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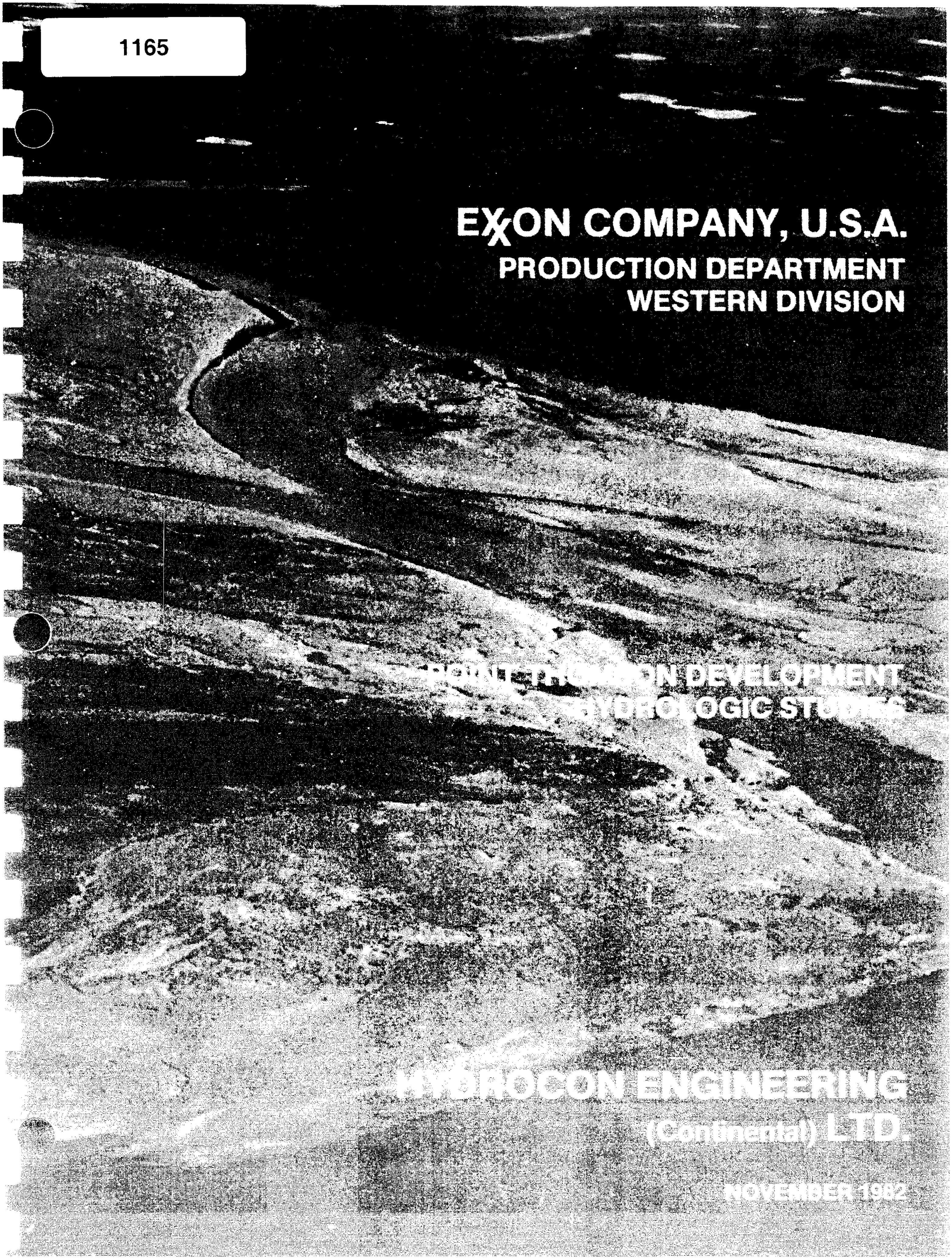

# EXXON COMPANY, U.S.A.
## PRODUCTION DEPARTMENT
## WESTERN DIVISION

# POINT THOMSON DEVELOPMENT
# HYDROLOGIC STUDIES

HYDROCON ENGINEERING
(Continental) LTD.

NOVEMBER 1982

EXXON COMPANY, U.S.A.
PRODUCTION DEPARTMENT
WESTERN DIVISION

# POINT THOMSON DEVELOPMENT HYDROLOGIC STUDIES

HYDROCON ENGINEERING
(Continental) LTD.

NOVEMBER 1982

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**HYDROCON ENGINEERING (Continental) LTD.**
ENGINEERING CONSULTANTS IN WATER RESOURCES

November 22, 1982

File: 107-40.2

Mr. R.W. Walls, P.E.
Senior Supervising Engineer
Point Thomson Project Group
Production Department, Western Division
Exxon Company, U.S.A.
1800 Avenue of the Stars
LOS ANGELES, California
90067

SUBJECT: POINT THOMSON DEVELOPMENT PROJECT
HYDROLOGIC TECHNICAL SERVICES, PTD-8202

Dear Mr. Walls:

In accordance with the original terms of reference and as refined at several progress meetings, we are herein pleased to submit our final report. The project was a joint effort of our Alaskan office and this office.

The report outlines the recommended pipeline and road corridor from the Point Thomson area to Prudhoe Bay, discusses and illustrates the findings of the 1982 field work, outlines pipeline and road river crossing concepts and criteria and finally, illustrates conceptual designs for the major streams to be crossed. [redacted] Finally, appended in a separate volume, are an annotated bibliography, glossary, and regional hydrometereologic data. The study should serve as a compendium of available hydrologic information, preliminary design values and concepts and thus the starting point for future hydrologic investigations.

We have thoroughly enjoyed assisting you and your staff in this project and trust this meets with your requirements at this time.

Yours truly,
HYDROCON ENGINEERING (Continental) LTD.

W.M. Veldman
W.M. Veldman, P.E.

WMV/po
cc: A. Erwin

220 - 4014 - Macleod Tr. S.E., Calgary, Alberta, Canada, T2G 2R7. (403) 243-8073

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SUMMARY

# 1.0 EXECUTIVE SUMMARY

Exxon Company, U.S.A., Western Production Division, is in the initial stages of planning a pipeline and road to run westward for 50 miles from the Point Thomson Development to the existing facilities at Prudhoe Bay. A self-sufficient production facility is being proposed in the area of Flaxman Island.

Hydrocon Engineering (Continental) Ltd. was engaged by Exxon to undertake field and office studies to define the nature of the river crossings in the 50-mile long study area and to provide preliminary hydraulic design data and criteria for the proposed road and pipeline river crossings.

Hydrocon's field work consisted of a one day pre-breakup reconnaissance trip in May 1982, a 10 day breakup reconnaissance and monitoring trip in late May and early June 1982, and a 5 day trip in July 1982 to survey cross-sections and measure flows at the major crossings. The work was concentrated on the three major crossings, namely the Main Channel Sagavanirktok, the Kadleroshilik and Shaviovik Rivers and two intermediate-sized unnamed streams. Qualitative observations were undertaken at the other minor crossings.

In the hydrologic studies to provide preliminary design flow values, the watersheds were first classified into three physiographic provinces, namely the Brooks Range, Arctic Foothills and Arctic Coastal Plain. The percentage of the crossing's drainage area falling into each category greatly affects the timing and magnitude of flood peaks. Streams originating in the Brooks Range, such as the Sagavanirktok River, are characterized by early spring runoff and peak flows which are generally induced by heavy summer rains. The peak flows for streams contained in the Arctic Coastal Plain occur in spring breakup due to snowmelt runoff. The streams with a high percentage of their drainage area in the Arctic Foothills (like the Shaviovik and Kadleroshilik Rivers) may have either spring breakup or rainfall-induced peaks.

Using available flow data from adjacent and regional gaging stations, preliminary design flow values were computed for the proposed river crossings. Additional field data, further analysis of regional data and evaluation of various runoff models is recommended to refine the design flood values.

The alternative road and pipeline river crossing techniques and their preliminary design criteria are outlined. For the road crossings, a minimum 1:100 year return flood is recommended while a 1:200 year flood is recommended as the minimum design value for the pipeline bridges. In the case of the road bridges or culverts, the choice depending largely on the size of the stream, an emergency overflow section in the roadway embankment is recommended as a general rule to ensure adequate freeboard is maintained at the bridge for all possible flow and ice conditions. Access requirements to the Point Thomson Development may affect the design of these overflow sections. The pipeline crossing type selected depends mainly on the size of the stream and economics. Alternative types are modular bridges, pilings or the pipeline incorporated with the road bridge.

For economic reasons, river training structures will likely be required at the major river crossings to confine the river into a waterway opening of a reasonable length. Bank heights, which are very low at some of the crossings, will affect the size of the bridges. With a low bank height, crossing length, all other factors being equal, will have to be greater to minimize flooding beyond the banks. By locating the pipeline crossing immediately adjacent to and downstream of the road bridge, the same training structures can then be used to also reduce the necessary length of the pipeline river crossing. At minor crossings, the relative proximity of the pipeline to the road will likely have little effect on costs since the pipeline river crossing, assuming piles are used, will essentially be similar to the mile-by-mile design. Preliminary pipeline and road crossing concepts are presented for the Main Channel Sagavanirktok, Kadleroshilik and Shaviovik Rivers and for two intermediate-sized unnamed streams. Buried as well as elevated pipeline crossings are shown for the cross-sectional data surveyed in July, 1982.

The study concludes that design flow for the study area may be estimated from regional data. Additional office studies and a field data collection program are necessary to test the applicability of various hydrologic models, and from this, refine the design flood values. Mile-by-mile studies are required to select the overall optimum alignment and from this, the location of river crossings can be refined. As part of this work, the status of the North Slope Borough's Conservation Zone, particularly at the river crossings, should be determined. A general study of the stability of North Slope rivers is also recommended. This would involve a review of historic river changes via airphotos to determine particularly the conditions which could cause major channel switches - a significant consideration in the design of several of the major crossings in the reach studied.

An annotated bibliography, glossary and representative regional hydrometeorologic data are appended. The report and its appendices is thus intended to serve not only as a preliminary assessment of hydrologic design values and crossing concepts, but also as a compendium of available and relevant hydrologic data. In this manner, it is expected that it will be the basis and starting point for all future hydrologic studies in the area.

