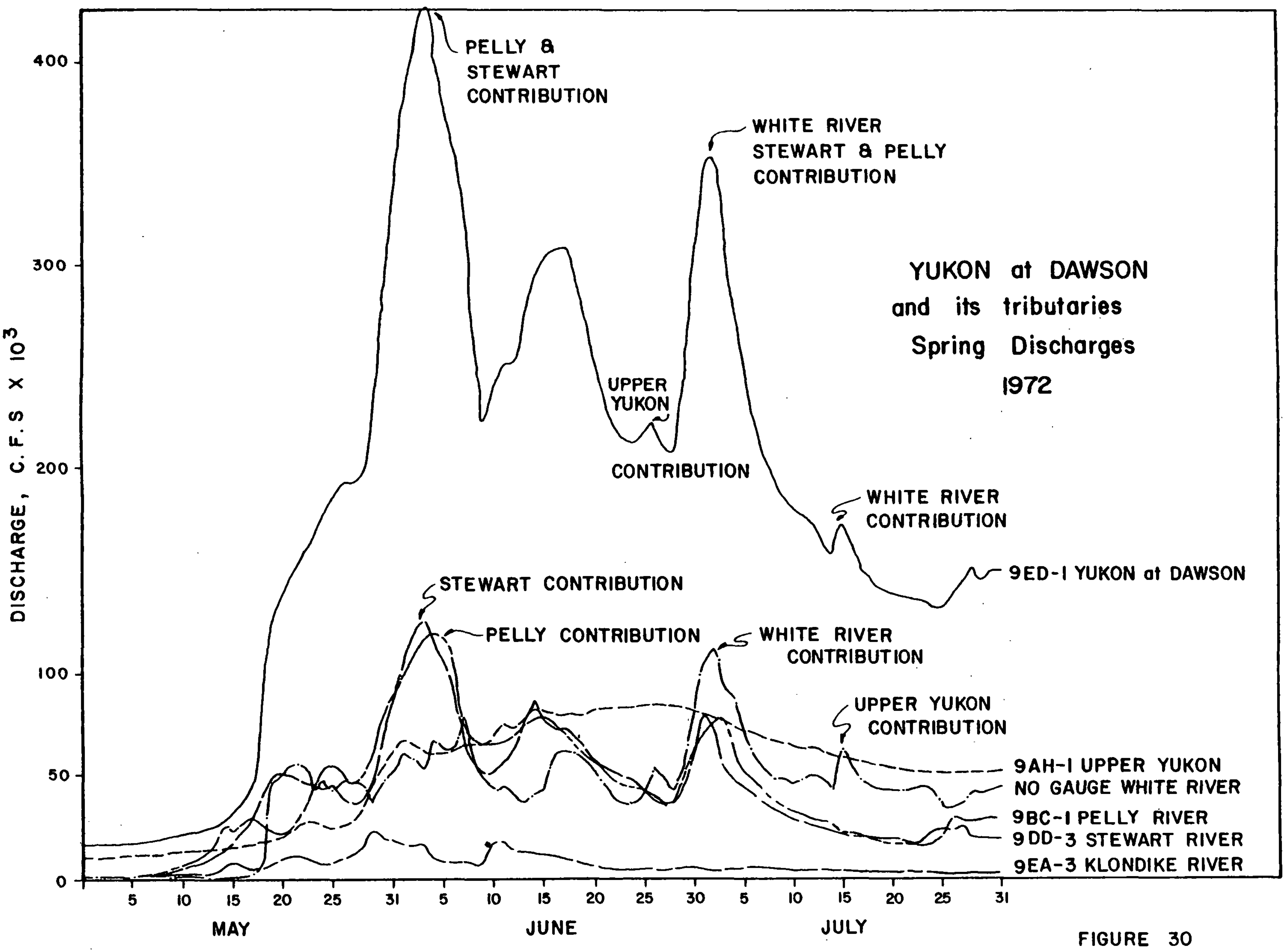
WATERSHEDS of the YUKON RIVER and TRIBUTARIES

FIGURE 28



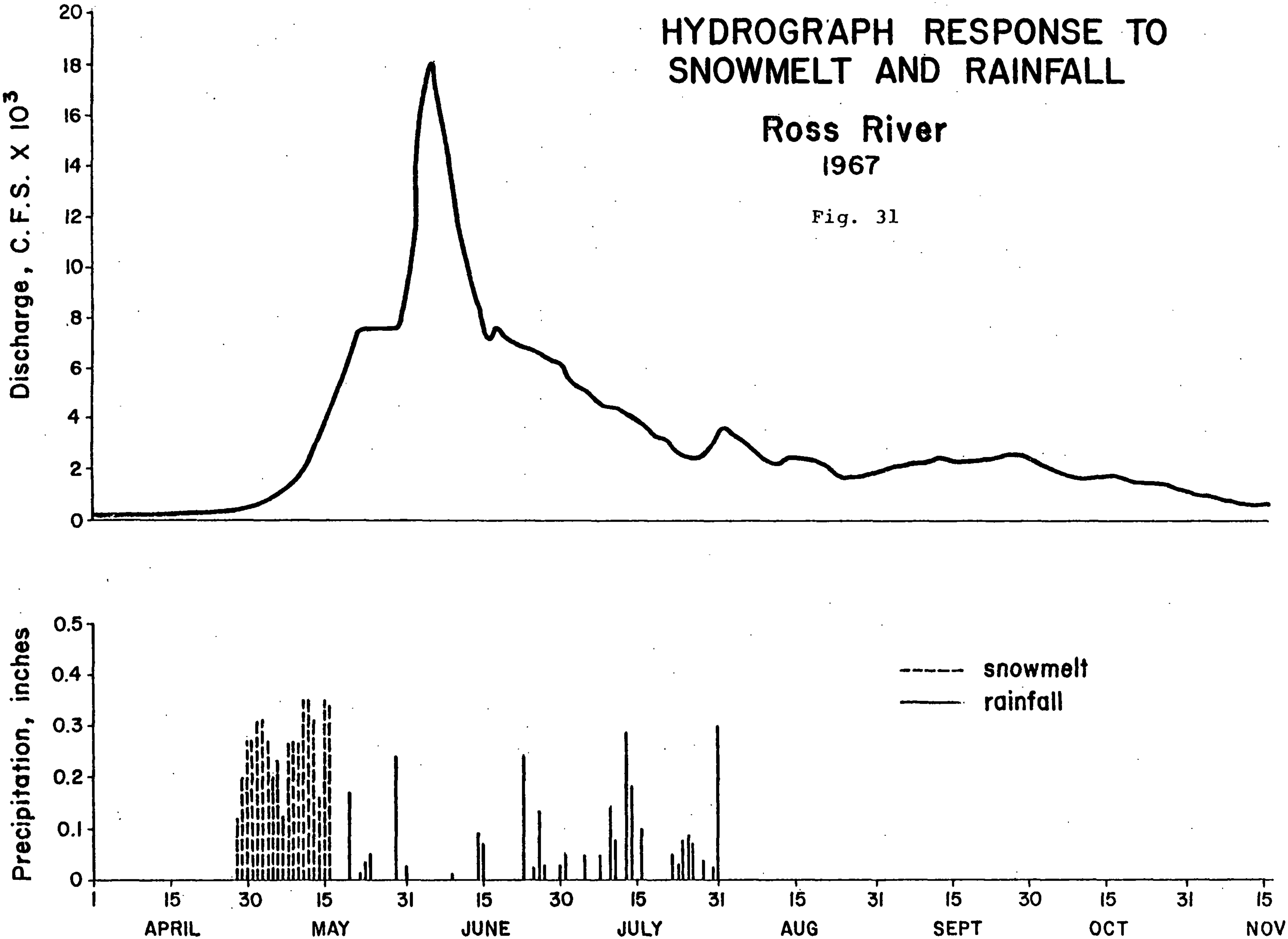
YUKON at DAWSON
and its tributaries
Spring Discharges
1971
DISCHARGE , C. F. S. X 10^3
300
200
150
100
50
0
5
10
15
20
25
31
5
10
15
20
25
30
5
10
15
20
25
31
MAY
JUNE
JULY
9 ED-1 YUKON at DAWSON
NO GAUGE WHITE RIVER
9AH-1 YUKON at CARMACKS
9 DD-3 STEWART RIVER
9BC-1 PELLY RIVER
9EA-3 KLONDIKE RIVER

FIGURE 29



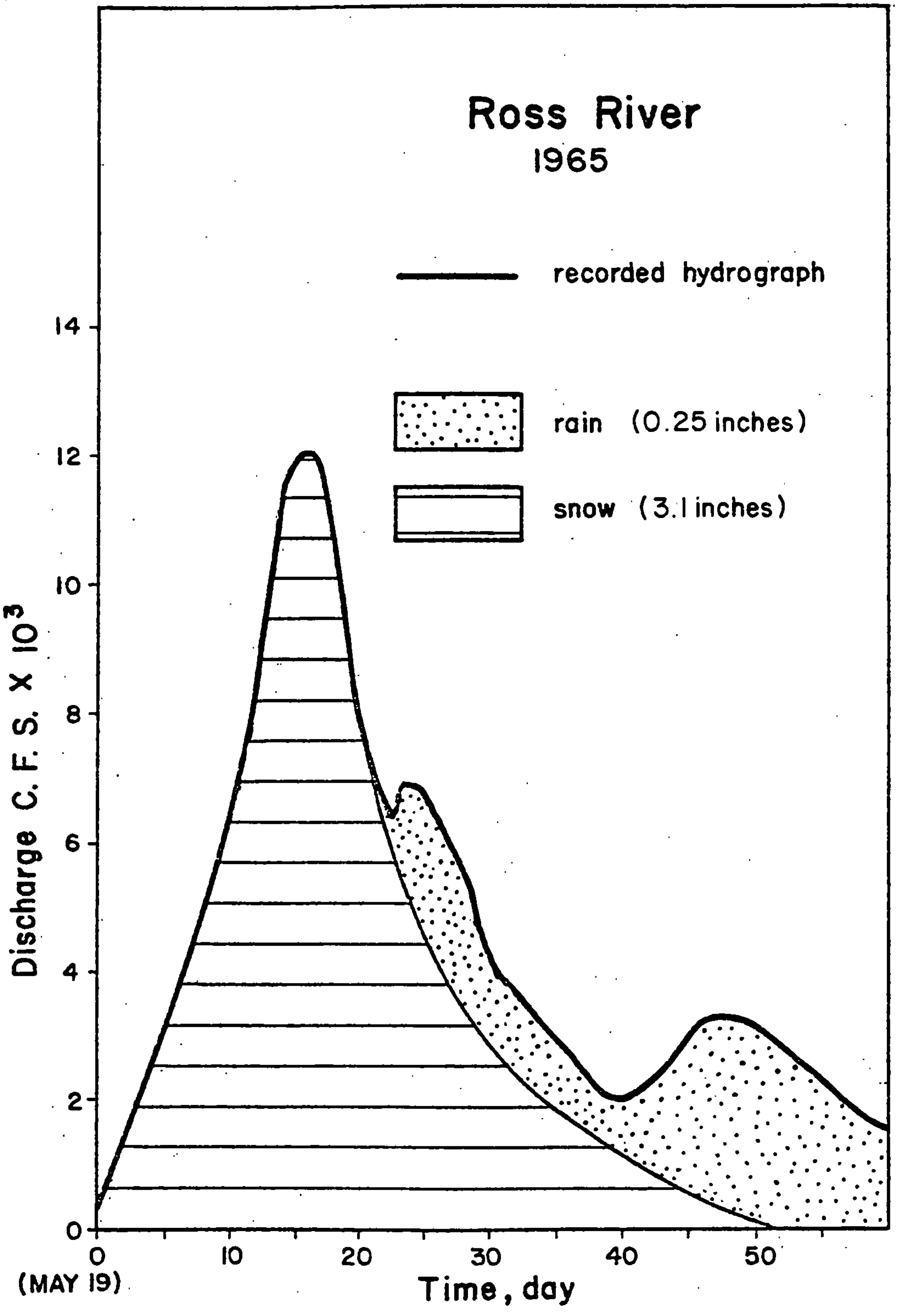
PELLY & STEWART CONTRIBUTION
WHITE RIVER STEWART & PELLY CONTRIBUTION
YUKON at DAWSON and its tributaries Spring Discharges 1972
UPPER YUKON CONTRIBUTION
WHITE RIVER CONTRIBUTION
9ED-1 YUKON at DAWSON
STEWART CONTRIBUTION
PELLY CONTRIBUTION
WHITE RIVER CONTRIBUTION
UPPER YUKON CONTRIBUTION
9AH-1 UPPER YUKON
NO GAUGE WHITE RIVER
9BC-1 PELLY RIVER
9DD-3 STEWART RIVER
9EA-3 KLONDIKE RIVER
DISCHARGE, C.F.S X 10³
0
50
100
200
300
400
5
10
15
20
25
31
MAY
JUNE
JULY