# INTRODUCTION

# 2.0 INTRODUCTION

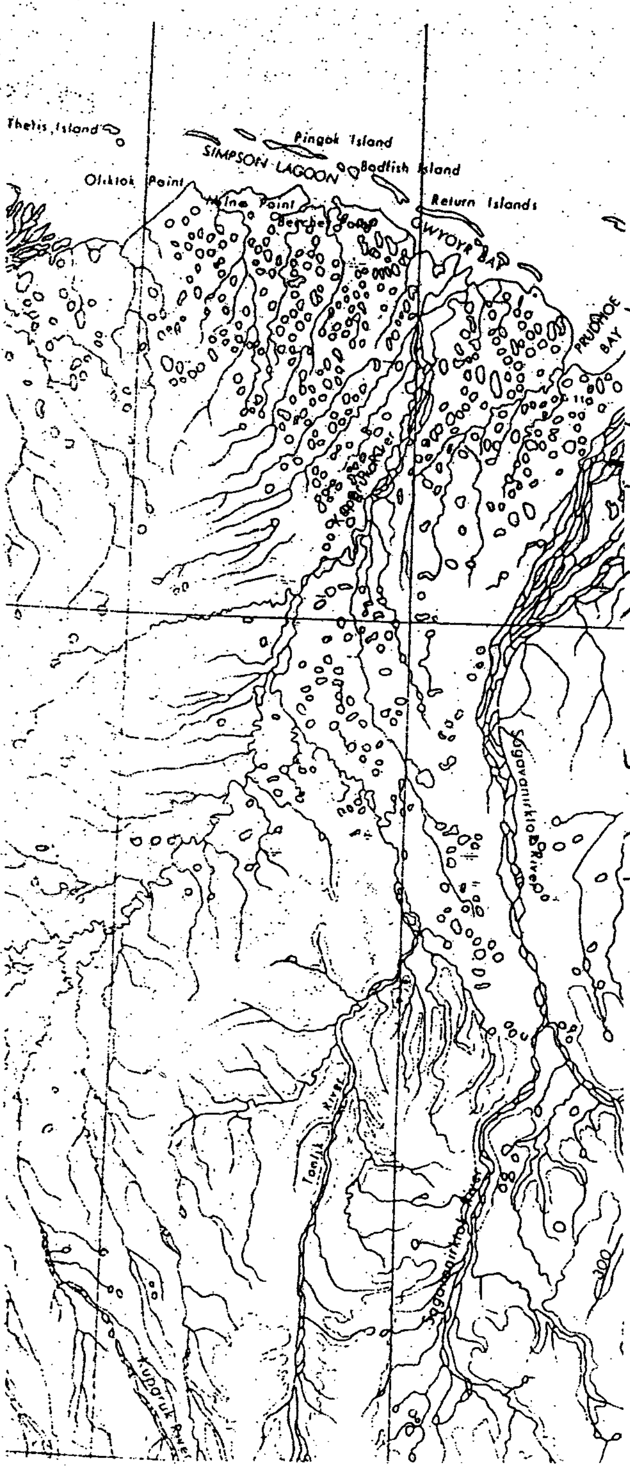
## 2.1 DESCRIPTION OF PROJECT

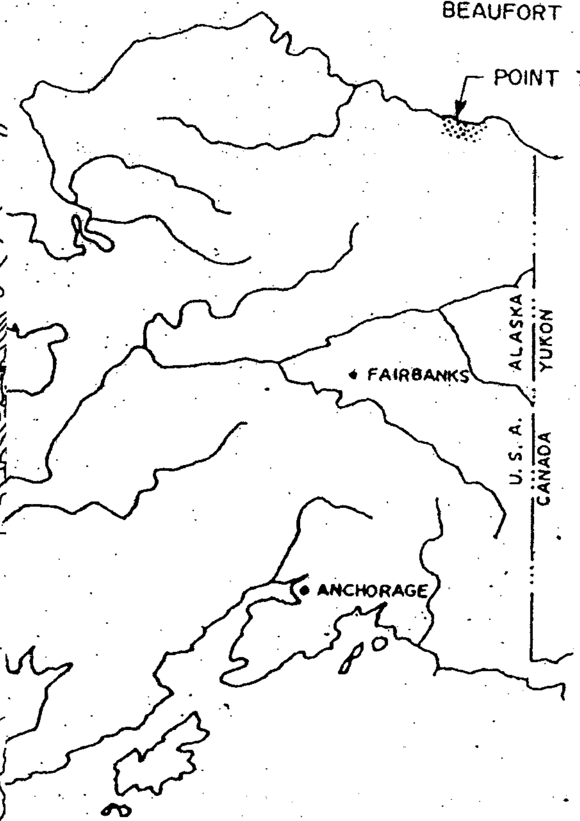
Exxon Company, U.S.A., Western Production Division, is in the initial stages of planning a pipeline and road from Prudhoe Bay to the Point Thomson Development located approximately 50 miles east of Prudhoe Bay. A self-sufficient production facility is being proposed in the area of Flaxman Island. A general location plan is shown on Drawing 1.

## 2.2 SCOPE OF HYDROLOGIC STUDIES

Exxon engaged Hydrocon Engineering (Continental) Ltd. to undertake an initial program of hydrologic studies to determine the character of streams in the Prudhoe Bay to Point Thomson area and to provide a preliminary quantification of the proposed road and pipeline crossings. The general purposes of the work, as outlined in the study's scope of services, are:

- Define and plan a data collection program to develop hydrologic data and preliminary criteria to support design and location of pipeline and access road crossings through the area defined as follows:
    - A two-kilometer wide pipeline/road corridor extending from the ARCO bridge across the West Channel of the Sagavanirktok River to a point approximately one kilometer south of Point Hopson; and
    - A rectangular area extending from Point Hopson to the east end of the Point Thomson Development, and within approximately two miles of the coast.
- Data collection to begin with the 1982 river breakup. Observe and discuss the relationship between sea and river ice during the 1982 breakup.
- Administer and implement data collection program. Responsible for obtaining all necessary permits and letters of non-objection for work on non-OWNER leases.
- Analyze field data and prepare preliminary design criteria.
- Provide hydrologic technical assistance to OWNER as required.
- Prepare progress reports and final report as required by the OWNER.





## KEY PLAN

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| CLIENT | EXXON COMPANY U.S.A. | | | | | | |
| PROJECT | POINT THOMSON - HYDROLOGIC STUDIES | | | | | | |
| SUBJECT | LOCATION PLAN | | | | | | |
| HYDROCON ENGINEERING (CONTINENTAL) LTD | | | | | | | |
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More specifically the requirements of the study again as outlined in the scope of services, are:

- Conduct a literature search to identify and abstract literature describing the hydrologic and engineering approaches applicable to design for the streams within the study area.
- Observe, measure and photograph the winter ice conditions in the streams.
- Observe and photograph the interaction of breakup flow with the winter ice both in the streams and immediately offshore.
- Observe the nature and size gradation of the stream bed and bank materials.
- Observe and photograph from the air any apparent tendencies of the Canning River to divert westward over its abandoned fan or distributaries.
- Measure the discharge magnitude and stage during the 1982 breakup on the Sagavanirktok (Main Channel), Kadleroshilik and Shaviovik Rivers using current meters; and on representative smaller streams using staff gages.
- Cross-section the streams where gaged and observe stream slope.
- Observe sediment concentration of each of the major streams; if heavily laden, observe flow patterns.
- Prepare a report presenting the observations made during the 1982 breakup, providing preliminary criteria, identifying specific problem areas and providing recommendations for future study.

The program undertaken by Hydrocon was essentially as outlined above. It consisted of a brief pre-breakup reconnaissance trip, an extended monitoring/ reconnaissance trip during breakup and a post-breakup trip to measure discharges and survey river cross-sections. The interaction of breakup flow with the winter sea ice was not observed since, due to the relatively steep gradients of the streams and the location of the proposed pipeline and road corridor, sea ice and offshore water levels will not affect the river crossings.

Highlights and mileposts of Hydrocon's work were as follows:

- April 27, 1982, contract awarded.
- May 10, 1982, reviewed scope of work with Exxon in Los Angeles.
- May 11, 1982, pre-breakup reconnaissance.
- May 28-June 6, 1982, breakup monitoring.
- July 14-18, 1982, post-breakup monitoring and surveys.
- September 10, 1982, meeting with Exxon in Los Angeles to review progress of work and preliminary findings.
- October 6, 1982, submitted draft report to Exxon for review and comments.
- October 25, 1982, received review comments from Exxon, Western Production Division, Los Angeles and Exxon Production Research, Houston.
- November 22, 1982, final report submitted.

## 2.3 REPORT ORGANIZATION

The purpose, methods employed and results of field work undertaken are described. Photographs are liberally used to illustrate field conditions. Watershed characteristics and hydrologic design values, as obtained from field and regional data, are then discussed and estimated respectively. Following this, the alternative crossing types and design criteria are outlined followed by a description of river behavior and conceptual designs for the major crossings. Conclusions and recommendations complete the report. The latter includes detailed recommendations for future studies.

Appendices are attached and include an annotated bibliography, glossary and representative regional hydrometeorologic data.

## 2.4 ACKNOWLEDGEMENTS

Hydrocon acknowledges the assistance and guidance of Exxon's staff from the Western Production Division, Los Angeles, in the formulation and completion of this project. Specifically their main areas of involvement were as follows:

J.C. Symmes - Beaufort Sea Project Manager
P.R. Kartzke - scope of work and review
L.A. Paxton-Rousseau - development of scope of work and project coordination (early phases)
A. Erwin - project coordinator and review

Mr. A. Chen, of the Arctic Section, Production Operations Division of Exxon Production Research Company, Houston, participated in reviewing the work at the Los Angeles meeting on September 10, 1982 and the draft report.

The following Hydrocon and subcontractor personnel were involved in the study:

.Project Manager and Report Author - Wim M. Veldman

.Field Studies - J. Aldrich (Hydrocon, Alaska)
- C. Malcovish
- E.S. Clarke (Clarke Engineering)
- J. Smith (Clarke Engineering)

.Report Input and Review - J. Aldrich
- C. Malcovish

.Drafting - D. Laychuk

.Secretarial - G. Keyes
- A. Powers

.Administrative - S. Bradshaw
- T. Coulter

ROUTE

# 3.0 ROUTE DESCRIPTION

## 3.1 CORRIDOR CONSIDERATIONS

Prior to the commencement of the field work and office studies, a pipeline and road corridor was selected from Prudhoe Bay to the Point Thomson area. The following guidelines or criteria were used in the selection of this corridor:

- the western end point was selected as the east bank of the West Channel of the Sagavanirktok River at ARCO's causeway. Overflow channels to the West Channel approximately 1-2 miles east of this end point were considered, as was the West Channel, to be part of Exxon's on-going hydrologic studies for the proposed Duck Island Development.

- the alignment was selected landward from the "Conservation Zone" as designated on the August 17, 1981 North Slope Borough Zone Designation Maps. Since this Conservation Zone extends for many miles along and upstream from the mouths of the major rivers, it could not be avoided totally at the river crossings.

- minimize the length of corridor.

Within the corridor thus determined, optimum river crossing locations were selected as described in subsequent chapters. The corridor, mileposts and the North Slope Conservation Zone are illustrated on Drawing 2.

## 3.2 HYDROLOGIC FEATURES

The corridor, as shown on Drawing 2, crosses the following rivers:

- Milepost (M.P.) 7.3* - Main Channel, Sagavanirktok River. The crossing involves a major subchannel located 0.5 mile west of the main part of the river. The subchannel and main channel are approximately 1000 and 3400 feet wide respectively. The east bank of the main channel is relatively high while its west bank is subject to overtopping.

- M.P. 16.3 - Kadleroshilik River. Active main channel width is 300 feet while total floodplain width is approximately 1000 feet. The banks are relatively low.

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* Although pipeline stationing normally starts at the field and ends at the delivery point, the delivery point to an existing facility (ARCO's West Channel bridge) is used as the starting point for stationing in this report. This change in convention was needed since only the delivery point could be defined precisely at this time.

M.P. 22.2 - A minor unnamed tributary to the Shaviovik River.

.M.P. 25.8 - Shaviovik River. Active main channel width is 500 feet while the total crossing length, including a vegetated terrace, is about 4200 feet.

.M.P. 27.3 - A major unnamed river paralleling the Shaviovik River and emptying into Mikkelsen Bay. This stream was surveyed.

.M.P. 29.6 - A very minor stream draining into Mikkelsen Bay.

.M.P. 31.2 - A very minor tributary joining the M.P. 29.6 stream.

.M.P. 31.8 - An intermediate-size unnamed river which empties into Mikkelsen Bay. This stream was surveyed.

.M.P. 33.7 - A very minor unnamed stream which joins the previous stream near its mouth.

.M.P. 35.2 - A minor unnamed stream which empties into a bay just west of Bullen Point.

.M.P. 38.0 - A minor unnamed stream which empties into a bay just east of Bullen Point.

.M.P. 39.3 - A minor unnamed stream which empties into the Beaufort Sea midway between Bullen Point and Point Gordon.

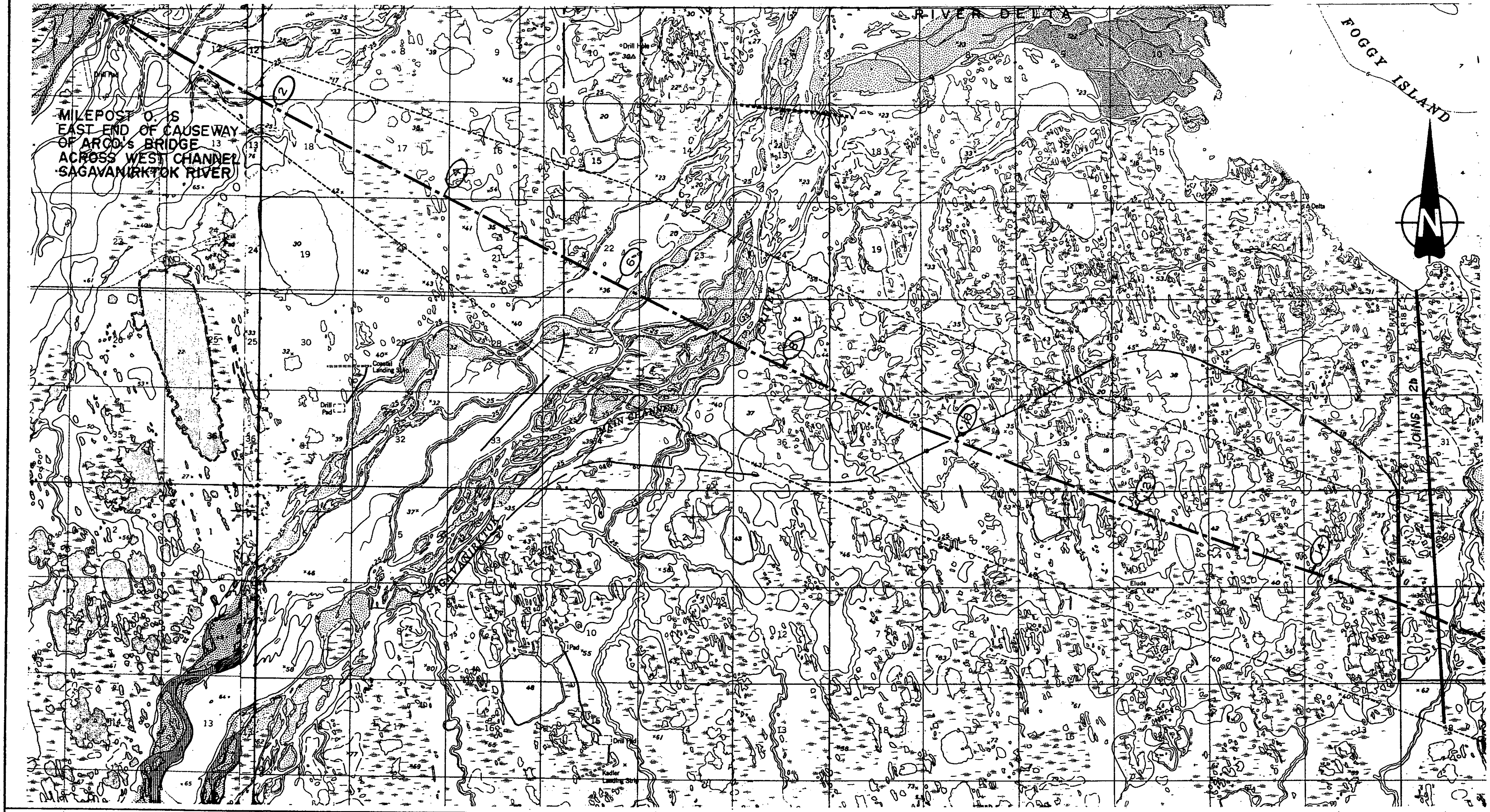
.M.P. 40.8 - A very minor unnamed stream linking a series of thermokarst lakes. It empties into the Beaufort Sea at Point Gordon.

.M.P. 41.8 - A very minor unnamed stream, like the previous one, draining and linking a series of thermokarst lakes. It empties into the Beaufort Sea just east of Point Gordon.

.M.P. 44.2 - A very minor unnamed stream which drains a series of thermokarst lakes. It empties just east of Point Hopson.

.M.P. 45.3 - A minor unnamed stream which discharges into the Beaufort Sea just west of Point Sweeney.

.M.P. 48.5 - A very minor coastal stream which discharges into the Beaufort Sea just east of Point Thomson.



## LEGEND

- — · — · — CENTERLINE OF PIPELINE AND ROAD CORRIDOR
- - - - - - - LIMITS OF PIPELINE AND ROAD CORRIDOR
- ............ ALTERNATE DOWNSTREAM CROSSING LOCATION
- — — APPROXIMATE LIMITS OF NORTH SLOPE BOROUGH CONSERVATION DISTRICT
- ○ MILEPOSTS

SCALE: 1:63,360

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CLIENT EXXON COMPANY U.S.A.
PROJECT POINT THOMSON - HYDROLOGIC STUDIES
SUBJECT PIPELINE AND ROAD CORRIDOR
MILEPOST 0 TO 15

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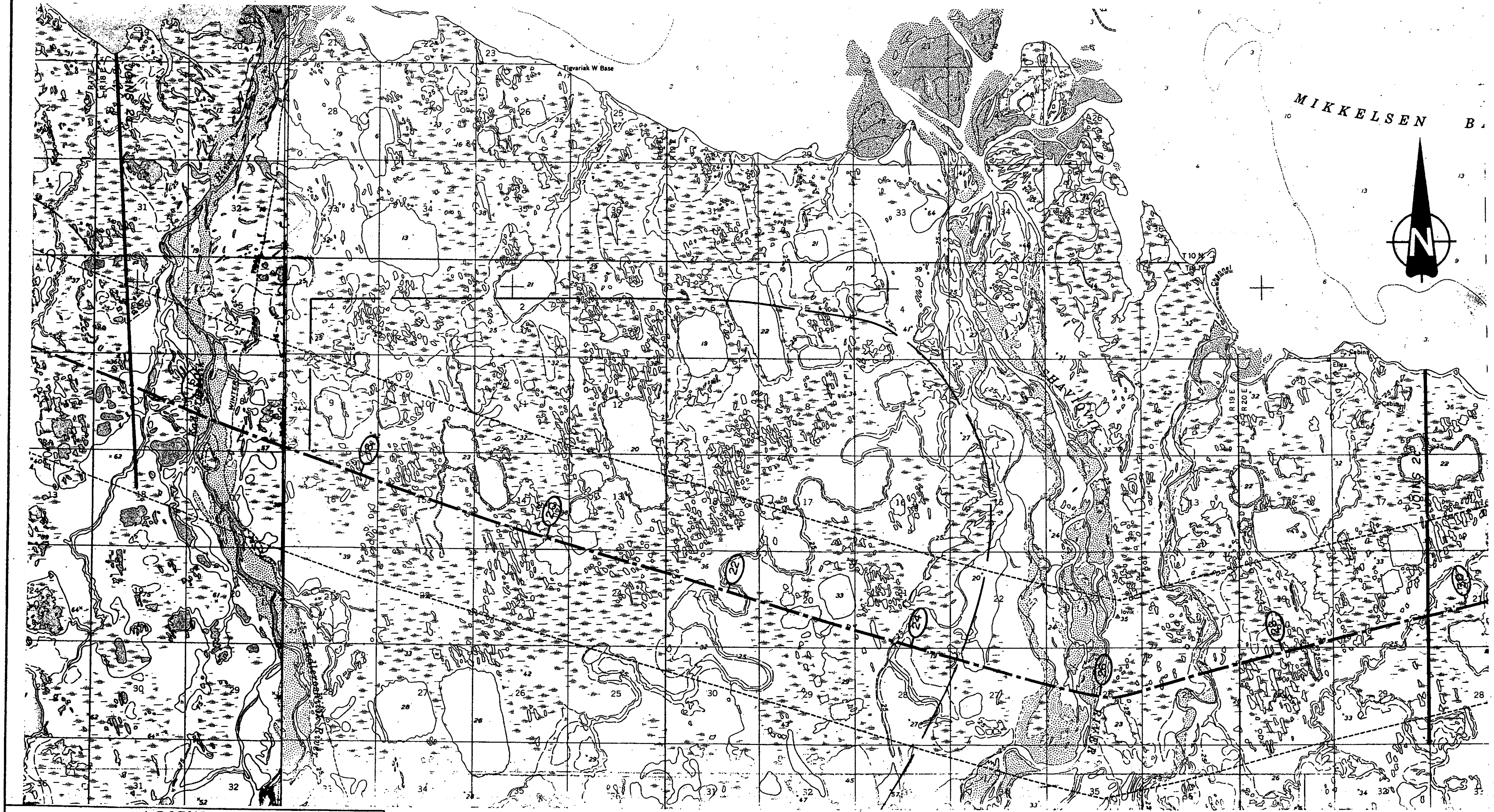

## LEGEND

- **— · · —** CENTERLINE OF PIPELINE AND ROAD CORRIDOR
- **- - - - -** LIMITS OF PIPELINE AND ROAD CORRIDOR
- **— —** APPROXIMATE LIMITS OF NORTH SLOPE BOROUGH CONSERVATION DISTRICT
- ○ MILEPOSTS

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CLIENT
EXXON COMPANY U.S.A.

PROJECT
POINT THOMSON - HYDROLOGIC STUDIES

SUBJECT
PIPELINE AND ROAD CORRIDOR
MILEPOST 15 TO 30

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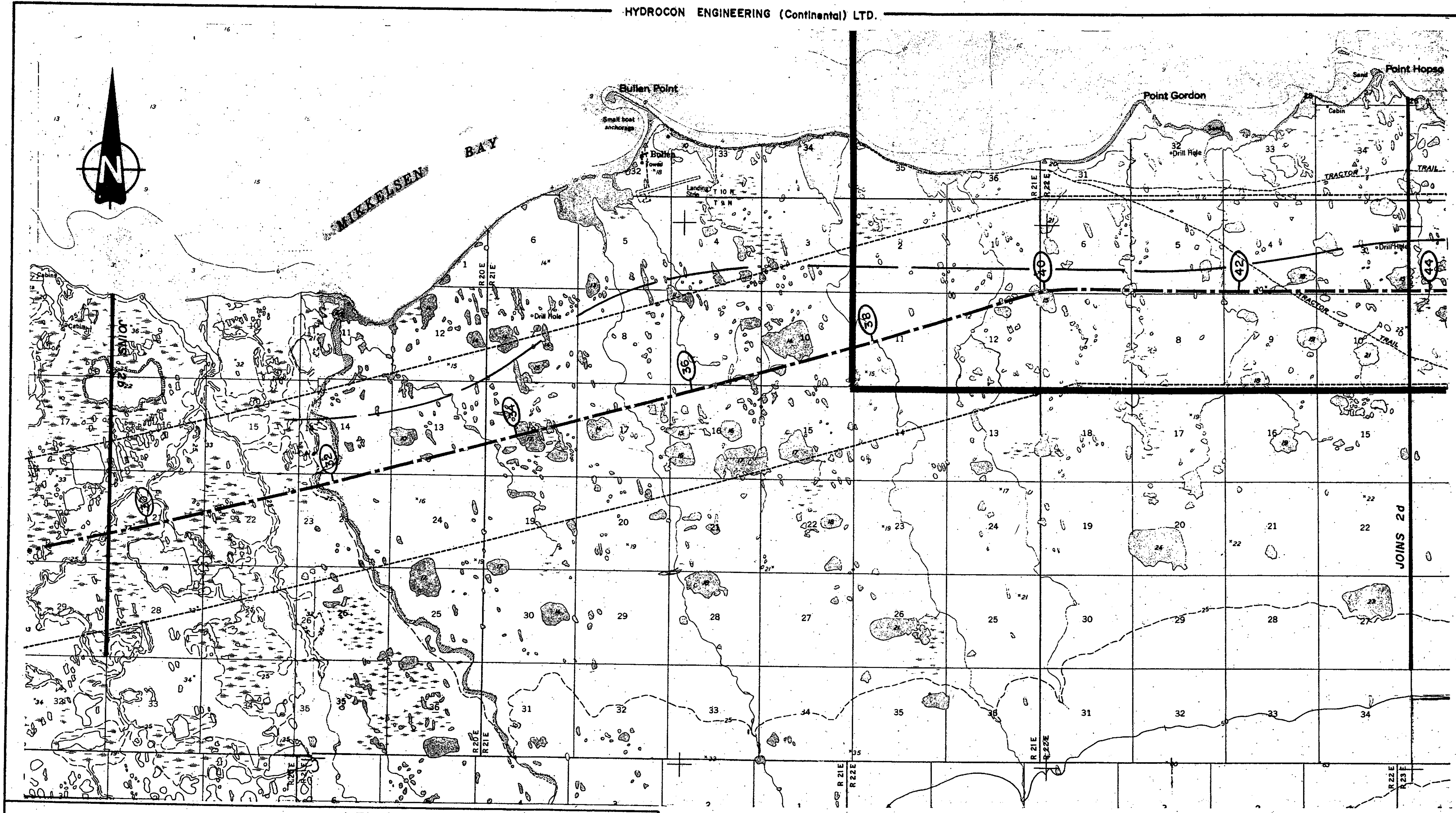