FIGURE 30



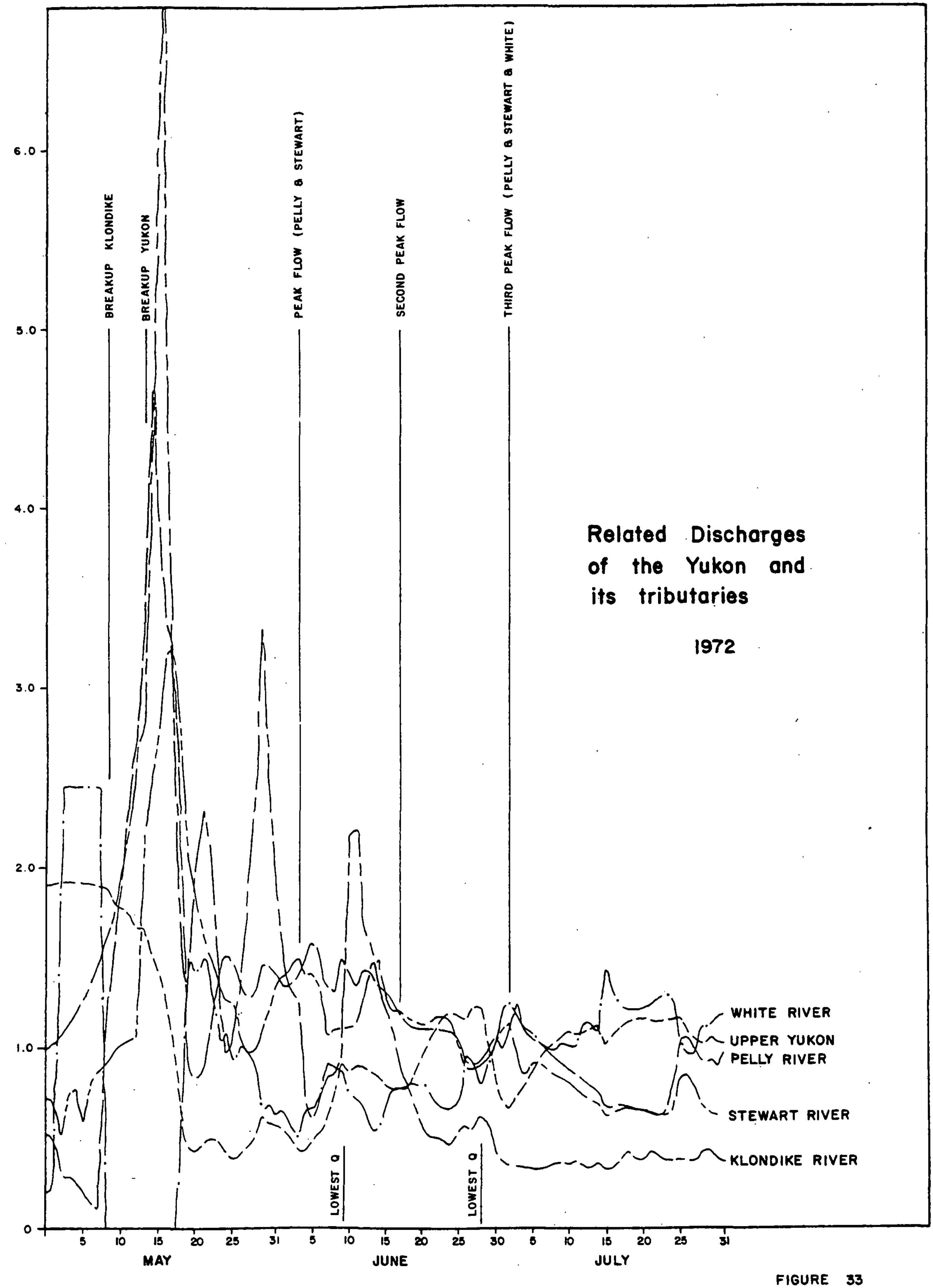
HYDROGRAPH RESPONSE TO SNOWMELT AND RAINFALL
Ross River
1967
Discharge, C.F.S. X 10³
0
2
4
6
8
10
12
14
16
18
20
Precipitation, inches
0
0.1
0.2
0.3
0.4
0.5
snowmelt
rainfall
1
15
30
15
31
15
30
15
31
15
31
15
30
15
31
15
APRIL
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV

Fig. 31



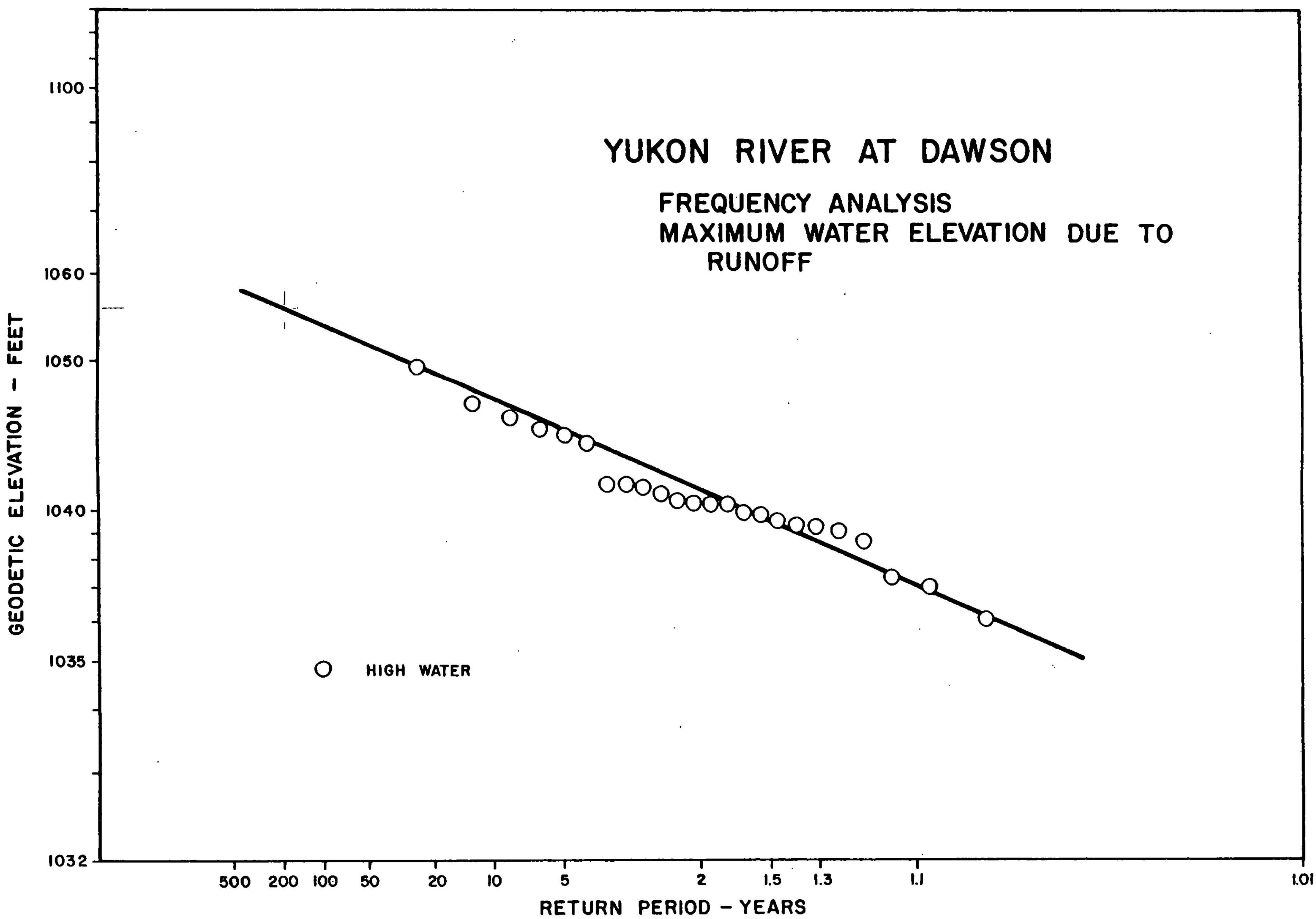
Ross River
1965
recorded hydrograph
rain (0.25 inches)
snow (3.1 inches)
Discharge C.F.S. X 10³
14
12
10
8
6
4
2
0
0
(MAY 19)
10
20
30
40
50
Time, day

Fig. 32



Related Discharges of the Yukon and its tributaries
1972
BREAKUP KLONDIKE
BREAKUP YUKON
PEAK FLOW (PELLY & STEWART)
SECOND PEAK FLOW
THIRD PEAK FLOW (PELLY & STEWART & WHITE)
LOWEST Q
LOWEST Q
WHITE RIVER
UPPER YUKON
PELLY RIVER
STEWART RIVER
KLONDIKE RIVER
6.0
5.0
4.0
3.0
2.0
1.0
0
5 10 15 20 25 31 5 10 15 20 25 30 5 10 15 20 25 31
MAY
JUNE
JULY

FIGURE 33



YUKON RIVER AT DAWSON
FREQUENCY ANALYSIS
MAXIMUM WATER ELEVATION DUE TO RUNOFF
GEODETIC ELEVATION - FEET
1100
1060
1050
1040
1035
1032
HIGH WATER
500 200 100 50 20 10 5 2 1.5 1.3 1.1 1.01
RETURN PERIOD - YEARS

Fig. 34

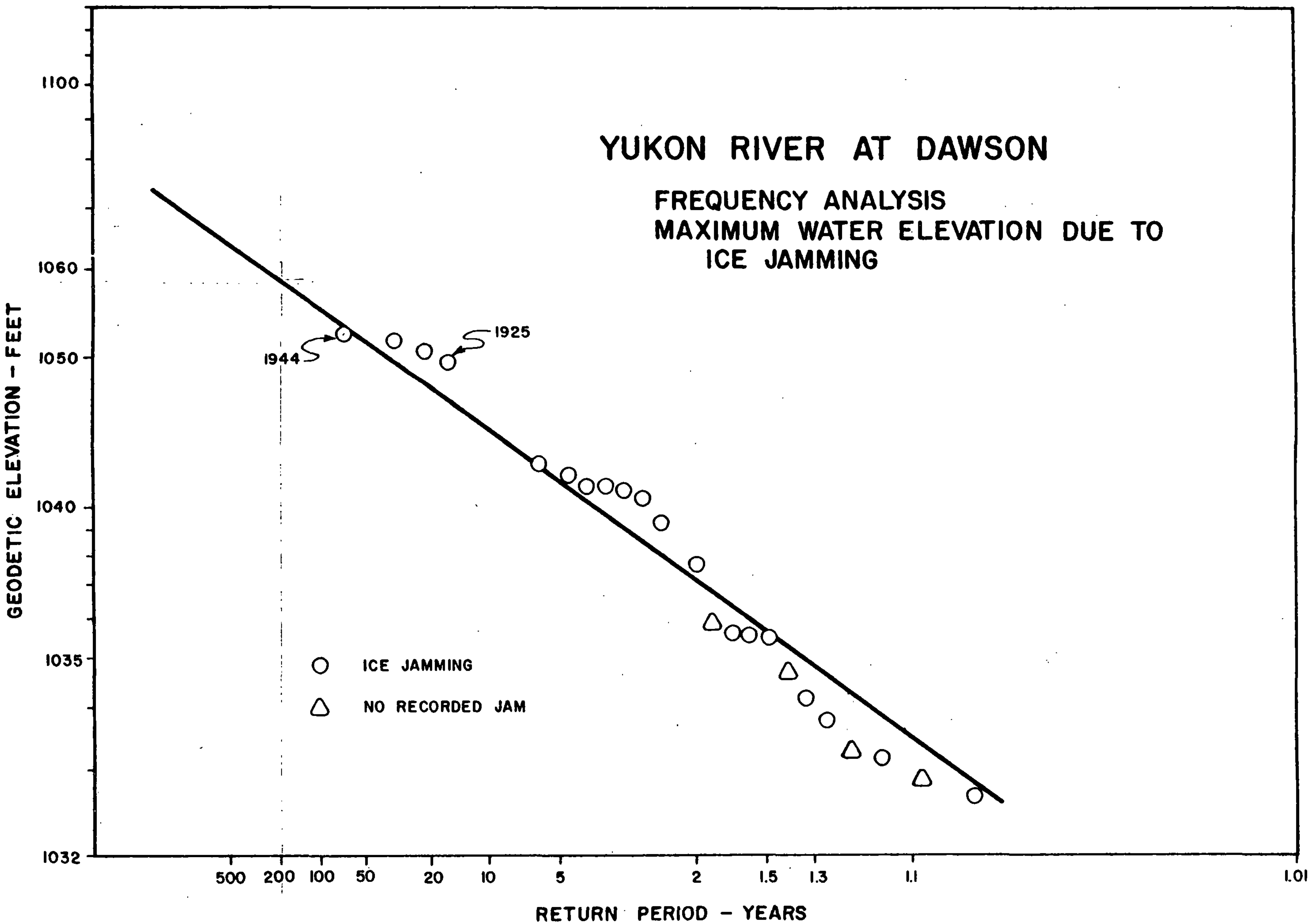
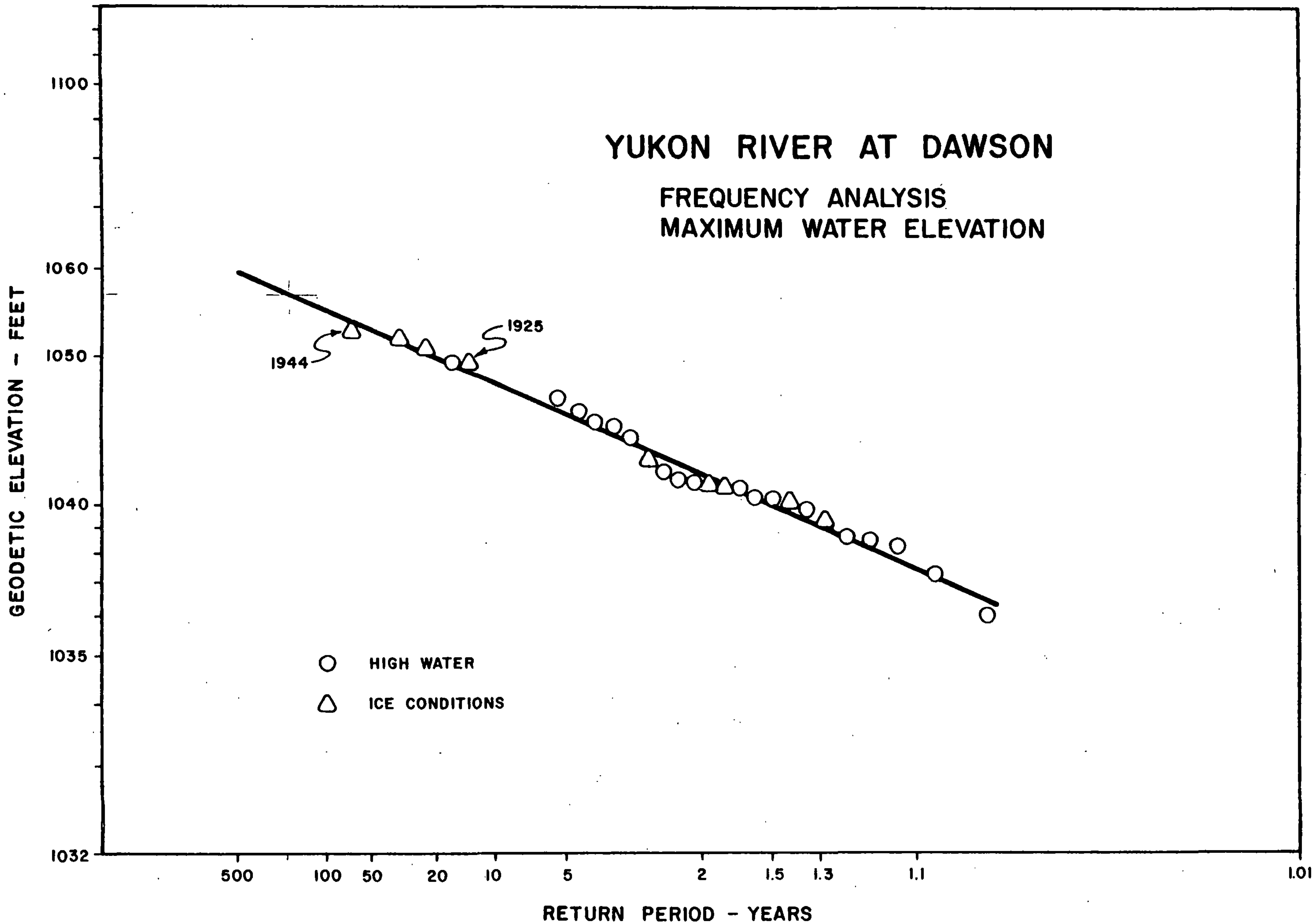