## LEGEND

- CENTERLINE OF PIPELINE AND ROAD CORRIDOR
- LIMITS OF PIPELINE AND ROAD CORRIDOR
- LIMITS OF POINT THOMSON DEVELOPMENT AREA
- APPROXIMATE LIMITS OF NORTH SLOPE BOROUGH CONSERVATION DISTRICT
- ○ MILEPOSTS

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PROJECT POINT THOMSON - HYDROLOGIC STUDIES

SUBJECT PIPELINE AND ROAD CORRIDOR
MILEPOST 30 TO 44

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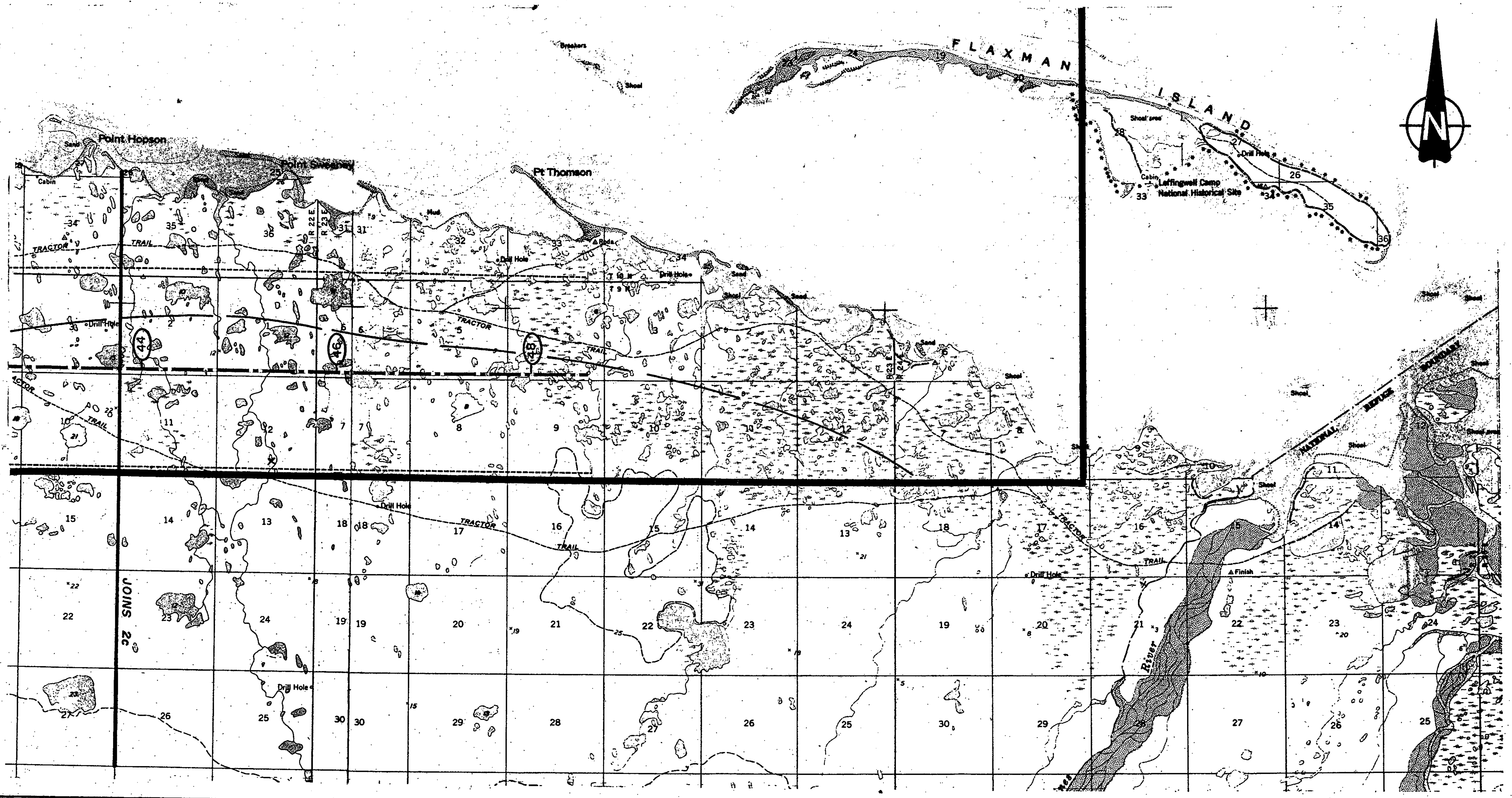

## LEGEND

- CENTERLINE OF PIPELINE AND ROAD CORRIDOR
- LIMITS OF PIPELINE AND ROAD CORRIDOR
- LIMITS OF POINT THOMSON DEVELOPMENT AREA
- APPROXIMATE LIMITS OF NORTH SLOPE BOROUGH CONSERVATION DISTRICT
- ○ MILEPOSTS

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PROJECT POINT THOMSON - HYDROLOGIC STUDIES

SUBJECT PIPELINE AND ROAD CORRIDOR
MILEPOST 44 TO 48

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From the West Channel of the Sagavanirktok River to M.P. 30 (east of the Shaviovik River), the landscape is dotted with thermokarst lakes - shallow saucer-like lakes that originated from thaw basins. Further eastward to the Staines River (just beyond the eastern limit of the Point Thomson Development), fewer lakes exist. The lakes, elongated in shape and generally oriented N15°W, range from a few feet to a mile in length.

## 3.3 TOPOGRAPHIC FEATURES

The profile of the route can generally be described as follows. Starting at the West Channel of the Sagavanirktok River and at an approximate elevation of 50 feet above sea level, the topography drops to an elevation of about 25 feet at the Main Channel of the Sagavanirktok River. The topography then rises to an elevation of 60 feet at the Kadleroshilik River, and falls to an elevation of 25 feet at the Shaviovik River. From the Shaviovik River, the topography generally drops to the 15-20 foot range in the Point Thomson area. The most significant topographic features are the pingos, which can rise up to 75 feet above the adjacent terrain.

FIELD STUDIES

# 4.0 FIELD STUDIES

## 4.1 PRE-BREAKUP RECONNAISSANCE

### 4.1.1 Purposes

The purposes of this phase of the field studies were to determine ice and snow conditions along the proposed corridor, determine presence and location of active aufeis areas, and to observe the height of ice relative to bankfull height.

### 4.1.2 Methodology

A one day helicopter reconnaissance was undertaken on May 11, 1982. High winds resulted in severe surface snow drifting and, except for gaining a general impression of the terrain, few meaningful observations could be made during the trip.

Since the breakup monitoring trip (May 28-June 6 1982), timed for the initiation of flow on the Main Channel of the Sagavanirktok River, enabled an assessment of pre-breakup conditions on the Kadleroshilik and Shaviovik and other unnamed streams, the lack of data obtained during the pre-breakup trip did not therefore significantly affect the scope of work completed or results of the study. The results presented below thus pertain to both trips.

### 4.1.3 Results

Although visibility was extremely limited during the May 11 helicopter reconnaissance, there was no visible ice within the corridor limits on the Main Channel of the Sagavanirktok River. Some aufeis was visible on the Kadleroshilik River.

In late May, the pre-breakup conditions on the Kadleroshilik River were as illustrated on Photo 1. Photos 2 to 4 illustrate an active aufeis area and the resultant ice mound produced by hydrostatic pressure. As cold weather reduces the available cross-sectional flow area under the ice, pressure builds up at some points to burst the surface ice cover. With the initiation of breakup, water exited through the cracks. However several days later, during which the warming trend continued, the flow stopped. This termination was probably due to the formation of flow passages, as a result of the available heat in the water, under the aufeis surface. A cross-section was surveyed across the ice pressure ridge on May 29, 1982 and the crest of it was measured to be 2.5 feet above the surrounding ice and only 1.4 feet below the channel bank on the west side of the crossing.

**PHOTO 1** **KADLEROSHILIK RIVER**

Looking downstream towards the crossing area prior to breakup.

107-2-35A May 29, 1982

**PHOTO 2** **KADLEROSHILIK RIVER**

Looking at ice pressure ridge. Height approximately 2.5 feet above surrounding ice and 1.4 feet below top of main channel bank on west side.

107-3-5 May 29, 1982

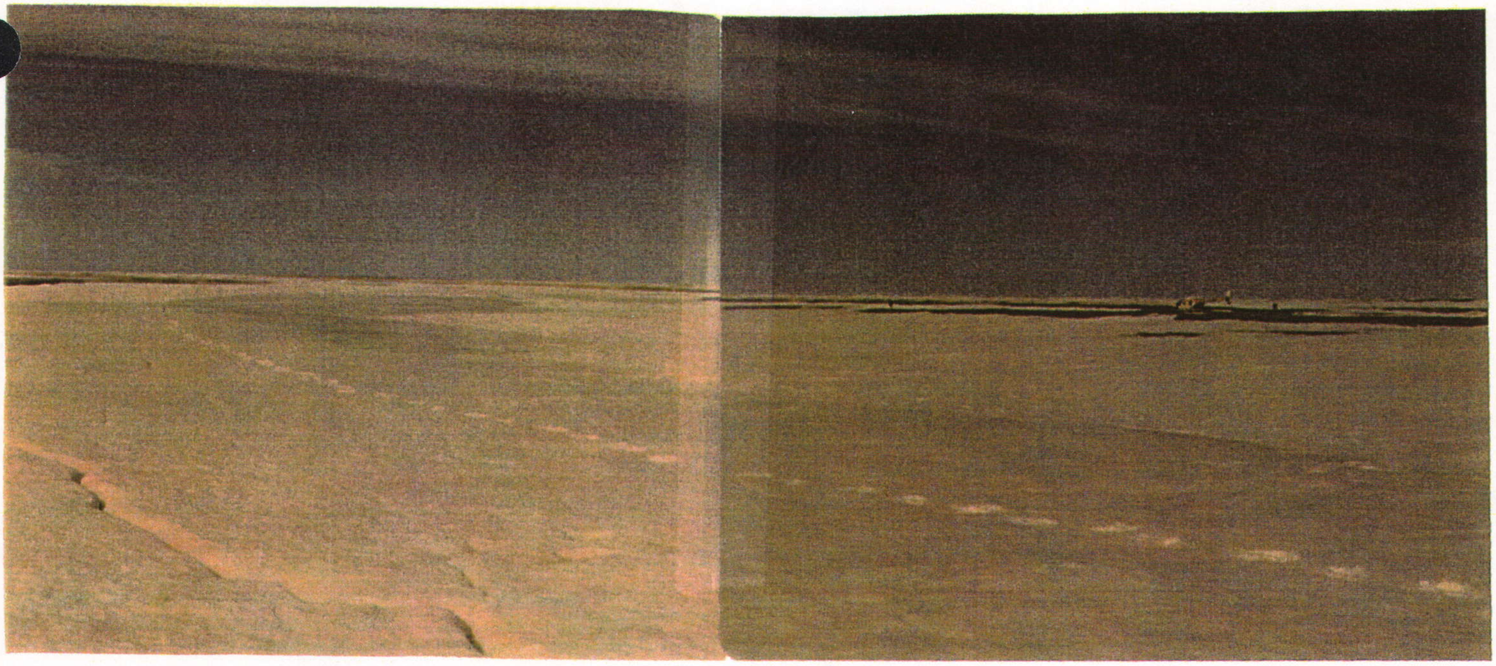

**PHOTO 3** **KADLEROSHILIK RIVER**
Panoramic view looking downstream and eastward at aufeis development.
107-4-17 & 18 May 31, 1982