YUKON RIVER AT DAWSON
FREQUENCY ANALYSIS
MAXIMUM WATER ELEVATION DUE TO ICE JAMMING
1100
1060
1050
1040
1035
1032
GEODETIC ELEVATION - FEET
1944
1925
ICE JAMMING
NO RECORDED JAM
500
200
100
50
20
10
5
2
1.5
1.3
1.1
1.01
RETURN PERIOD - YEARS

Fig. 35



YUKON RIVER AT DAWSON
FREQUENCY ANALYSIS
MAXIMUM WATER ELEVATION
GEODETIC ELEVATION - FEET
1100
1060
1050
1040
1035
1032
1944
1925
HIGH WATER
ICE CONDITIONS
500
100
50
20
10
5
2
1.5
1.3
1.1
1.01
RETURN PERIOD - YEARS

Fig. 36

CALCULATED-RISK DIAGRAM

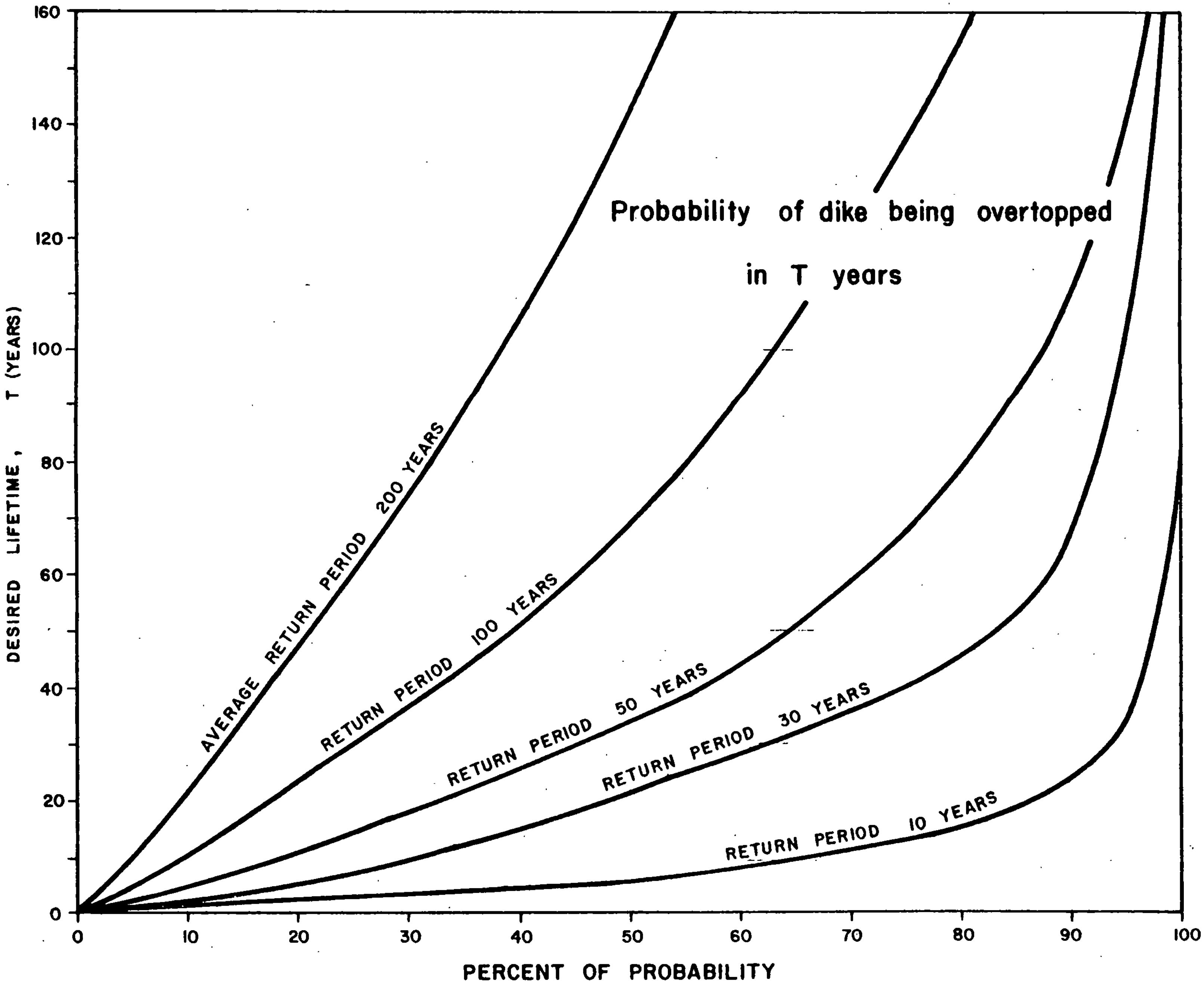


Fig. 37

YUKON RIVER NEAR DAWSON
LOCATION OF ICE JAMMING

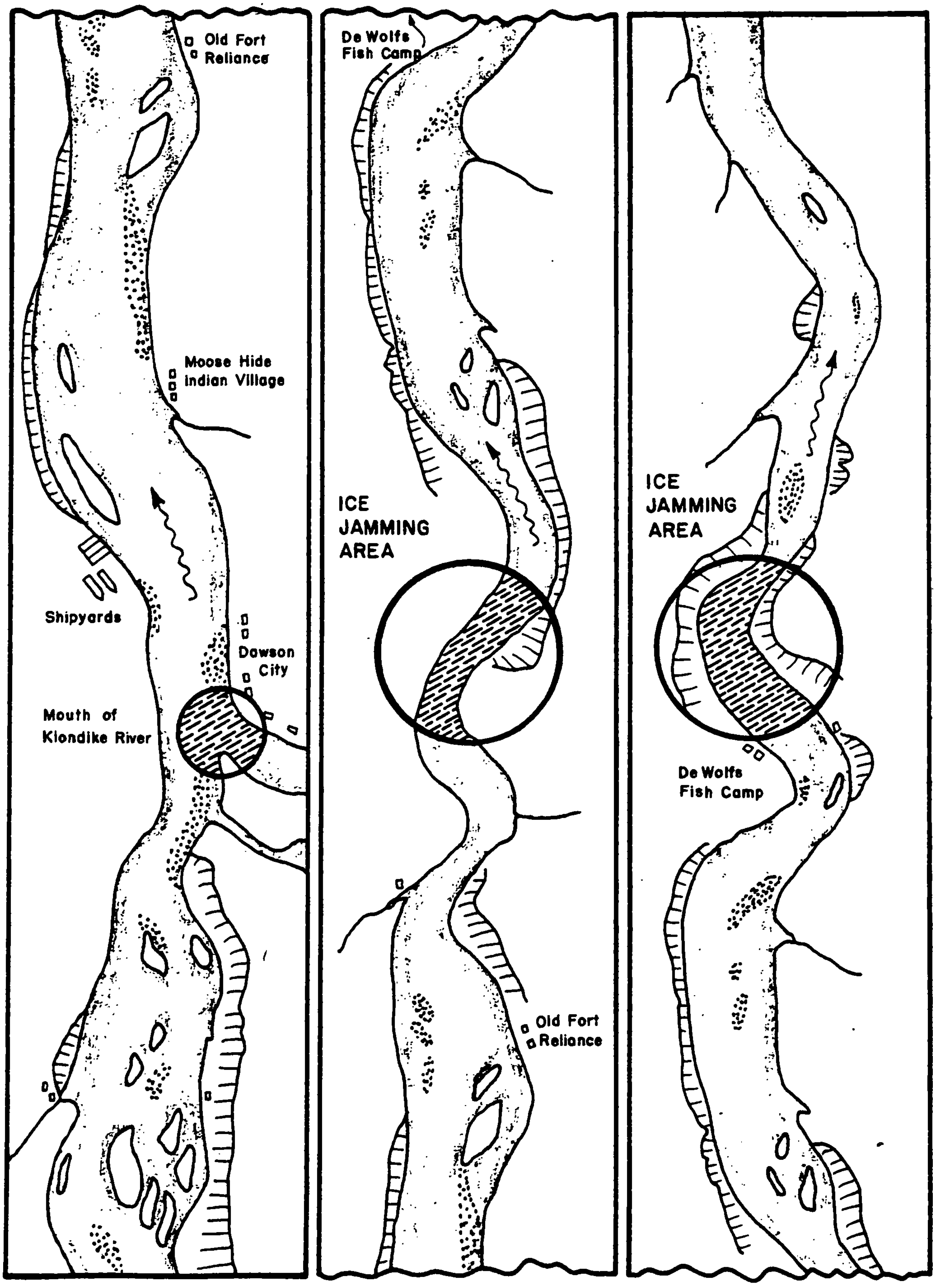


Fig. 38

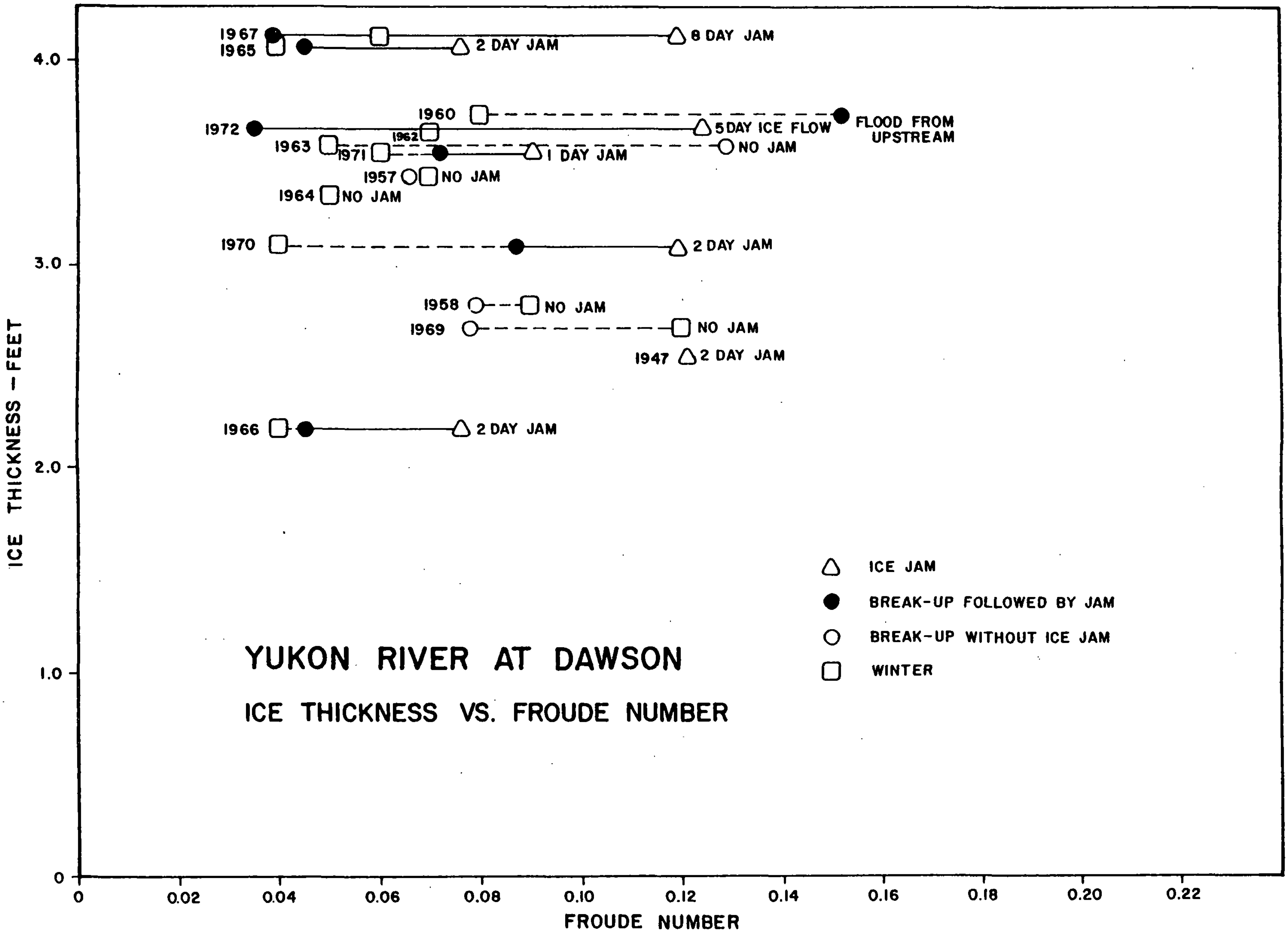

ICE THICKNESS – FEET
FROUDE NUMBER
4.0
3.0
2.0
1.0
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
0.22
1967
1965
8 DAY JAM
2 DAY JAM
1960
1972
1962
1963
1971
5 DAY ICE FLOW
FLOOD FROM UPSTREAM
NO JAM
1 DAY JAM
1957
NO JAM
1964
NO JAM
1970
2 DAY JAM
1958
NO JAM
1969
NO JAM
1947
2 DAY JAM
1966
2 DAY JAM
ICE JAM
BREAK-UP FOLLOWED BY JAM
BREAK-UP WITHOUT ICE JAM
WINTER
YUKON RIVER AT DAWSON
ICE THICKNESS VS. FROUDE NUMBER

Fig. 39

Yukon River at Dawson

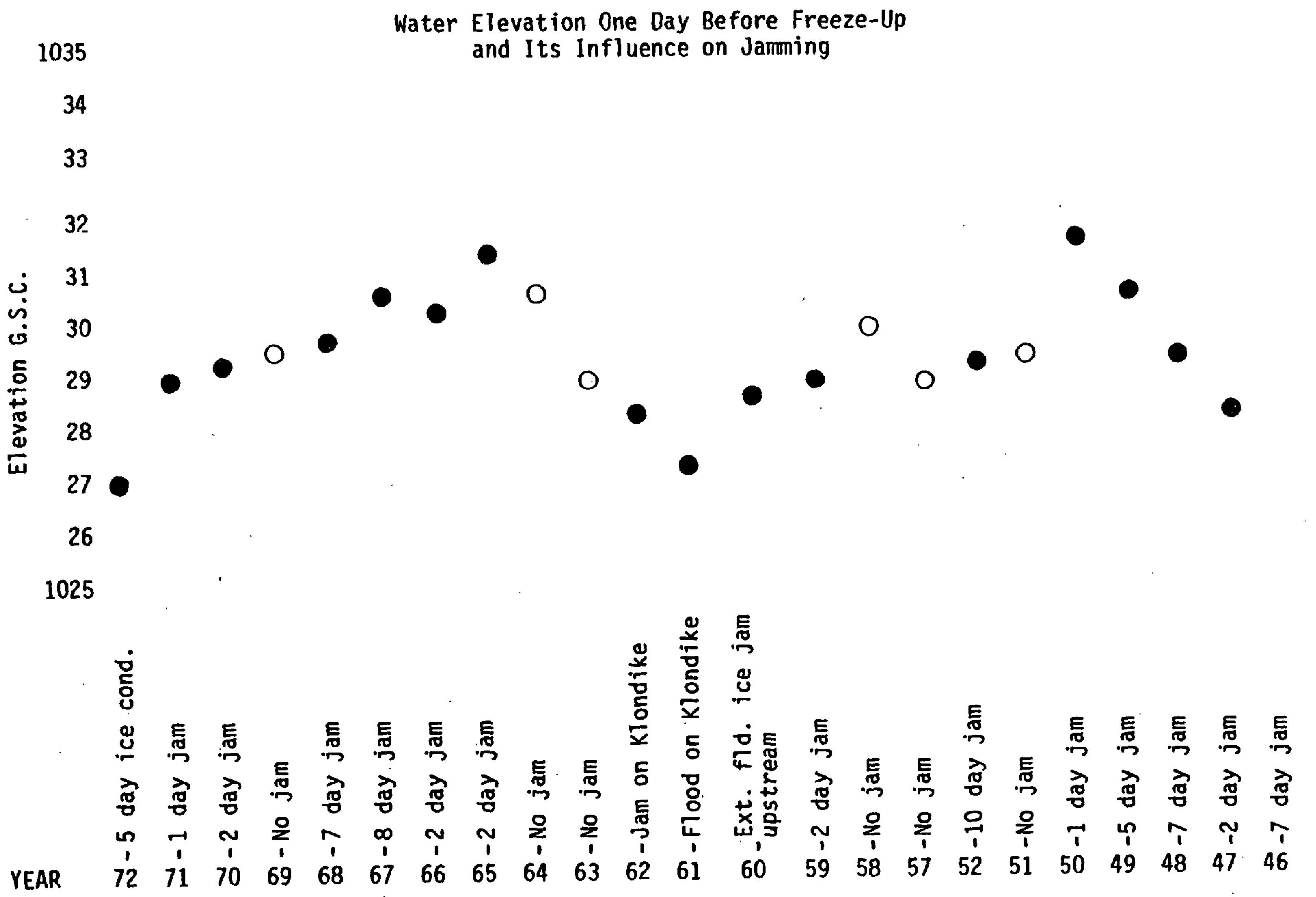


Fig. 40

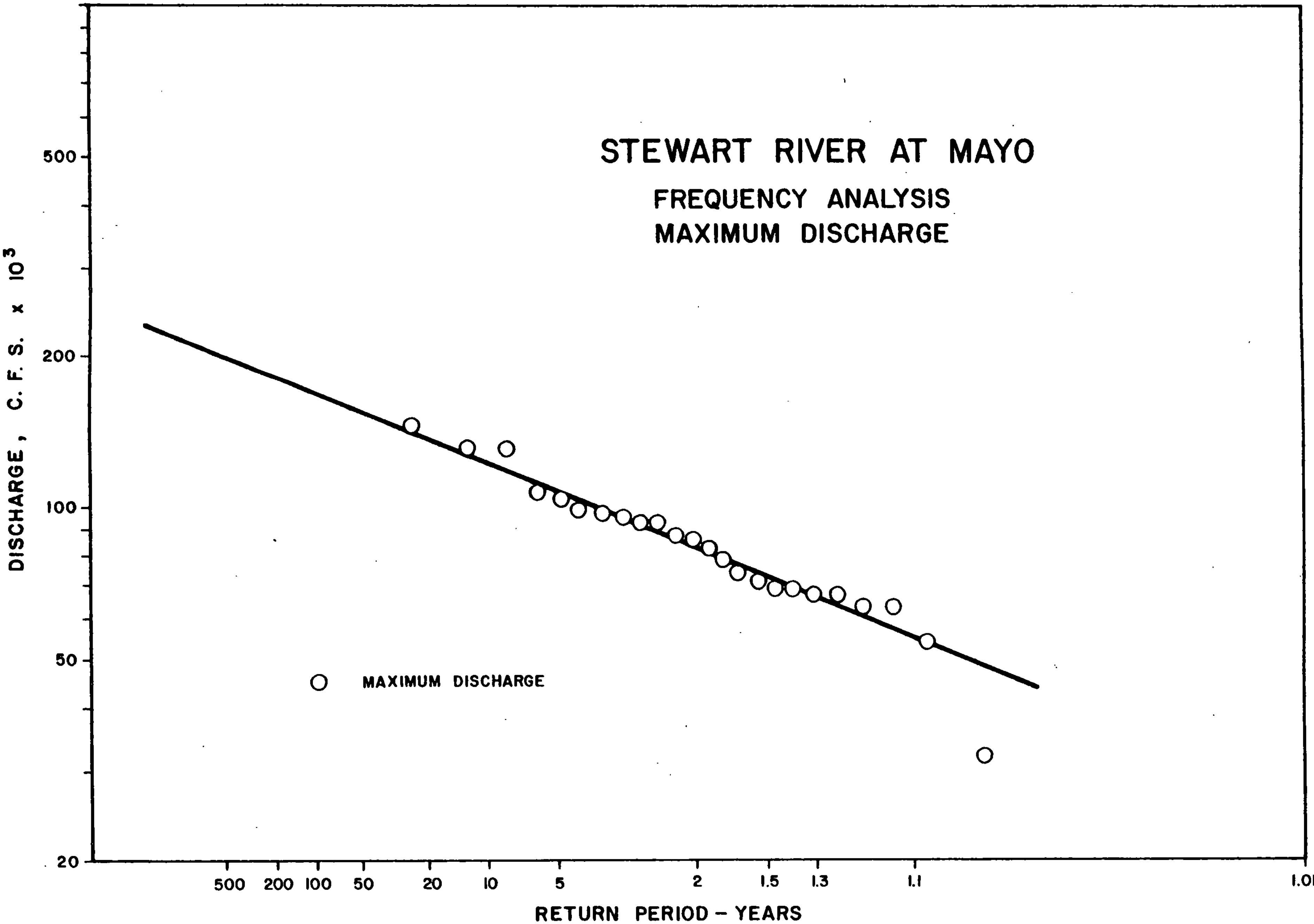

STEWART RIVER AT MAYO
FREQUENCY ANALYSIS
MAXIMUM DISCHARGE
MAXIMUM DISCHARGE
DISCHARGE, C.F.S. x 10^3
500
200
100
50
20
500 200 100 50 20 10 5 2 1.5 1.3 1.1 1.01
RETURN PERIOD - YEARS

Fig. 41

FIGURE 41A

YUKON FLOOD STUDY
MAYO

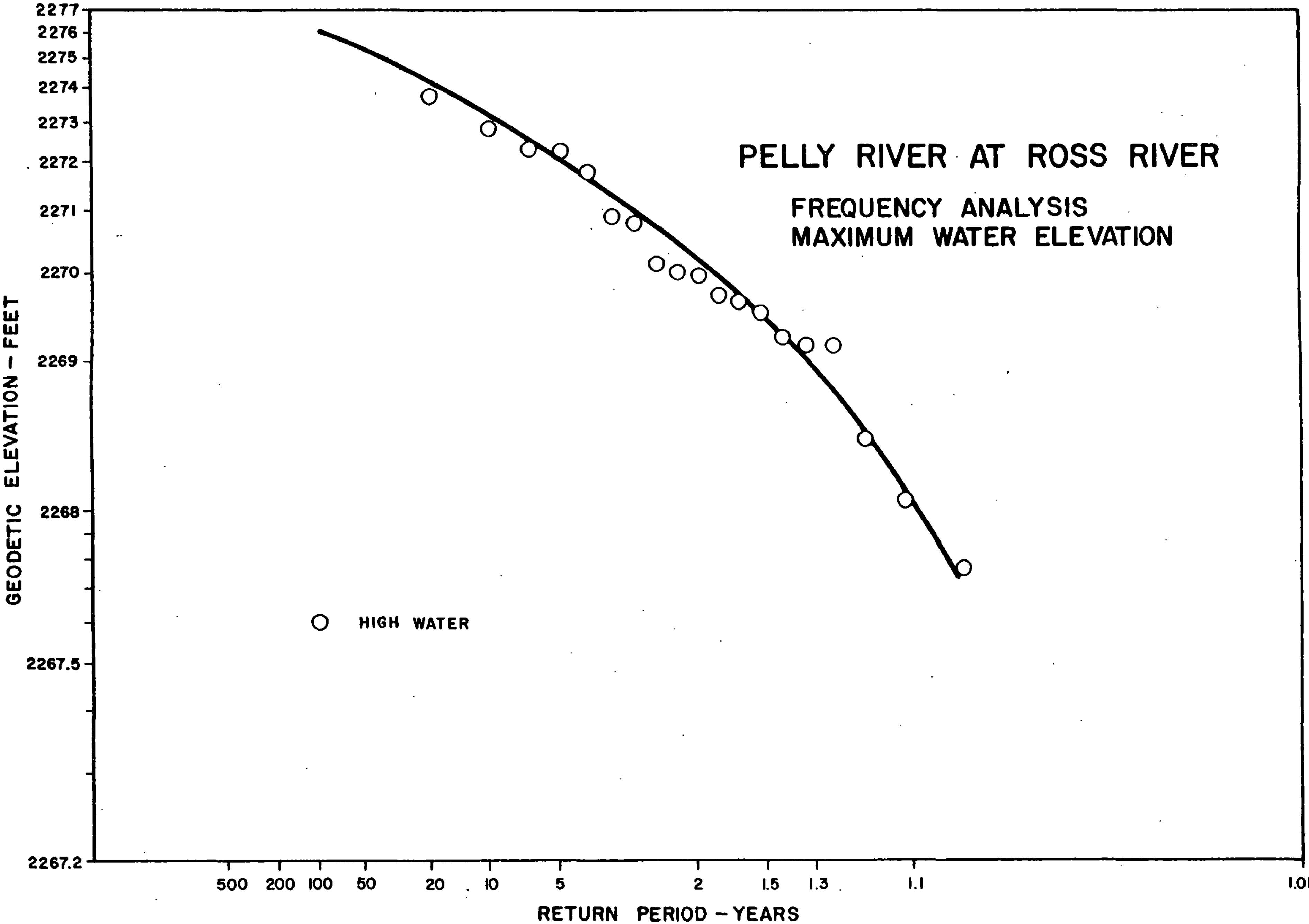
FLOODED AREA FOR 100 YEAR WATER ELEVATION

1608 FT — 100 YEAR FLOOD LINE

CONTOUR INTERVAL 5 FEET

— — — EXISTING DIKE

FENCO



PELLY RIVER AT ROSS RIVER
FREQUENCY ANALYSIS
MAXIMUM WATER ELEVATION
GEODETIC ELEVATION - FEET
RETURN PERIOD - YEARS
HIGH WATER
2277
2276
2275
2274
2273
2272
2271
2270
2269
2268
2267.5
2267.2
500
200
100
50
20
10
5
2
1.5
1.3
1.1
1.01

Fig. 42

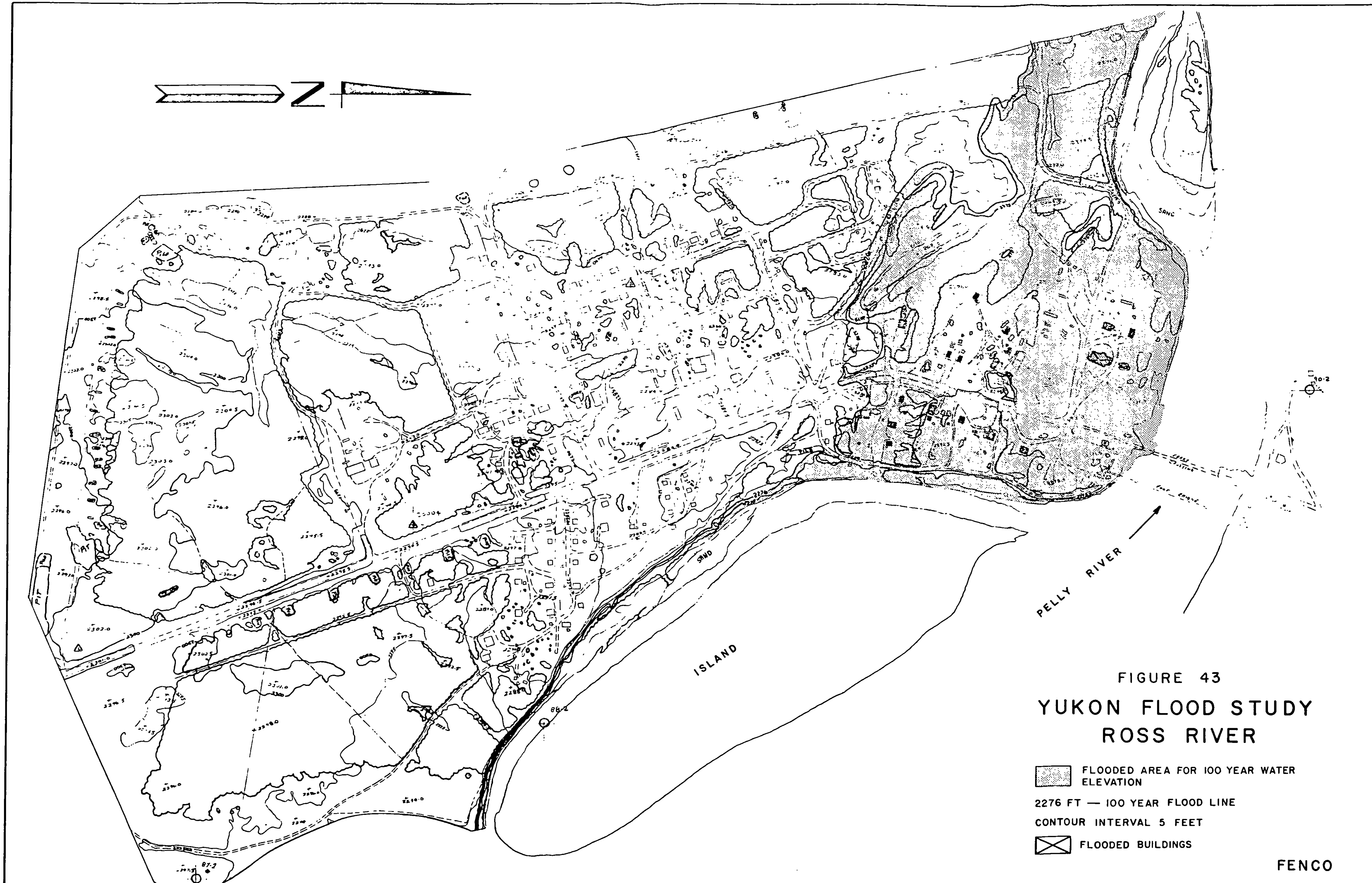
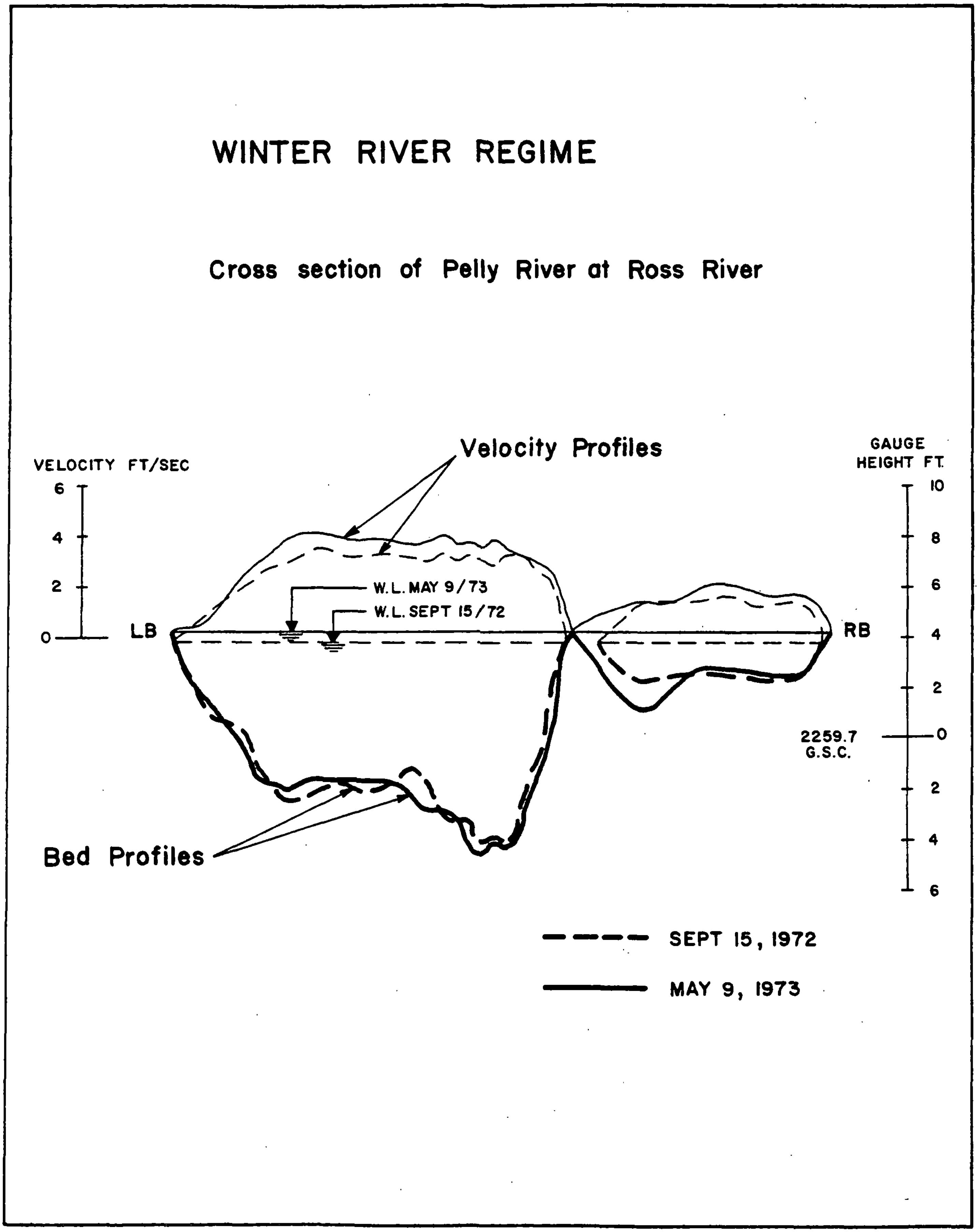