**PHOTO 4** **KADLEROSHILIK RIVER**
Flow exiting from pressure crack prior to breakup. Flow stopped several days later probably as a result of a flow passage melted under the aufeis.
107-3-6 May 29, 1982

Active aufeis formations were also present at the Shaviovik River crossing although the presence of a winter trail down the river may have contributed to the overflows.* Photos 5 and 6 illustrate pre-breakup conditions. A cross-section was surveyed across the ice on May 29, 1982 and the crest of the ice was measured to be 5.0 and 2.2 feet below the west main channel bank and mid-channel bar respectively. The east bank is significantly higher than the west bank as illustrated by Photo 6.

## 4.2 BREAKUP MONITORING

### 4.2.1 Purposes

To monitor and observe flow and ice conditions during breakup, an extended field trip was undertaken from May 28 to June 6, 1982. Selection of an optimum pipeline and road corridor, from a hydrologic viewpoint, was also an important aim of this work.

### 4.2.2 Methodology

The work was undertaken using a 1 or 2 man crew supported by a Bell 206 helicopter. Pre-breakup surveys of ice levels were conducted on the Shaviovik and Kadleroshilik Rivers as described in section 4.1.3. Water levels were observed at these crossings as well as at the Main Channel of the Sagavanirktok River. Breakup conditions were also observed on the West Channel of the Sagavanirktok, Putuligayuk and Kuparuk Rivers. Although these streams are not within the Point Thomson study area, they have been studied for a number of years and thus form a good basis for comparison with the data-scarce Point Thomson streams.

Cross-sections and discharge meterings were not obtained during the breakup period as initially intended. It was felt that the results of surveys during the post-breakup trip would be more meaningful and cost effective.

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* By destroying the insulating effect of snow, the winter trail could have caused the ice to fully freeze down to the riverbed thus resulting in the flows to surface.

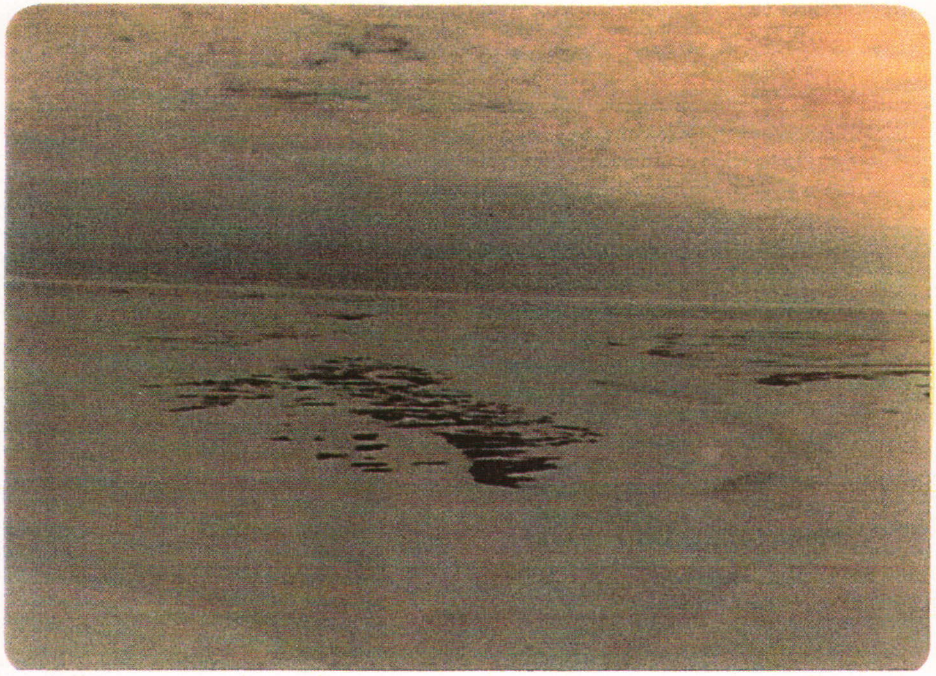


**PHOTO 5** **SHAVIOVIK RIVER**
Looking upstream at corridor.
107-2-32A May 28, 1982

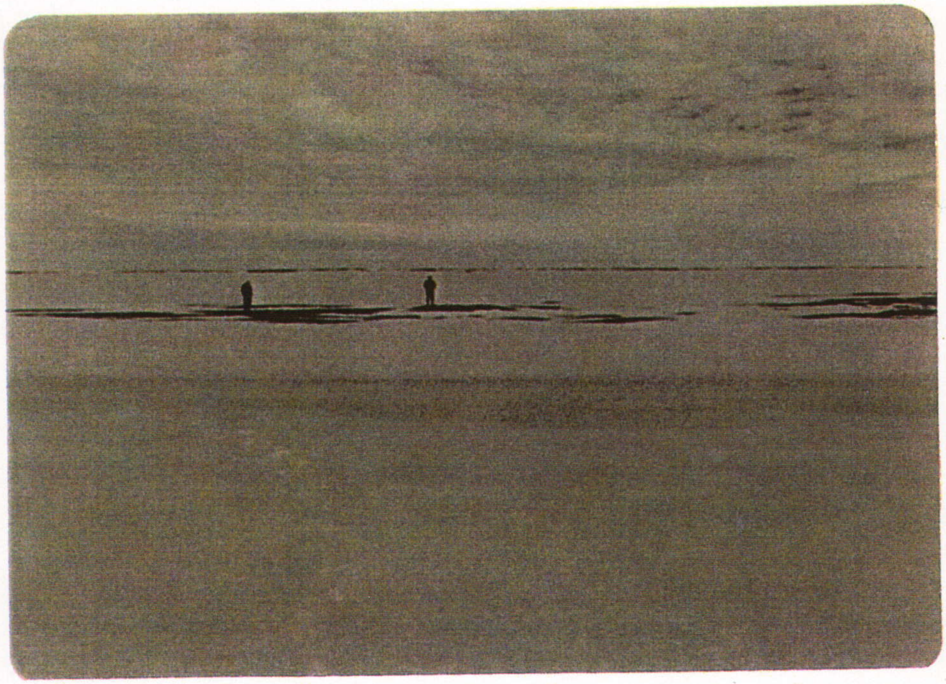


**PHOTO 6** **SHAVIOVIK RIVER**
Looking eastward from the west bank at main channel icings, mid-channel gravel bar and the high east bank in the background.
107-2-33A May 28, 1982

### 4.2.3 Results

4.2.3.1 General - Start of breakup was relatively late. Snow cover depths in the Prudhoe Bay area were slightly above normal. An area-wide rain in December 1981 which caused the formation of an ice layer in the snowpack, may have reduced drifting. The Main Channel of the Sagavanirktok River opened up first, followed by the Shaviovik, Kadleroshilik and finally the smaller unnamed Arctic Coastal streams. Flows - using the West Channel of the Sagavanirktok River which has been monitored for several years as a guide - were average during the initial stages of breakup. After the ice had passed, there are various opinions about the magnitude of flow in the Sagavanirktok River and particularly in the West Channel on June 6-7. The uncertainty may relate to the impact of ice, either still present at the West Channel bridge or still upstream resulting in ice-induced stages and a sudden release of water downstream, respectively. If there was no such impact, the estimated flows would have been the largest recorded breakup flow on the West Channel and thus probably on the Main Channel of the Sagavanirktok River as well.

4.2.3.2 Main Channel Sagavanirktok River - Flow commenced on the Main Channel on May 27 whereas the West Channel lagged by about 5 days. In late May, the flow contribution from the Ivishak - the major tributary to the Sagavanirktok River - was estimated to be approximately 60 percent. The characteristics of the bifurcation may account for the time lag between the Main and West Channels. The fact that the flow upstream of the bifurcation is along the east valley wall combined with less in-stream storage capacity in the Main Channel, probably results in a consistently earlier breakup on the Main Channel. The flow split at the bifurcation, approximately 50/50 this year, could vary depending on the location and intensity of aufeis at the bifurcation. Photos 7 and 8 illustrate the bifurcation area. It was observed that flow, which initially split into the Main Channel, was subsequently deflected into the West Channel by a blockage of ground-fast aufeis. Thus theoretical computations to predict the discharge that will occur in each of the channels, in any given year, is virtually impossible.

**PHOTO 7** **SAGAVANIRKTOK RIVER**

Looking downstream towards the point of bifurcation. The major channel in the foreground and the channel at the left form the Main Channel. The West Channel branch is just visible in the upper left hand corner of the photo.

107-4-11 May 31, 1982

**PHOTO 8** **SAGAVANIRKTOK RIVER**

A close-up view of aufeis (the greenish/blueish area at the right) at the bifurcation. Flow which initially split into the Main Channel (at the right) was deflected by the aufeis into the West Channel at the left of the photo.

107-3-14 May 29, 1982

The initial breakup flow, as generally happens each year, was over groundfast ice. If the warming trend continues uninterrupted, the aufeis generally lifts after 5-10 days at which time the ice has lost most of its strength. The shallow depth of the Sagavanirktok River combined with its many tortuous meanders, results in the majority of the large pieces of ice being grounded. Little movement of the larger pieces thus occurs. Flows up to 50X50 feet have been observed in the West Channel at the ARCO bridge in the past. If a cold spell follows the initial breakup flow, as in 1981, a thin ice cover is formed which, when breakup resumes, moves en masse downstream, as shown on Photos 9 and 10.

**PHOTO 9 MAIN CHANNEL, SAGAVANIRKTOK RIVER**
A thin layer of ice which formed as a result of a cold spell after the initial breakup, moves downstream with the resumption of breakup.
65-3-28 May, 1981

**PHOTO 10** MAIN CHANNEL, SAGAVANIRKTOK RIVER
Close-up of ice shown in Photo 9.
65-3-30 May, 1982

The early stages of breakup on the Main Channel are illustrated on Photos 11 and 12 which depict the area just upstream of the delta and the corridor area respectively. As can be seen in Photo 12, the western subchannel carried little or no flow in the early stages of breakup. As breakup progressed, this subchannel began to convey an increased percentage of flow, as shown in Photos 13 and 14.

**PHOTO 11 MAIN CHANNEL, SAGAVANIRKTOK RIVER**
Looking downstream at the delta area. An alternative crossing location initially considered is located at the islands and just upstream of the bifurcation to the right.
107-2-26A May 28, 1982

**PHOTO 12 MAIN CHANNEL, SAGAVANIRKTOK RIVER**
Looking downstream at the proposed corridor area. The west subchannel at the left of photo is carrying no flow at this time.
107-2-25A May 28, 1982

**PHOTO 13** **MAIN CHANNEL, SAGAVANIRKTOK RIVER**
Looking downstream at the corridor area. West subchannel at left is now carrying a substantial portion of the flow.
107-4-12 May 31, 1982

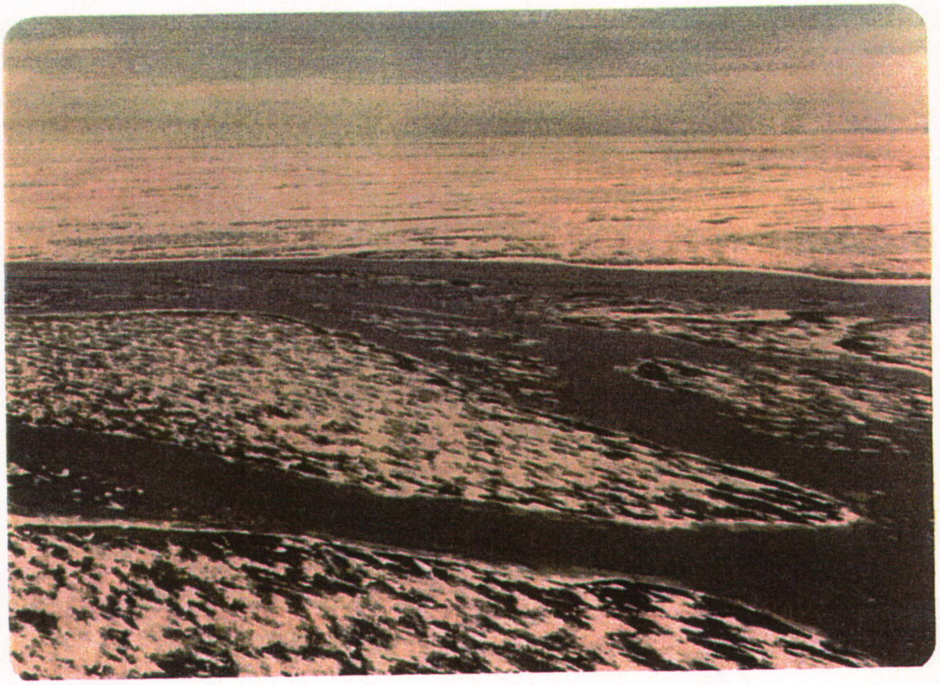


**PHOTO 14** **MAIN CHANNEL, SAGAVANIRKTOK RIVER**
Looking east across the corridor area. West subchannel in foreground.
107-4-13 May 31, 1982

Flows in the Main Channel were generally below bankfull stage in 1982. By comparison, in 1981, stages were generally at or slightly above the main banks and nearly inundated all mid-channel bars. The flat terrain beyond the main channel banks results in little increase in water levels after the bank is overtopped.

4.2.3.3 Kadleroshilik River - Breakup on the Kadleroshilik River commenced just prior to the end of the field trip. It was decided not to prolong the trip, but to obtain the necessary hydrologic and hydraulic data during the post-breakup trip. Photo 15 illustrates conditions in the approximate area of the corridor during the early stages of breakup.

**PHOTO 15** **KADLEROSHILIK RIVER**
Looking downstream during early stages of breakup in the vicinity of the corridor.
107-11-12A June 6, 1982

4.2.3.4 Shaviovik River - Breakup commenced on the Shaviovik River on June 1. The flow was over the bottom-fast ice and inundated some of the mid-channel gravel bars. Photos 16 and 17 illustrate the early phases of breakup. During latter stages, both the main east channel and the westernly subchannels conveyed substantial flow (Photo 18). Bank overtopping was not observed this year.

**PHOTO 16** **SHAVIOVIK RIVER**
Looking downstream towards the crossing area. Ice-covered lake partially visible at right of photo is located just upstream of the corridor area.
107-7-3A June 2, 1982

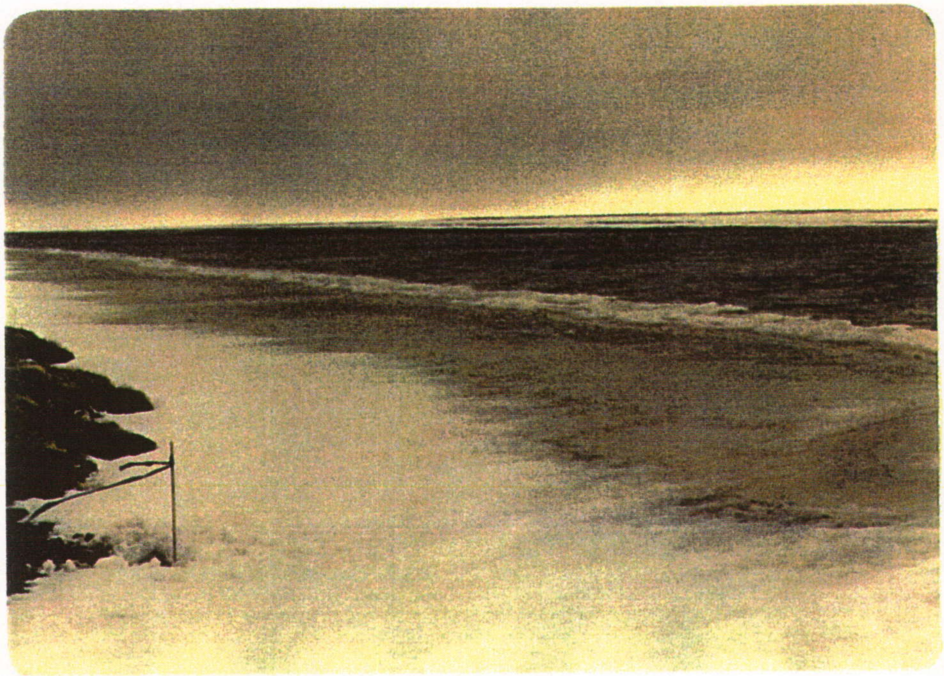


**PHOTO 17** **SHAVIOVIK RIVER**
Looking downstream along the west bank. High east bank visible in right background of photo.
107-7-2A June 2, 1982

**PHOTO 18** **SHAVIOVIK RIVER**
Looking downstream in the proposed corridor area at the west subchannel on the left and the main channel on the right.
107-11-10A June 6, 1982

4.2.3.5 Other Streams - Due to the time lag of breakup on the other unnamed streams, it was decided not to prolong the trip, but to obtain the necessary data and observations during the post-breakup trip.

## 4.3 POST-BREAKUP SURVEYS

### 4.3.1 Purposes

To complement the qualitative observations made during the breakup monitoring trip, to observe conditions at the unnamed streams not included in the previous trip and to survey river sections and hydrologic characteristics of the major streams, a field trip was conducted from July 14-18, 1982. Included at this time also was a qualitative assessment of the potential hydrologic impact of the Staines River on the Point Thomson Development area.

### 4.3.2 Methodology

The work was undertaken by either a 2 or 3 man crew depending upon the task to be performed, using a Bell 206 helicopter for support. Level surveys were done by wading or with the use of a powered inflatable raft. Temporary benchmarks were established. Flows were measured using a hand-held Price current meter.

As the cross-sections were used mainly to serve as backup to hydraulic and hydrologic calculations and to enable the preparation of conceptual designs, their precise location does not necessarily correspond with the optimum crossing location. Considering the conceptual nature of this study combined with the fact that the road and pipeline crossings may not always be proximate, this approach is considered to be adequate at this time.

### 4.3.3 Results

4.3.3.1 Main Channel Sagavanirktok River - Both the downstream crossing site just upstream of the delta area (see Photos 11 and 12 and Drawing 2) and the corridor area were assessed qualitatively. Since the downstream alignment is significantly longer and the crossing appears to offer no apparent hydrologic advantages with regard to crossing length, bank height and stability and bed material, it was not studied further.

At the corridor area, the mid-summer flow conditions are depicted on Photos 19 and 20. The Main Channel consists of numerous subchannels which form the main eastern channel and a west subchannel. Although the latter is substantially smaller than the eastern main channel, it is deeper and conveyed nearly as much flow at the time of the survey. The depth is probably attributable to the high flow concentration along its frozen eastern bank as depicted on Photo 21. Channel depths adjacent to relatively non-erodible boundaries such as permafrost banks are generally greater than next to free-eroding boundary conditions.

Two cross-sections separated by about 1000 feet and each about 3400 feet long were surveyed across the eastern channel. A single section about 900 feet long was surveyed across the western subchannel. The two areas, separated by a 3000 foot wide island (Photo 19) were not joined in the level survey. The upstream cross-section depicted as the centerline of the corridor is shown on Drawing 7 in Section 7.2. The measured flow on July 15, 1982 was 1925 and 1234 cubic feet per second in the eastern main channel and western subchannel, respectively. Median bed material sizes were estimated to be less than one inch while the channel slope was surveyed at 0.00046, which is approximately 2.5 feet per mile. Surveyed data is summarized on Table 4.1.

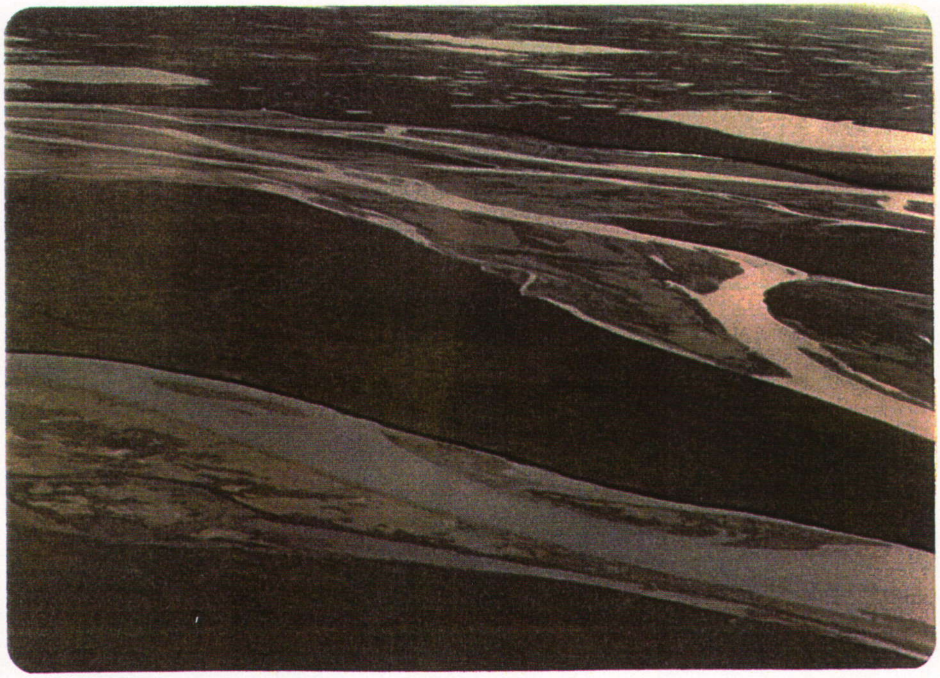


**PHOTO 19** **MAIN CHANNEL, SAGAVANIRKTOK RIVER**
Looking eastward across the corridor area between the two lakes in the background. Western subchannel in foreground.
107-12-25 July 14, 1982