FIGURE 43

YUKON FLOOD STUDY
ROSS RIVER



WINTER RIVER REGIME
Cross section of Pelly River at Ross River
Velocity Profiles
VELOCITY FT/SEC
6
4
2
0
LB
W.L. MAY 9/73
W.L. SEPT 15/72
RB
GAUGE HEIGHT FT.
10
8
6
4
2
2259.7 G.S.C.
0
2
4
6
Bed Profiles
SEPT 15, 1972
MAY 9, 1973

Fig. 44

SPRING FLOOD RIVER REGIME

Cross section of Pelly River at Ross River

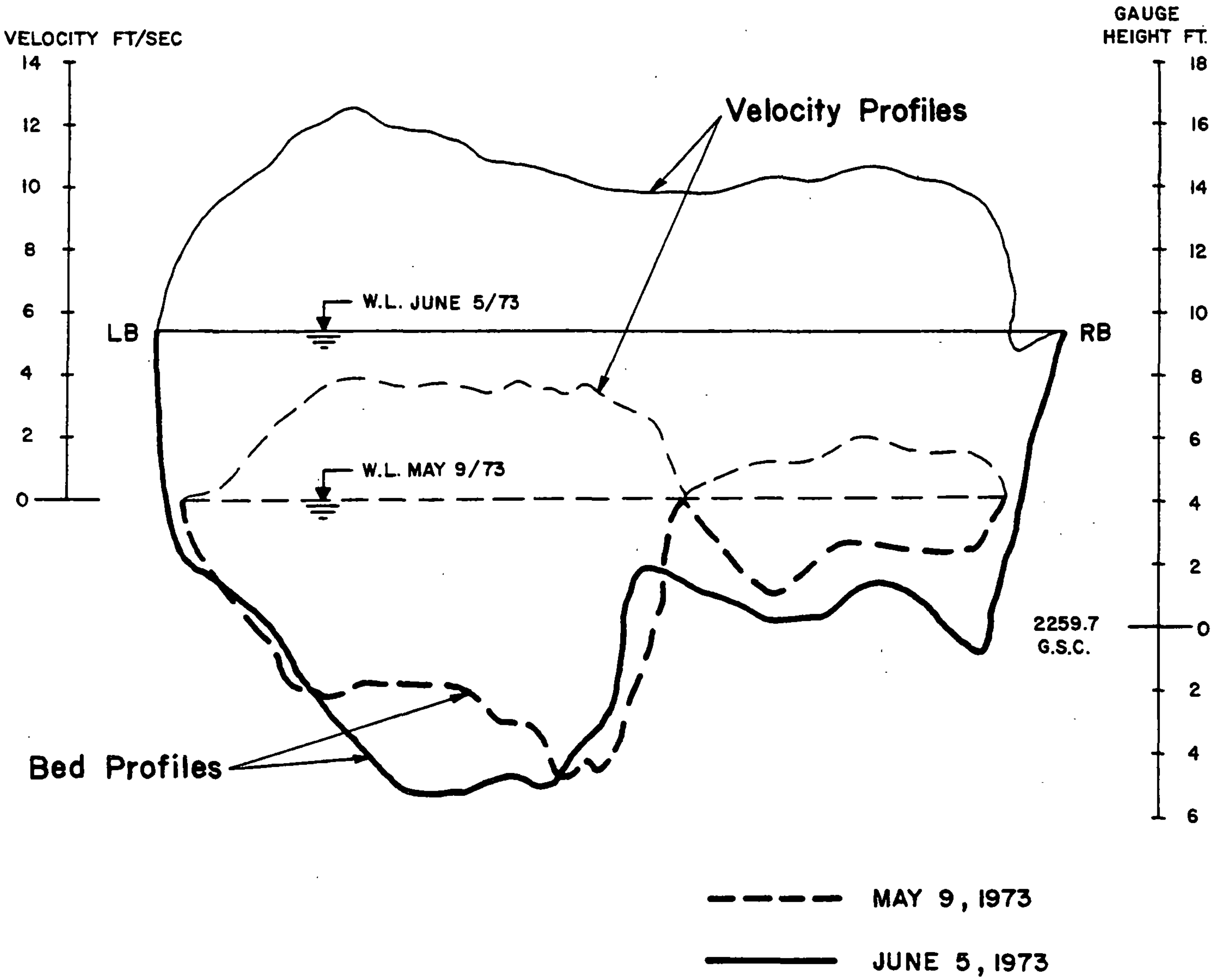


Fig. 45

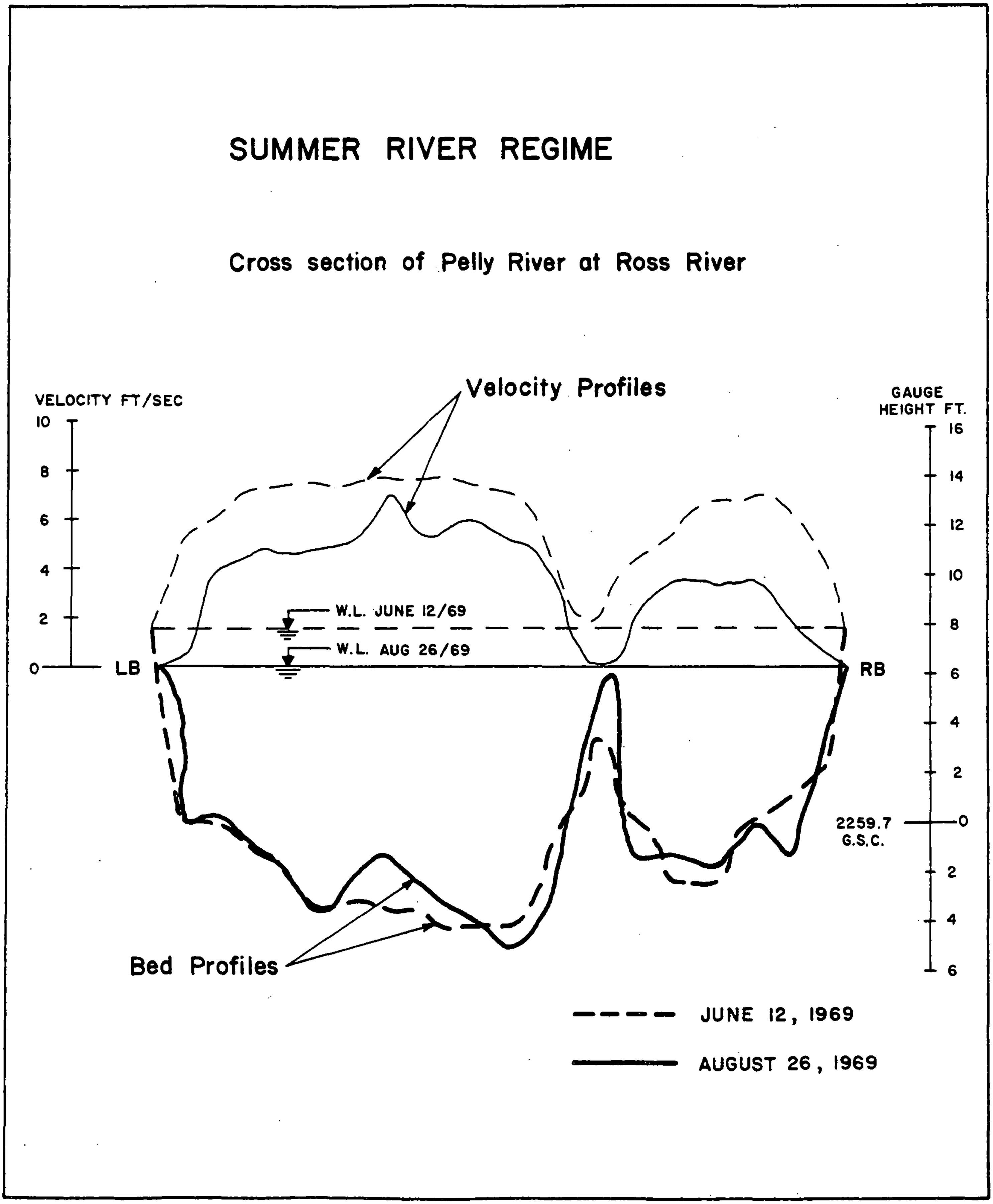
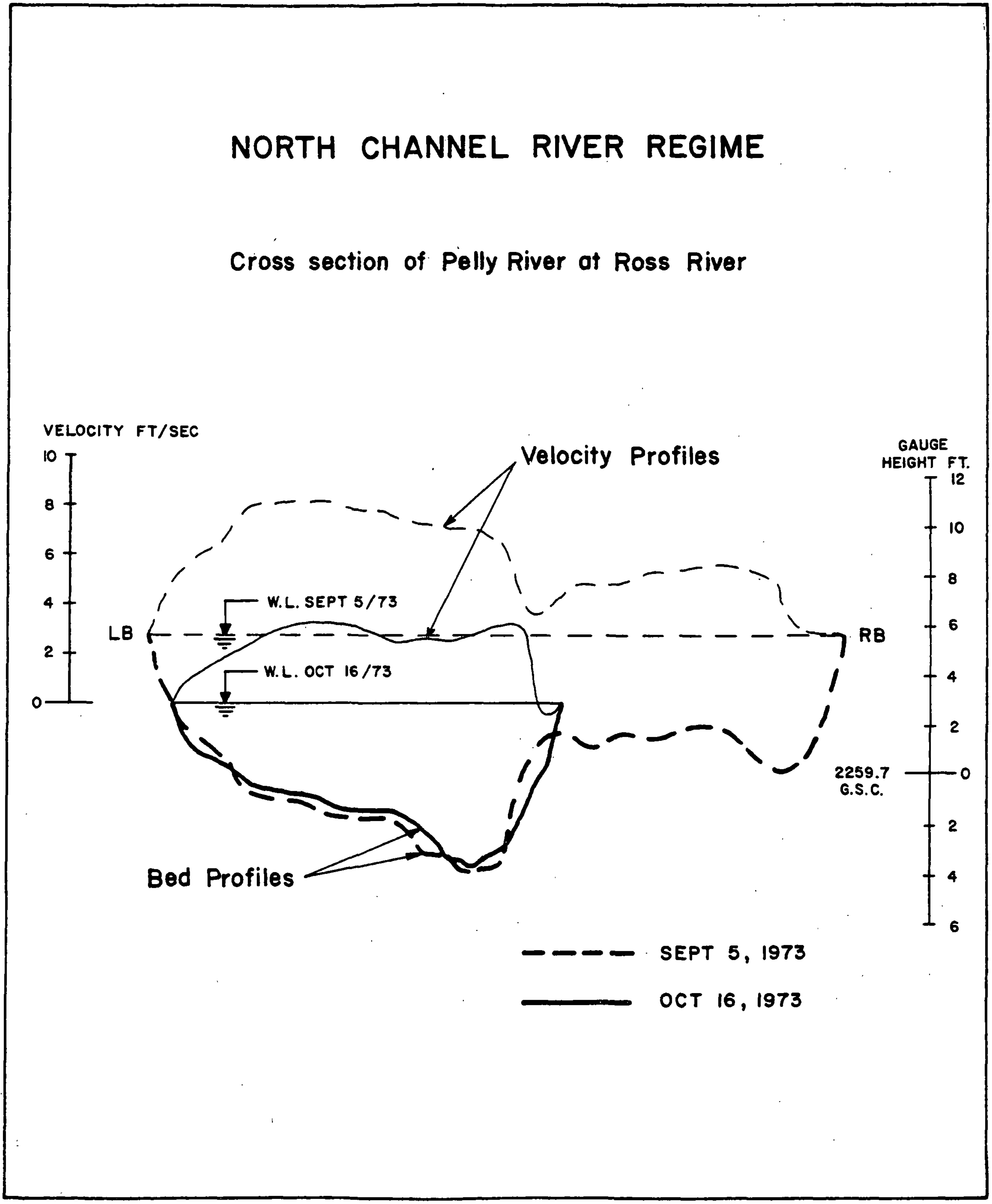

SUMMER RIVER REGIME
Cross section of Pelly River at Ross River
Velocity Profiles
VELOCITY FT/SEC
GAUGE HEIGHT FT.
W.L. JUNE 12/69
W.L. AUG 26/69
LB
RB
2259.7 G.S.C.
Bed Profiles
JUNE 12, 1969
AUGUST 26, 1969

Fig. 46

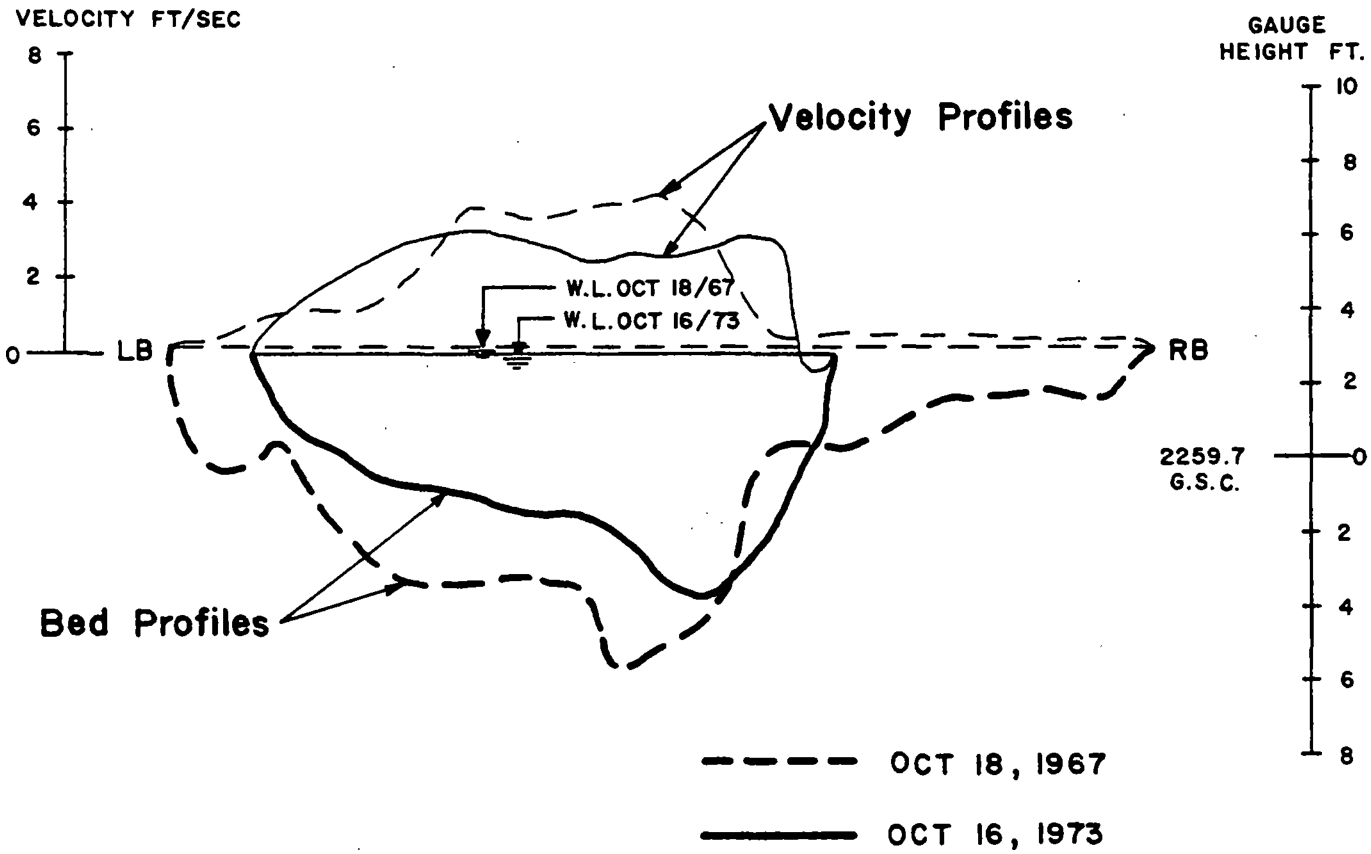


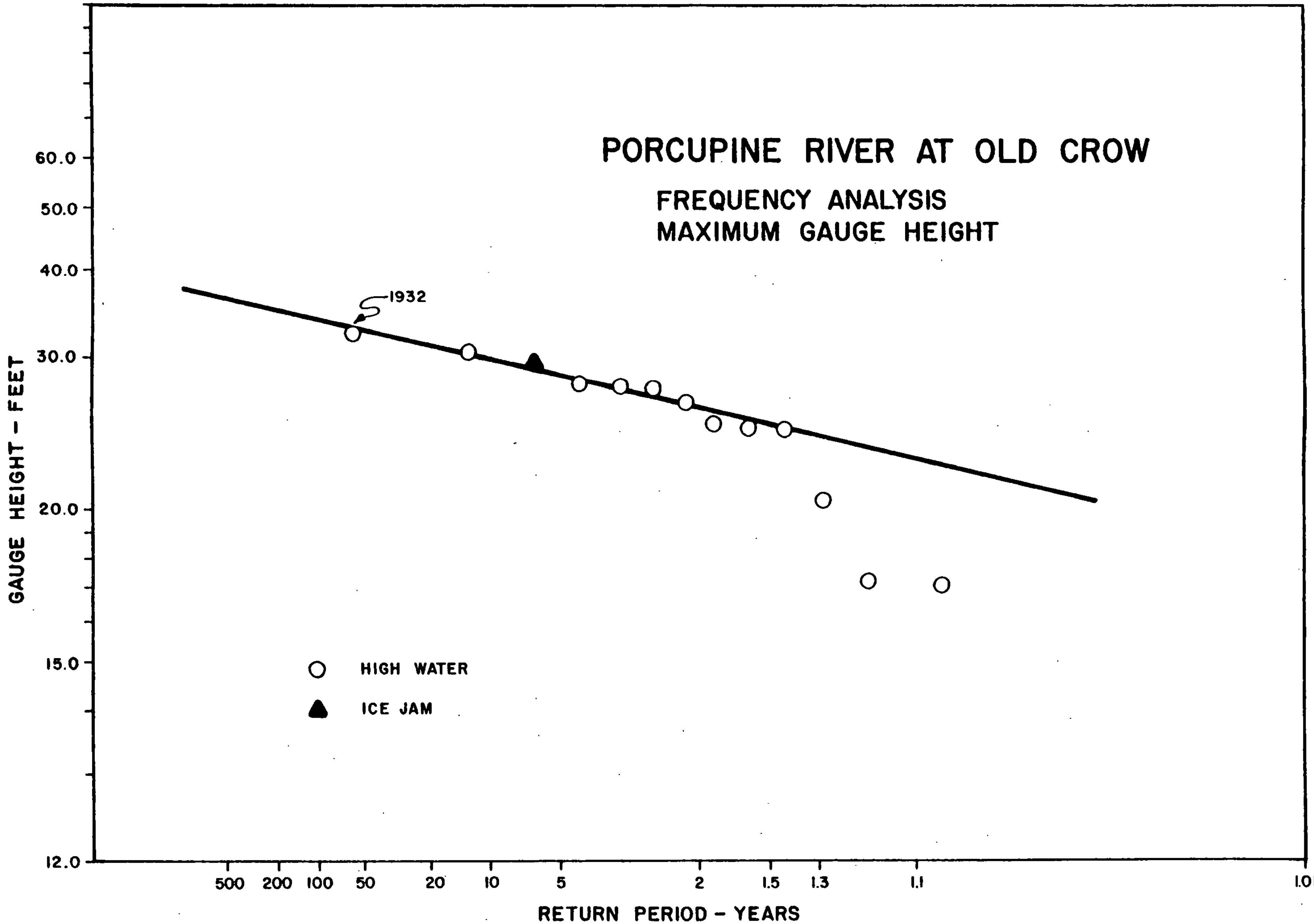
NORTH CHANNEL RIVER REGIME
Cross section of Pelly River at Ross River
VELOCITY FT/SEC
10
8
6
4
2
0
Velocity Profiles
GAUGE HEIGHT FT.
12
10
8
6
4
2
0
2
4
6
W.L. SEPT 5/73
W.L. OCT 16/73
LB
RB
2259.7 G.S.C.
Bed Profiles
SEPT 5, 1973
OCT 16, 1973

Fig. 47

YEARLY RIVER REGIME

Cross section of Pelly River at Ross River





PORCUPINE RIVER AT OLD CROW
FREQUENCY ANALYSIS
MAXIMUM GAUGE HEIGHT
1932
HIGH WATER
ICE JAM
GAUGE HEIGHT - FEET
60.0
50.0
40.0
30.0
20.0
15.0
12.0
500 200 100 50 20 10 5 2 1.5 1.3 1.1 1.01
RETURN PERIOD - YEARS

Fig. 49

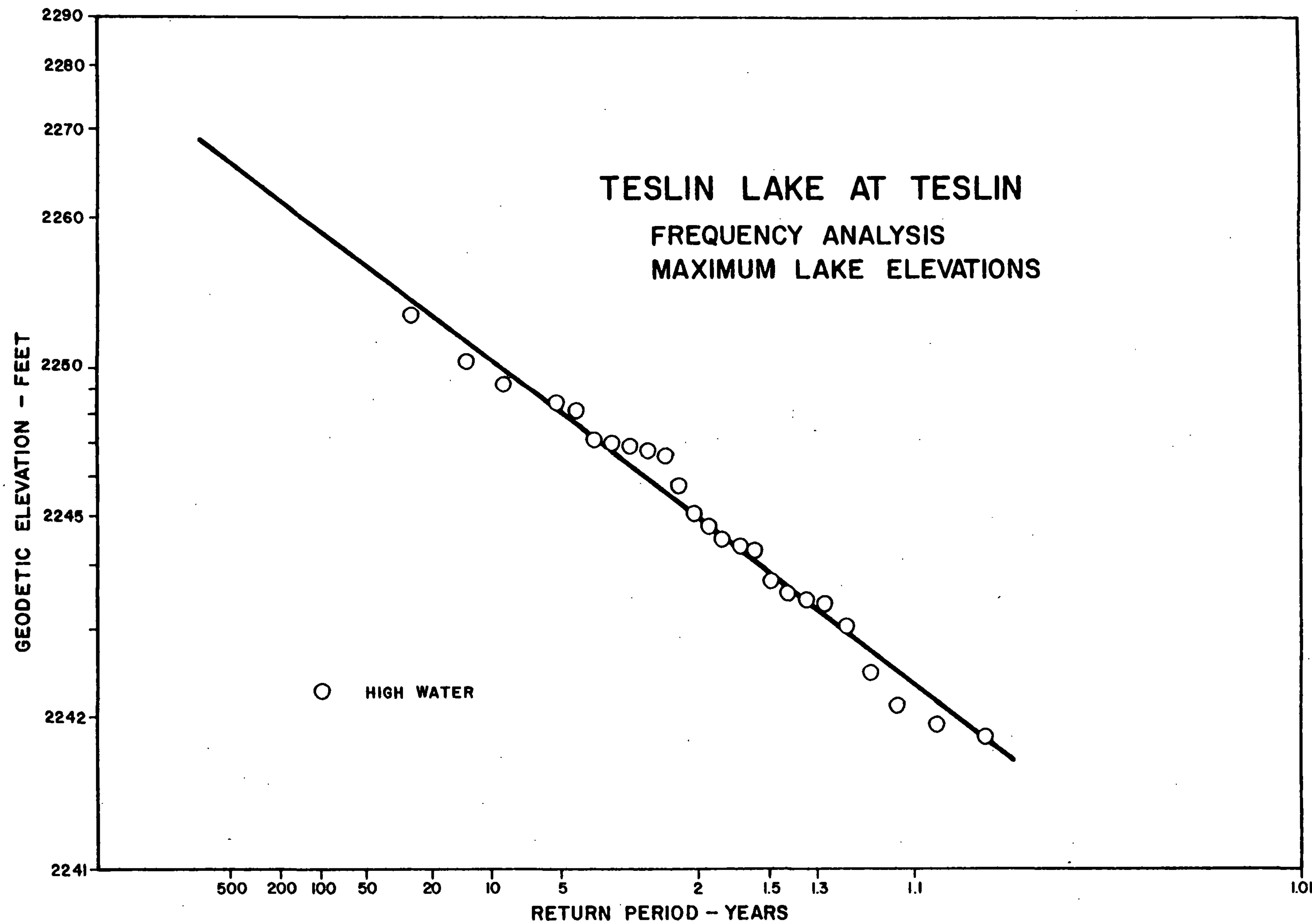

TESLIN LAKE AT TESLIN
FREQUENCY ANALYSIS
MAXIMUM LAKE ELEVATIONS
HIGH WATER
GEODETIC ELEVATION - FEET
2290
2280
2270
2260
2250
2245
2242
2241
500
200
100
50
20
10
5
2
1.5
1.3
1.1
1.01
RETURN PERIOD - YEARS