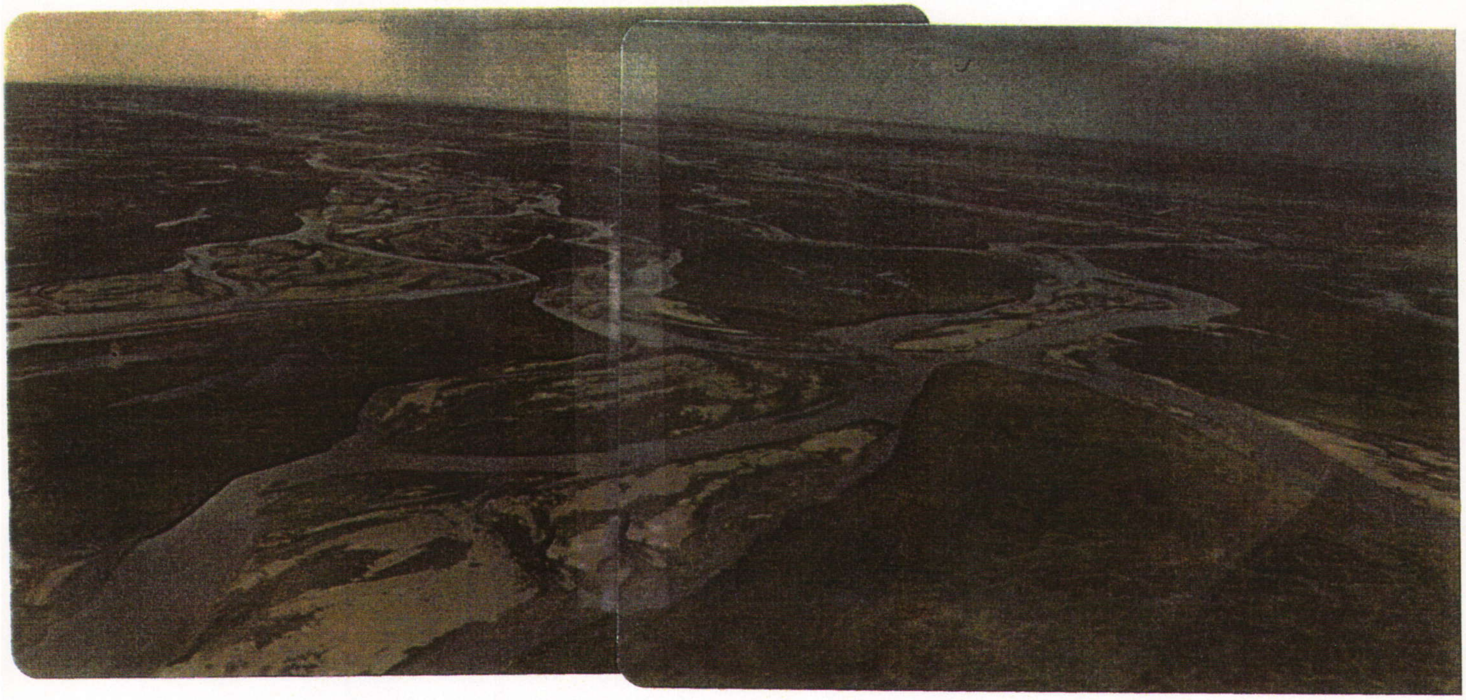


**PHOTO 20** **MAIN CHANNEL, SAGAVANIRKTOK RIVER**
Panoramic view looking upstream from the corridor area. Note bifurcation into the west subchannel at the lower right of photo.
107-12-23, 24 July 14, 1982

**PHOTO 21** **MAIN CHANNEL, SAGAVANIRKTOK RIVER**
Looking downstream along the east bank of the west subchannel. Flow concentrated along this frozen bank.
107-12-26 July 14, 1982

4.3.3.2 Kadleroshilik River - On July 17, 1982, the flow in the Kadleroshilik River was measured to be 44 cubic feet per second. A single 1200 foot long section was surveyed, the results of which are shown on Drawing 8 in Section 7.3. The average river slope in the area is 0.002 or approximately 10 feet per mile. Surveyed data is summarized on Table 4.1.

The most unusual feature of the river is its high gravel bed forms, up to a height of 4.5 feet, which probably progress downstream during flood events. An aerial view of the corridor area is shown on Photo 22 while Photo 23 illustrates a close-up of the bedforms.

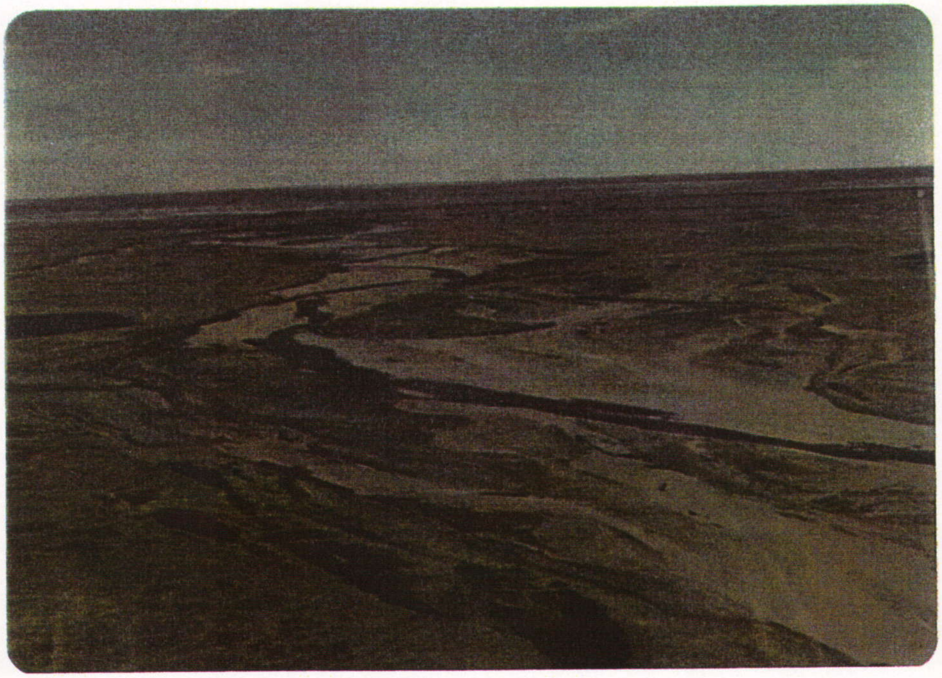


**PHOTO 22** **KADLEROSHILIK RIVER**
Looking downstream at the corridor area. The aufeis area noted on Photos 1-4 is at the left edge of photo opposite the lake.
107-12-32 July 14, 1982

**PHOTO 23** **KADLEROSHILIK RIVER**
Close-up of bedforms, maximum height of 4.5 feet.
107-12-37 July 14, 1982

4.3.3.3 Shaviovik River - On July 17, 1982, the flow in the Shaviovik River was measured to be 358 cubic feet per second. Two cross-sections were surveyed about 1500 feet apart. The sections, varying in width from 2200 to 2800 feet, were taken opposite and downstream of the right (east) bank lake shown on Photos 24 and 25. One of the sections is as shown on Drawing 9 in Section 7.4. The average river slope was measured at 0.0016 or approximately 8.5 feet per mile. Surveyed data is summarized on Table 4.1.

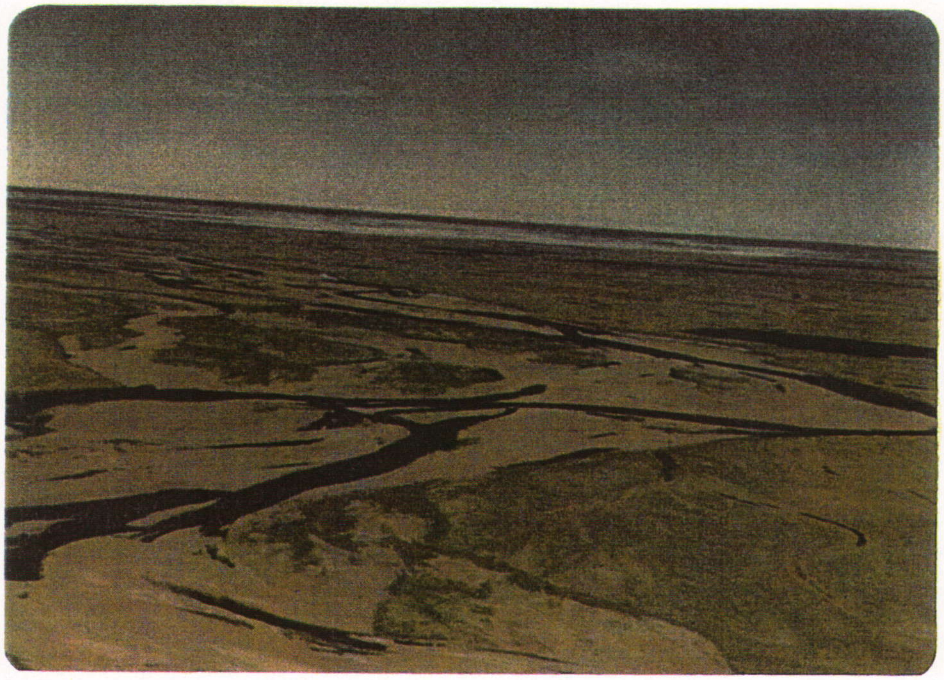


**PHOTO 24** **SHAVIOVIK RIVER**

Looking downstream towards the corridor area just downstream of the lake on the right (east bank).

107-13-5 July 14, 1982

**PHOTO 25** **SHAVIOVIK RIVER**

Looking eastward with the west subchannel in the foreground and the main channel in the background.

107-13-6 July 14, 1982

The river bifurcates into the main eastern channels, which were the only ones flowing at the time of survey, and an overflow channel to the west. The east bank of the main channel is very high and not subject to overtopping while the partially vegetated terrace area between the main east channels and west subchannels exhibits signs of overtopping. Photo 26 illustrates the main eastern channels.

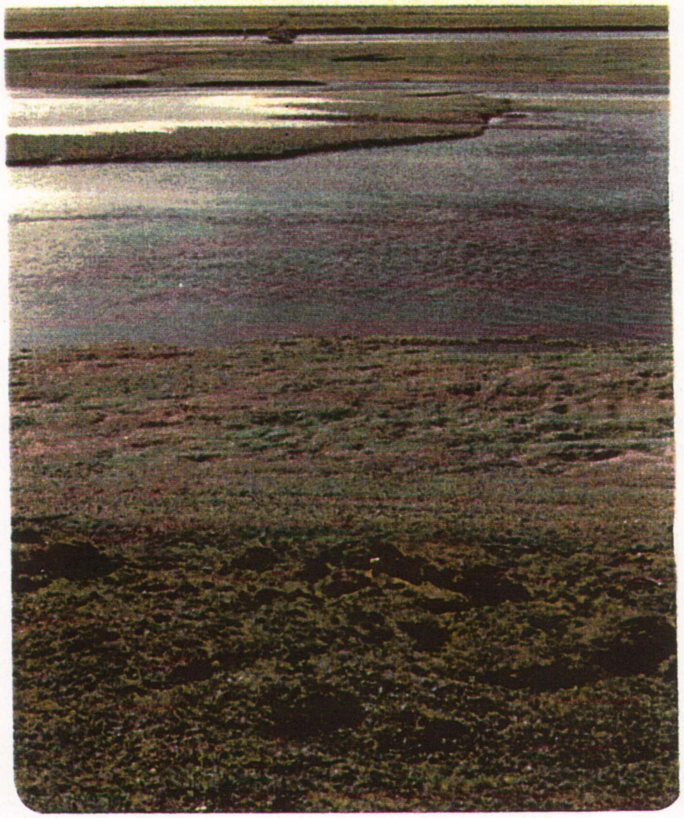


**PHOTO 26** **SHAVIOVIK RIVER**
Looking west across the main eastern channels from the high east bank.
107-13-7 July 14, 1982

4.3.3.4 <u>Unnamed Stream at M.P. 27.3</u> - On July 18, 1982, the flow at this unnamed stream was measured at 3.5 cubic feet per second. Two cross-sections approximately 650 feet apart were surveyed. These varied from 1100 to 1560 feet in length. The slope of the channel was surveyed at 0.0011 or approximately 6 feet per mile. Surveyed data is summarized on Table 4.1. One of the sections is shown on Drawing 10 in Section 7.5. Photo 27 illustrates the stream in the corridor area.