Fig. 50

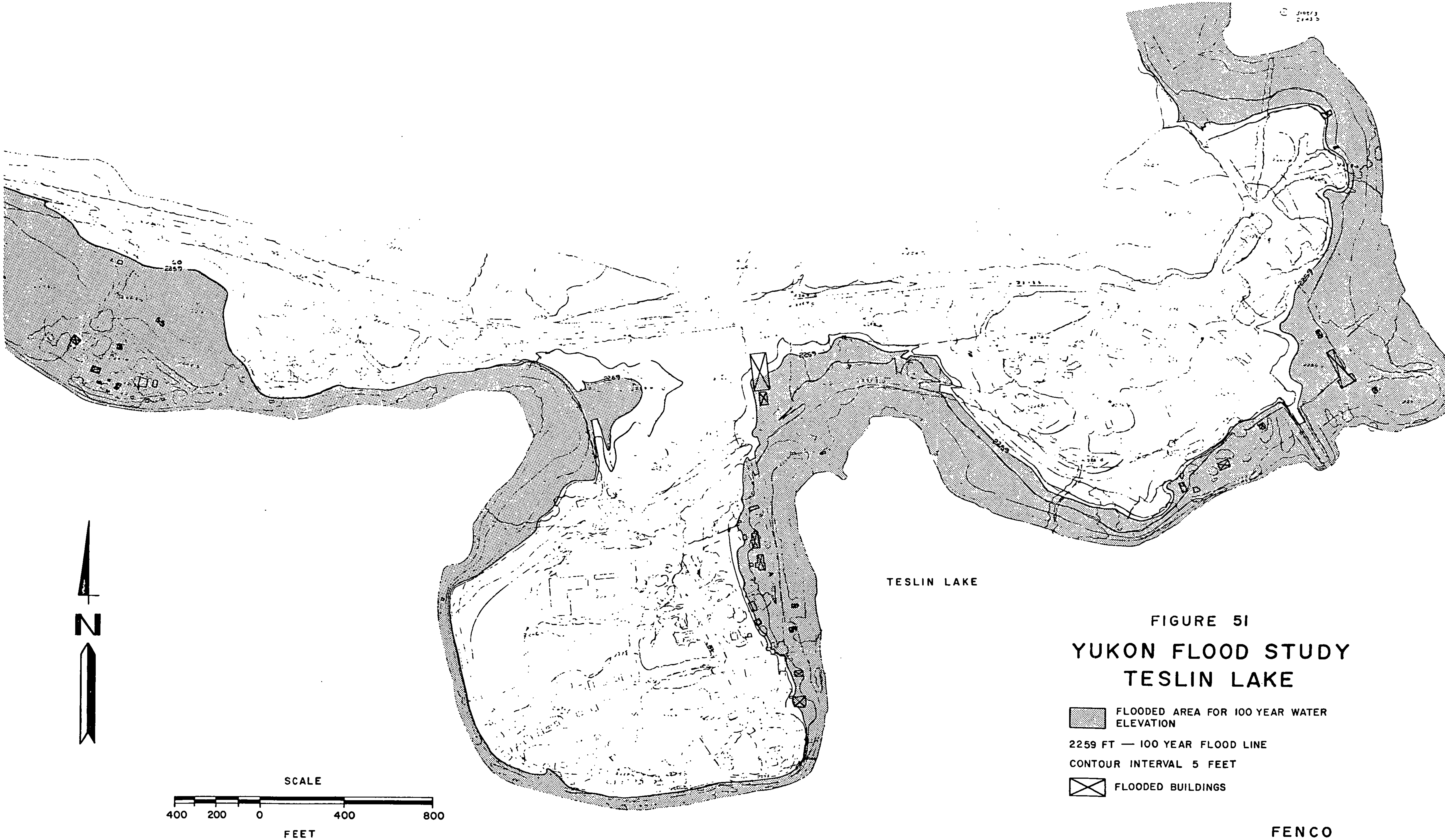


FIGURE 51

YUKON FLOOD STUDY
TESLIN LAKE

FENCO

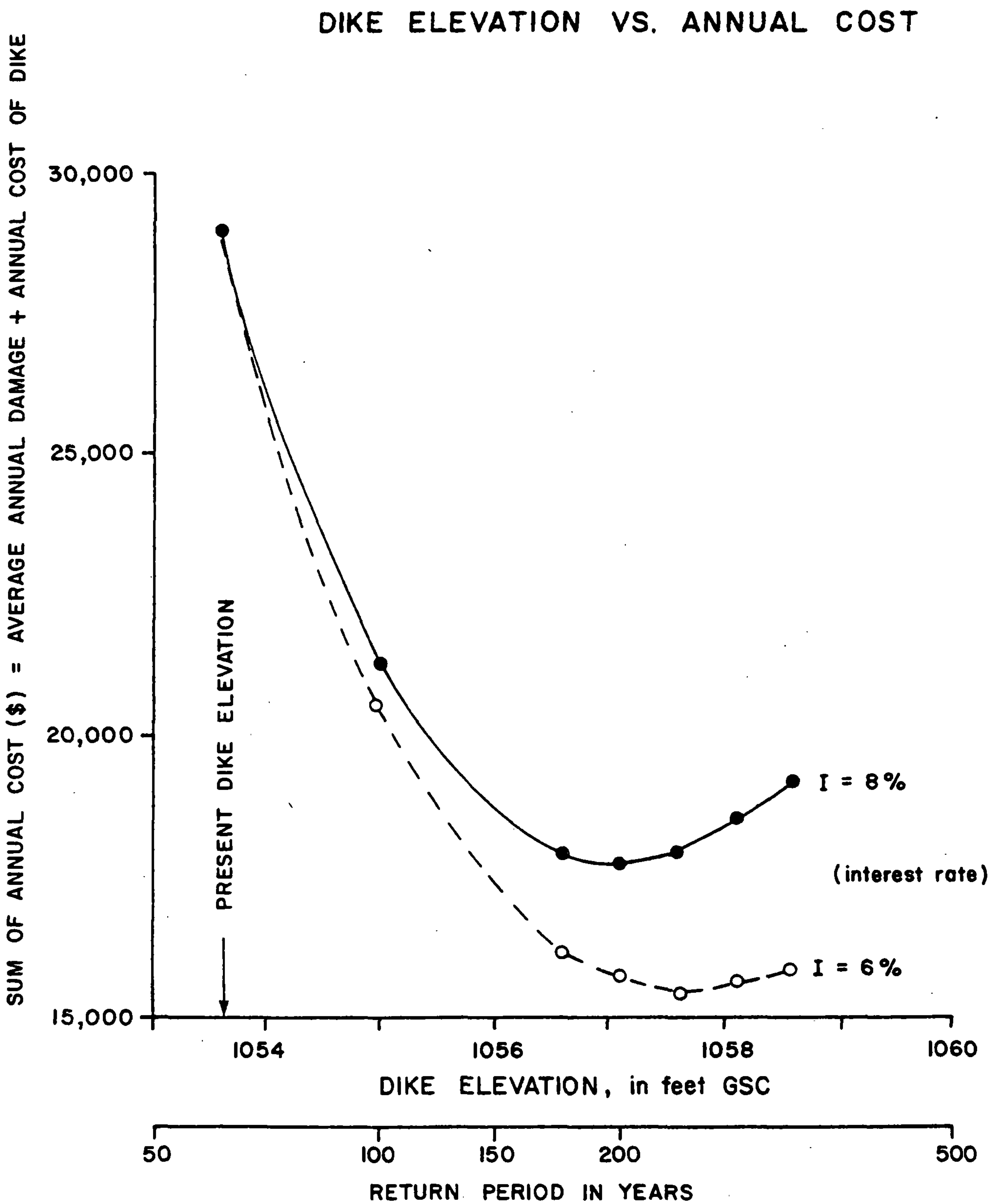

DIKE ELEVATION VS. ANNUAL COST
SUM OF ANNUAL COST ($) = AVERAGE ANNUAL DAMAGE + ANNUAL COST OF DIKE
30,000
25,000
20,000
15,000
PRESENT DIKE ELEVATION
I = 8%
(interest rate)
I = 6%
1054
1056
1058
1060
DIKE ELEVATION, in feet GSC
50
100
150
200
500
RETURN PERIOD IN YEARS

Fig. 52

Table 1

Maximum Discharge and Date

Year	Ross at Ross River 9BA-1	Pelly at Ross River 9BC-2	Pelly at Pelly x-ing 9BC-1	Stewart at Mayo 9DC-2	Stewart at Mouth 9DD-3	Klondike 9EA-3	Yukon at Dawson 9EB-1	Porcupine Below Bell 9EB-1	Porcupine Old Crow 9ED-1	Yukon at White Horse 9AB-1
1973	May 10 14,100	May 19 30,600		June 12 67,300				May 18 101,000	May 31 135,000	
1972	June 2 29,600	June 1 62,100	June 4 122,000	June 2 103,000	June 3 128,000	May 29 22,600	June 3 426,000	June 1 100,000e	June 1 121,000	Aug. 24 21,000
1971	June 13 13,900	June 12 32,400	July 1 76,600	June 14 93,200	June 16 98,200	June 11 16,800	June 16 269,000	Aug. 13 88,600	May 22 218,000	Aug. 23 22,700
1970	June 7 18,600	June 7 37,600	June 10 80,600	June 7 104,000	June 9 106,000	June 25 12,100	June 10 246,000	July 9 57,700	May 28 85,000	Aug. 11 14,100
1969	July 15 11,600	July 15 31,500	June 13 49,300	June 13 66,700	June 14 66,400	June 11 10,100	June 15 216,000	Aug. 26 23,500	Aug. 7 55,800	July 20 17,900
1968	May 23 15,800	May 23 34,400	May 25 70,900	June 14 73,900	May 29 78,900	May 21 12,600	May 26 257,000	June 25 24,600	June 2 158,000	Aug. 23 17,100
1967	June 5 18,000	June 2 51,600	June 5 106,000	June 4 97,400	June 4 101,000	June 2 14,500	June 6 347,000	--	June 5 158,000	Sept 25 18,600
1966	June 17 11,400	June 17 30,100	June 13 60,500	June 17 78,200	June 18 74,100	June 9 15,300	June 21 247,000	--	May 17 159,000	Aug. 3 16,200
1965	June 3 12,200	June 3 33,200	June 3 62,600	June 3 63,800	June 3 69,100	July 5 16,000	June 3 233,000	July 28 88,800	May 25 178,000	Aug. 2 16,100
1964	June 10 24,400	June 7 71,000	June 11 147,000	June 10 145,000	June 13 199,000	NO RECORD	June 11 526,000	June 6 178,000	June 4 237,000	Aug. 28 20,900
1963	May 25 17,200	May 25 42,300	May 28 87,900	May 25 85,700	NO RECORD		July 14 279,000	NO RECORD	May 18 194,000	Sept 20 21,500
1962	June 18 20,800	June 18 57,200	NOT AVBL.	NOT AVBL.			June 18 386,000		May 27 168,000	Aug. 27 19,000
1961	NO RECORD	June 11 53,400					June 13 357,000		June 5 76,000	Aug. 25 22,200
1960	NO RECORD	June 21 25,100					Aug. 1 230,000		NO RECORD	Aug. 16 19,700

Table 2

Yukon River at Dawson

Discharge and Maximum Water Elevation

Year	Maximum Daily Discharge C.F.S.	Date	Maximum Water Elevation GSC	Maximum Ht. During Ice Condition GSC	Date of Ice Jam
1972	426,000	June 3	1,046.44	1,035.60	May 13-18
1971	269,000	June 16	1,040.81	1,035.51	May 12
1970	246,000	June 9&10	1,039.85	1,035.49	May 12-13
1969	216,000	June 15	1,038.56	1,034.17	--
1968	257,000	May 26	1,040.31	1,033.18	May 11-17
1967	347,000	June 6	1,043.76	1,033.48	May 13-21
1966	247,000	June 21	1,039.89	1,051.87	May 11-12
1965	233,000	June 3	1,039.30	1,041.00	May 19-20
1964	✓ 526,000	June 11	1,049.47	1,035.80	--
1963	279,000	July 14	1,041.22	1,033.28	--
1962	386,000	June 18	1,045.21	--	--
1961	357,000	June 13	1,044.11	--	--
1960	230,000	Aug. 1	1,039.17	1,050.70	May 7
1959	276,000	May 21	1,041.10	1,037.64	May 15
1958	209,000	June 13	1,038.25	1,033.75	May 3
1957	376,000	May 28	1,044.77	1,041.00	May 10
1956	191,000	July 3	1,037.39	--	--
1955	NO RECORD			NO RECORD	
1954	NO RECORD			NO RECORD	
1953	NO RECORD			NO RECORD	
1952	217,000	July 4	1,038.61	1,032.54	May 22
1951	164,000	June 3	1,036.01	1,032.84	--
1950	184,000	June 21	1,037.04	1,039.37	May 13
1949	260,000	June 3	1,040.44	1,041.74	May 17
1948	255,000	June 1	1,040.23	1,040.97	May 19
1947	279,000	June 2	1,041.22	1,042.14	May 11
1946	259,000	May 31	1,040.39	1,035.94	till May 16
1945	235,000	May 22	1,039.39	✓ 1,052.37	--
1944	--	--	--	✓ 1,052.37	May 6-10

Table 3

Date of Break-Up of Klondike River and Yukon River at Dawson

Date of Break-Up on Klondike River	Time Difference Between Klondike Break-Up and Yukon River Break-Up	Year	Date of Break-Up on Yukon River
May 3	5	1973	May 8
May 8	5	1972	May 13
		1971	May 11-12
May 7- 8	3	1970	May 11
April 27-28	7	1969	May 5
May 4	5	1968	May 9
May 8 or 9	4	1967	May 12
May 6	5	1966	May 11
		1965	May 18
		1964	May 28
April 25	10	1963	May 5
May 9	3	1962	May 12
April 28	11	1961	May 9-15
April 28	6	1960	May 4
May 12-13	2	1959	May 15
April 29	5	1958	May 4- 5- 6
May 5	4	1957	May 9
May 6	1	1956	May 7
		1955	May 7-13
		1954	May 12-13
		1953	May 5-14
		1952	May 5-12
		1951	May 8-12
		1950	May 8-10
		1949	May 6-13
		1948	May 12-13
		1947	May 9-12
		1946	May 9
		1945	May 9-16
		1944	May 5-16
NO RECORD		1943	May 2- 4
		1942	May 2- 6
		1941	April 30
		1940	April 28-30
		1939	May 12
		1938	May 12
		1937	May 10-12
		1936	May 5
		1935	May 16
		1934	May 2
		1933	May 9
		1932	May 2
		1931	May 11
		1930	May 10
		1929	May 7
		1928	May 9

Table 3

<u>Date of Break-Up of Klondike River and</u>

<u>Yukon River at Dawson</u> (continued)

Date of Break-Up on Klondike River	Time Difference Between Klondike Break-Up and Yukon River Break-Up	Year	Date of Break-Up on Yukon River
		1927	May 13
		1926	May 3
		1925	May 9
		1924	May 8
		1923	May 10
		1922	May 14
		1921	May 12
		1920	May 18
		1919	May 10-11
		1918	May 11
		1917	May 15
		1916	May 3
		1915	May 3
NO RECORD		1914	May 10
		1913	May 14
		1912	May 9
		1911	May 7
		1910	May 11
		1909	May 11
		1908	May 7
		1907	May 5
		1906	May 11
		1905	May 10
		1904	May 7
		1903	May 13
		1902	May 11
		1901	May 14
		1900	May 8
		1899	May 17
		1898	May 8
		1897	May 17
		1896	May 19

Table 4

Yukon River at Dawson

Break-Up and Ice Jamming

Year	Date of Break-Up	Date of Jamming	Maximum Recorded Ht. of Ice	Min. Q at Time of Jam Max. Q	Corresponding Depths	Corresponding Froude No.	Winter Froude No.	Description
1973	May 8							
1972	May 13	May 13-18	1,035.60	24,000 to 78,000	23.11 21.65	0.035 0.124	--	5 days of ice condition, highway flooding, ice jam upriver.
1971	May 11-12	May 12	1,035.51	44,000 to 62,000	21.19 23.02	0.072 0.090	0.06	One day jam, level from 1,033.68 to 1,035.51.
1970	May 11	May 12-13	1,035.49	56,000 to 82,000	22.05 23.00	0.087 0.119	0.04	Two days jam, level from 1,034.70 to 1,035.49.
1969	May 5	--	1,034.17	49,500	21.68	0.078	0.12	No jam, level dropped, mild run-off.
1968	May 9	May 11-17	1,033.18	22,500 to 68,500	20.60 20.42	0.039 0.119	0.10	Ice jam on Klondike on May 4, 7 days ice jam, level from 1,032.99 to 1,033.18.
1967	May 12	May 13-21	1,037.48	43,000 to 110,000	24.20 21.41	0.058 0.178	0.06	8 days ice condition & jam, level from 1,036.69 to 1,037.48.
1966	May 11	May 11-12	1,051.87	40,000 to 100,000	27.24 35.28	0.045 0.076	0.04	One day jam, level from 1,037.14 to 1,051.87, flood, jam on Klondike too.
1965	May 18	May 19-20	1,041.00	68,000 to 90,000	24.05 28.51	0.092 0.095	0.04	Two days jam, level from 1,034.50 to 1,041.00.
1964	May 28	--	1,035.80	160,000	--	--	0.05	No jam, flood in June due to heavy run-off.
1963	May 5	--	1,033.28	76,000	20.70	0.129	0.05	No jam, jam on Klondike April 30.
1962	May 12	--	--	49,600	--	--	0.07	Gauge Height missing, some jamming in Klondike.
1961	May 9	--	--	31,000	--	--	0.04	Gauge Height missing, flooding near end of April on Klondike with road wash-out.
1960	May 4	May 7	1,050.70	134,000	27.17	0.152	0.08	Extensive flood due probably, to ice jam coming from upstream.
1959	May 15	May 15	1,037.64	118,000 to 132,000	20.63 20.15	0.202 0.168	0.05	Two days jam, Klondike jammed on May 11-12, water level from 1,033.12 to 1,037.64.
1958	May 4	May 3	1,033.75	39,000 to 45,800	20.52	0.079	0.09	One day jam before break-up.
1957	May 7	May 10	1,041.00	52,000 to 44,000	22.57	0.066	0.07	Heavy volume of water coming from Klondike, level from 1,039.06 to 1,045.00.
1956	May 7	--	--	--	--	--	--	NO RECORD
1955-1953	--	--	--	--	--	--	--	NO RECORD
1952	May 12	till May 22	1,032.64	11,800 to 80,000	16.75 20.79	0.028 0.135	--	Ten days of ice conditions and jam.
1951	May 8	--	1,032.84	112,000	20.35	0.193	--	No jam.
1950	May 10	May 13	1,039.37	NOT AVAILABLE	--	--	--	One day jam 3 days after break-up, level from 1,037.77 to 1,039.37.
1949	May 13	May 17	1,041.74	NOT AVAILABLE	--	--	--	5 days ice condition & jam, level from 1,035.24 to 1,041.74.
1948	May 12	May 19	1,040.97	NOT AVAILABLE	--	--	--	7 days ice condition & jam, level from 1,033.54 to 1,040.94.
1947	May 9	May 11	1,042.14	120,000 to 122,000	29.65 22.55	0.121 0.180	--	Ice jam after break-up, level from 1,035.04 to 1,042.14.
1946	May 9	till May 16	1,035.94	--	--	--	0.06	Ice condition & jam for 7 days, level from 1,034.69 to 1,035.94.
1945	May 16	--	1,040.24	50,000 161,000	--	--	--	Jam 8 days after break-up, level from 1,030.54 to 1,040.24.
1944	May 5	May 6-10	1,052.37	--	--	--	--	15 mile long ice jam lasting four days, considerable flooding.

Table 5

Yukon River at Dawson

Winter Measurements at Dawson

Date	Discharge at Time of Measurement c.f.s.	Ice Thickness (feet)	Slush Conditions	Average Velocity f.p.s.	Average Depth (feet)	Froude Number (winter)
Feb. 20 1973	15,100	3.73	Slight in mid-stream	0.98	13.60	0.047
Dec. 14 1972	17,900	3.28	Some slush	1.19	12.82	0.059
April 5 1972	13,300	3.76	Slush full width of river	1.40	9.13	0.082
Feb. 21 1972	15,000	3.24	78' wide approx. 10' deep	1.72	8.19	0.106
Apr. 27 1971	17,700	3.55		1.22	12.72	0.604
Apr. 13 1970	14,500	3.09		0.92	16.21	0.040
Apr. 23 1969	20,300	2.29	Mid-stream to left bank approx 16' deep	2.07	8.35	0.126
March 7 1969	12,900	2.68	Mid-stream 675' wide to bottom	1.74	6.18	0.123
Mar. 19 1968	19,000	n.a.	Extends to bottom - entire width	1.94	11.50	0.100
May 1 1967	16,400	4.12	Some slush to bottom 270' from right bank	1.22	13.81	0.057
Apr. 20 1966	18,100	2.18		1.00	22.88	0.036

Winter Measurements At Dawson (continued)

Date	Discharge at Time of Measurement cfs	Ice Thickness (feet)	Slush Conditions	Average Velocity f.p.s.	Average Depth (feet)	Froude Number (winter)
Apr. 23 1965	19,500	4.07	Some slush	1.11	20.23	0.043
Apr. 24 1964	19,100	3.29	Some slush to bottom	1.29	17.21	0.054
April 9 1963	17,000	3.59	400' wide in mid-stream	1.16	17.18	0.049
Apr. 11 1962	17,000	3.65	10' thick for 740' in mid-stream	1.45	13.60	0.069
Apr. 14 1961	14,400	3.07		0.92	14.09	0.043
April 4 1960	15,100	3.74	750' wide approx 10-12' thick	1.37	9.52	0.078
Apr. 10 1959	12,600	3.25		0.94	12.62	0.046
Mar. 19 1958	15,200	2.8	10' thick for full width	1.57	8.54	0.094
April 3 1957	13,100	3.44		1.25	9.29	0.072
RECORDS FROM 1956 to 1947 NOT AVAILABLE						
Feb. 27 1946	16,700	Not Available	Slush to bottom full width	1.39	14.55	0.064
Mar. 15 1945	13,800	3.72	Some slush	1.43	9.50	0.081

Table 6

Yukon River at Dawson

Degree Days Related to Break-Up

Year	First Day Above 32°F	Date of Break-Up	Total No. Of Days To Break-up	Total No. Of Days Above 32°F	Degree Days To Break-Up	No. of Days Above 32°F Until Jamming	Degree Days Until Jamming
1972	April 18	May 13	26	16	112.4	21	137.4
1971	" 13	" 11	29	24	137.0	25	156.5
1970	" 13	" 11	29	27	163.5	31	225.5
1969	" 3	" 5	33	30	171.0	--	---
1968	" 4	" 9	36	22	168.4	30	254.4
1967	" 3	" 12	40	20	157.0	29	217.4
1966	" 3	" 11	39	20	167.9	21	172.9
1965	" 3	" 18	46	27	167.9	29	197.4
1964	" 8	" 29	51	25	210.9	--	---
1963	" 6	" 5	30	23	163.4	--	---
1962	March 31	" 12	43	22	99.4	--	---
1961	April 23	" 9	17	14	91.9	--	---
1960	" 8	" 4	27	17	178.4	20	222.4
1959	" 8	" 15	38	18	152.4	18	152.4
1958	" 5	" 4	30	26	122.4	25	110.4
1957	" 21	" 7	17	12	60.0	15	87.0
1956	" 11	" 7	27	17	126.5	--	---
1955 - 1953		NO RECORD			NO RECORD		
1952	April 10	May 12	33	25	157.0	35	290.5

<u>Degree Days Related to Break-Up</u> (continued)

Year	First Day Above 32°F	Date of Break-Up	Total No. of Days to Break-Up	Total No. of Days Above 32°F	Degree Days To Break-Up	No. of Days Above 32°F Until Jamming	Degree Days Until Jamming
1951	April 6	May 8	33	22	220.4	--	---
1950	" 12	" 10	29	28	238.9	31	290.9
1949	" 17	" 13	27	22	149.4	26	195.4
1948	" 8	" 12	35	20	110.5	42	241.0
1947	" 9	" 9	31	23	193.9	25	222.4
1946	" 15	" 9	25	23	194.4	30	304.8
1945	" 23	" 16	24	18	137.0	26	290.5
1944	" 15	" 5	28	20	152.0	25	202.0

Table 7

Pelly River at Ross River

Discharge and Maximum Water Elevation

Year	Maximum Discharge	Date	G.S.C. Elevation	Date of Break-Up
1973	30,600	May 19	2,269.43	May 10
1972	62,100	June 1	2,273.37	May 12
1971	32,400	June 12	2,269.47	May 13
1970	37,600	June 7	2,270.17	May 10
1969	31,500	June 11	2,268.80	May 8
1968	34,400	May 23	2,269.19	May 12
1967	51,600	June 2	2,271.23	
1966	30,100	June 17	2,268.60	May 14
1965	33,200	June 2	2,269.03	May 19
1964	71,000	June 7	2,273.20	May 23
1963	42,300	May 25	2,270.65	May 9
1962	57,200	June 18	2,271.46	May 18
1961	53,400	June 11	2,271.18	May 12
1960	25,100	June 21	2,267.87	May 5
1959	30,300	June 10	2,269.19	May 16
1958	20,800	May 27	2,252.06	May 5
1957	43,200	May 26	2,270.85	May 8
1956	35,600e	June 10	2,269.91	May 22
1955	37,600	July 3	2,270.17	May 16

Table 8

Porcupine River at Old Crow

Ice Jamming at Old Crow

Year	Date of Break-Up	Date of Jam	Max. Recorded Height of Ice	Max. & Min. Q at Time of Jam	Description
1973	May 17	May 18	30.16	NOT AVAILABLE	Extensive flooding in west side of town - big jam.
1972	May 27		17.38		No jam, ga. ht. rose from 14.13' to 17.38' to 15.94' in 3 days.
1971	May 21		24.35		Ice went out May 21, Q max. on May 22 (218,000 C.F.S.).
1970	May 21		9.95		Ice went out May 22, 5 days ice condition and jam.
1969	May 12		17.00		Ice went out May 12.
1968	May 22				No record in May.
1967	May 10		16.29		Poor record.
1966	May 14		19.69		Poor record.
1965	May 23		23.57		Water running over ice, Q max. on May 25 (178,000 C.F.S.).
1964	May 30	June 1	23.84	134,000 237,000	Ice jam below gauge, ice running bank to bank on June 1, Q max. on June 4 (237,000 C.F.S.).
1963	May 15				Q max. on May 18 (194,000 C.F.S.).
1962	May 23		11.85		Heavy ice running, Q max. on May 28 (168,000 C.F.S.).
1961	May 19	May 22	17.00		No records in May, date is estimated from notes.

Table 9

Expenditure on Flood Control and Floods

Location	1960	1963	1965	1967	1968	1972	1973	Total
Dawson City		$6,373.24	$37,650.21	$46,622.38	$ 89.07			$90,734.90
Dawson Dike	$23,251.86			$22,217.92	$932.87			$46,402.65
Mayo			$24,653.27			$4,596.21	$ 7,658.80	$36,908.28
Mayo Dike					$970.20			$ 970.20
Ross River					$ 55.17		$15,232.50	$15,287.67

Annual Cost of Flood Risk

Table 10

Top of Dike Elevation	Water Elevation	Damage ($)	Probability of event in interval	Annual Damage ($)
53.6	53.6 - 54.1	400,000	0.018-0.013 = 0.005	2,000
	54.1 - 55	1,500,000	0.013-0.010 = 0.003	4,500
	55 - 57	2,000,000	0.010-0.005 = 0.005	10,000
	57 -	2,500,000	0.005 = 0.005	12,500
		Annual cost of flood risk:	TOTAL	$ 29,000
55	55 - 55.5	400,000	0.010-0.0072=0.0028	1,120
	55.5 - 56.5	1,500,000	0.0072-0.0065=0.0007	1,050
	56.5 -	2,500,000	o.0065 =	16,250
		Annual cost of flood risk:	TOTAL	$ 18,420
56.6	56.6 - 57.1	400,000	0.0065-0.0046=.0019	760
	57.1 - 58.1	1,500,000	0.0046-.0035 =.0011	1,650
	58.1 -	2,500,000	.0035	8,750
		Annual cost of flood risk:	TOTAL	$ 11,160
57.1	57.1 - 57.6	400,000	0.0046-0.0043=0.0003	120
	57.6 - 58.6	1,500,000	0.0043-0.0032=0.0011	1,650
	58.6 -	2,500,000	0.0032 =0.0032	8,000
		Annual cost of flood risk:	TOTAL	$ 9,770
57.6	57.6 - 58.1	400,000	0.0043-0.0035=0.0008	320
	58.1 - 59.1	1,500,000	0.0035-0.0024=0.0011	1,650
	59.1 -	2,500,000	0.0024 =0.0024	6,000
		Annual cost of flood risk:	TOTAL	$ 7,970
58.1	58.1 - 58.6	400,000	0.0035-0.0032=0.0003	120
	58.6 - 59.6	1,500,000	0.0032-0.0020=0.0012	1,800
	59.6 -	2,500,000	0.0020 =0.0020	5,000
		Annual cost of flood risk:	TOTAL	$ 6,920
58.6	58.6 - 59.1	400,000	0.0032-0.0024=0.0008	320
	59.1 - 60.1	1,500,000	0.0024-0.0017=0.0007	1,050
	60.1 -	2,500,000	0.0017 =0.0017	4,250
		Annual cost of flood risk;	TOTAL	$ 5,620

Sum of Annual Cost

Table 11

Return Period (years)	Dike Elevation (feet)	Average Annual Damage ($)	Cost of Dike ($)	Annual Cost of Dike I = 8% ($)	Sum of Annual Costs 8%	Annual Cost of I = 6%	Sum of Annual Costs 6%
56	53.6	29,000	0		29,000		29,000
100	55	18,420	36,000	2,880	21,300	2,160	20,580
154	56.6	11,160	85,000	6,800	17,960	5,100	16,260
217	57.1	9,770	100,000	8,000	17,770 minimum	6,000	15,770
233	57.6	7,970	125,000	10,000	17,970	7,500	15,470
286	58.1	6,920	145,000	11,600	18,520	8,700	15,620
313	58.6	5,620	170,000	13,600	19,220	10,200	15,820