**PHOTO 27** **UNNAMED STREAM, M.P. 27.3**
Looking downstream towards the corridor in the middle of photo. Note overflow channel at bottom left of photo.
107-13-9 July 14, 1982

4.3.3.5 Unnamed Stream at M.P. 31.8 - On July 14, 1982, two cross-sections, varying in width from 300 to 380 feet, were surveyed at this unnamed stream. The sections were located about 700 feet apart. The flow was estimated to be less than 2 cubic feet per second. The average river slope at the survey site was measured at 0.0023 or approximately 12 feet per mile. Surveyed data is summarized on Table 4.1. One of the sections is shown on Drawing 11 in Section 7.6.

Photos 28 and 29 illustrate an aerial and ground view respectively of the corridor area. The stream is well confined to a single channel. Although the banks are relatively low, little or no overtopping of the main bank was apparent. Lower vegetated terraces exhibited signs of overtopping.

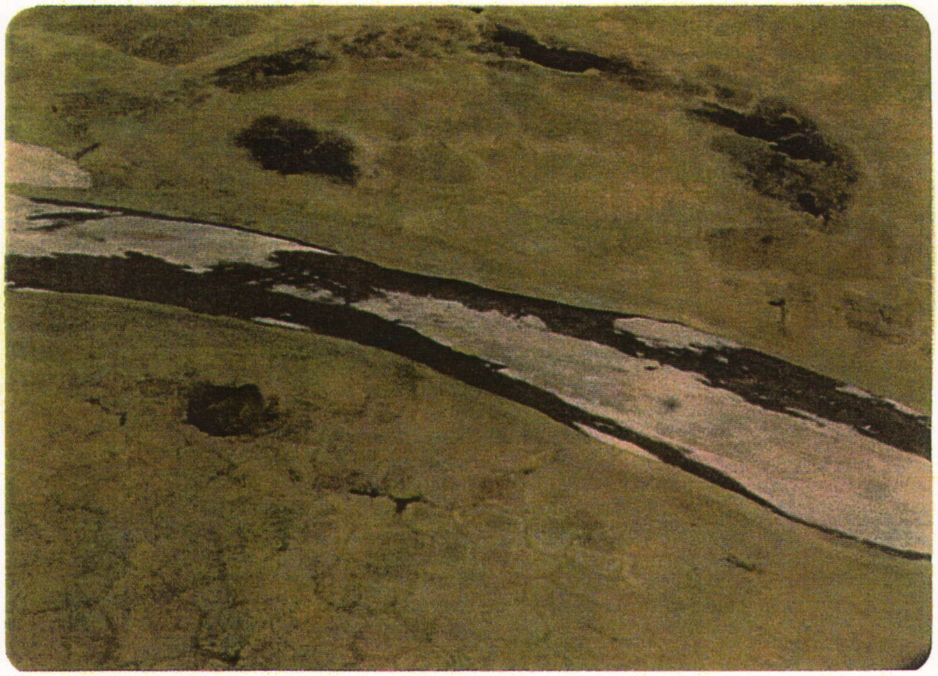


**PHOTO 28** **UNNAMED STREAM, M.P. 31.8**
Looking eastward across the crossing.
107-13-14 July 14, 1982

**PHOTO 29** **UNNAMED STREAM, M.P. 31.8**
Looking downstream in the surveyed area.
107-13-22, 23 July 14, 1982

# TABLE 4.1

## SUMMARY OF STREAM CHARACTERISTICS FROM POST-BREAKUP SURVEYS

## JULY 14-18, 1982

| Stream | MAIN CHANNEL | | | SUBCHANNEL[3] | | | Average |
|---|---|---|---|---|---|---|---|
| | Width[1] feet | Depth[2] feet | Flow cfs. | Width feet | Depth feet | Flow cfs. | Slope[4] ft/mile |
| Main Channel Sagavanirktok | 3400 | 11 | 1925 | 1000 | 15.5 | 1234 | 2.5 |
| Kadleroshilik | 1200 | 7 | 44 | ---- | ---- | ---- | 10.0 |
| Shaviovik | 2000 | 7.5 | 358 | 600 | 5.5 | 0 | 8.5 |
| M.P. 27.3 | 1300 | 13 | 3.5 | ---- | ---- | ---- | 6.0 |
| M.P. 31.8 | 340 | 5 | 2.0 | ---- | ---- | ---- | 12.0 |

NOTES:

1. Average width of surveyed sections.
2. As measured to the top of the lowest bank.
3. Includes width of active floodplain.
4. Local surveyed slope.

4.3.3.6 Other Minor Streams - Other representative minor streams in the area photographically documented and included herein are:

.M.P. 22.2 - Photo 30
.M.P. 29.6 - Photo 31
.M.P. 31.2 - Photo 32
.M.P. 35.2 - Photo 33
.M.P. 38.0 - Photo 34
.M.P. 40.8 - Photo 35
.M.P. 44.2 - Photo 36

The nature of these streams is visible from these photos and is as more fully described in Section 7.7.

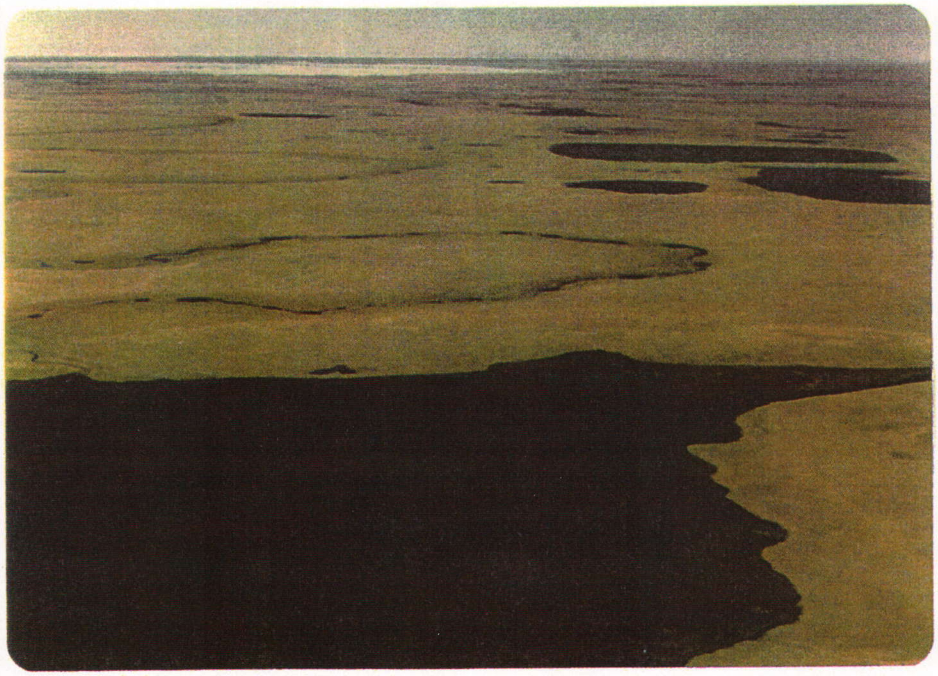


**PHOTO 30** **UNNAMED STREAM, M.P. 22.2**
Stream drains lake in foreground. Looking north.
107-13-2 July 14, 1982

**PHOTO 31** **UNNAMED STREAM, M.P. 29.6**
Looking northward.
107-13-12

July 14, 1982

**PHOTO 32** **UNNAMED STREAM, M.P. 31.2**
Looking north.
107-13-13

July 14, 1982

**PHOTO 33** **UNNAMED STREAM, M.P. 35.2**
Looking north. Note bank instabilities.
107-13-16 July 14, 1982

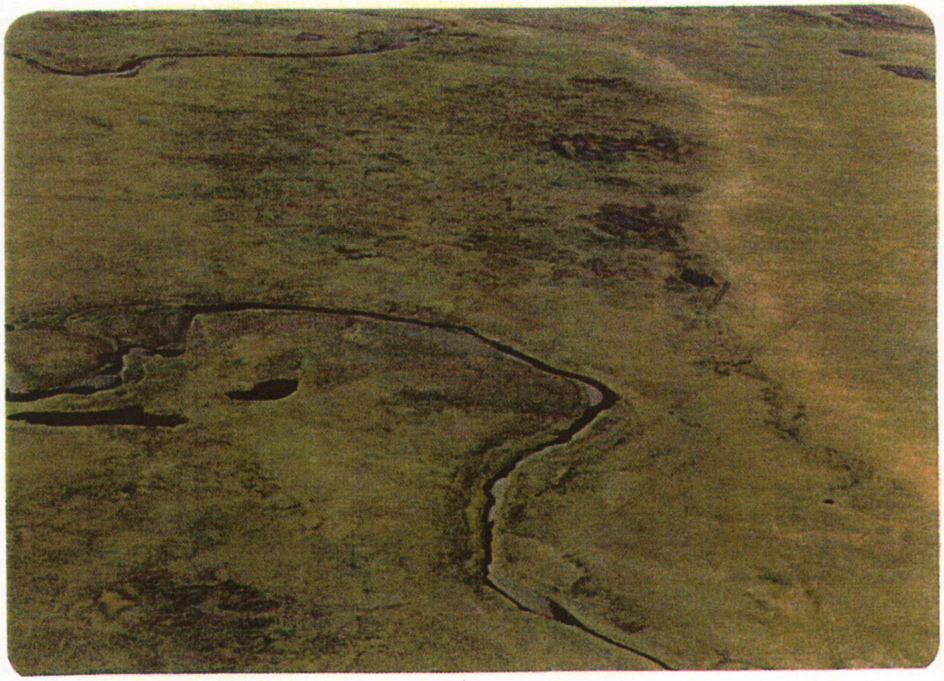


**PHOTO 34** **UNNAMED STREAM, M.P. 38.0**
Looking north.
107-13-17 July 14, 1982

**PHOTO 35** **UNNAMED STREAM, M.P. 40.8**
Stream draining a series of lakes. Looking north.
107-13-18 July 14, 1982

**PHOTO 36** **UNNAMED STREAM, M.P. 44.2**
A minor incised stream. Looking north.
107-13-19 July 14, 1982

4.3.3.7 Staines River - An aerial reconnaissance of the Staines River was undertaken during the July 14, 1982 trip. The Staines, which is essentially a bifurcation or overflow channel from the Canning River, conveyed no flow at the time of the reconnaissance. Its bed was covered with a light vegetative mat indicating a low frequency of occurrence and duration of flow. There were no signs of overflow from the Staines into the Point Thomson Development area. Photo 37 illustrates the aufeis-laden central channel of the Canning River and the Staines riverbed in the background. The severity of aufeis combined with the magnitude of breakup flow probably govern the volume of overflow into the Staines River.

**PHOTO 37** **CANNING/STAINES RIVER**

Looking downstream from the Canning/Staines River bifurcation (14 miles upstream of coast). Canning River in foreground still heavy with aufeis. Staines River, barely visible in upper left of photo, conveying no flow at this time.

107-13-20 July 14, 1982

# HYDROLOGY

# 5.0 HYDROLOGY

## 5.1 WATERSHED CHARACTERISTICS

### 5.1.1 General

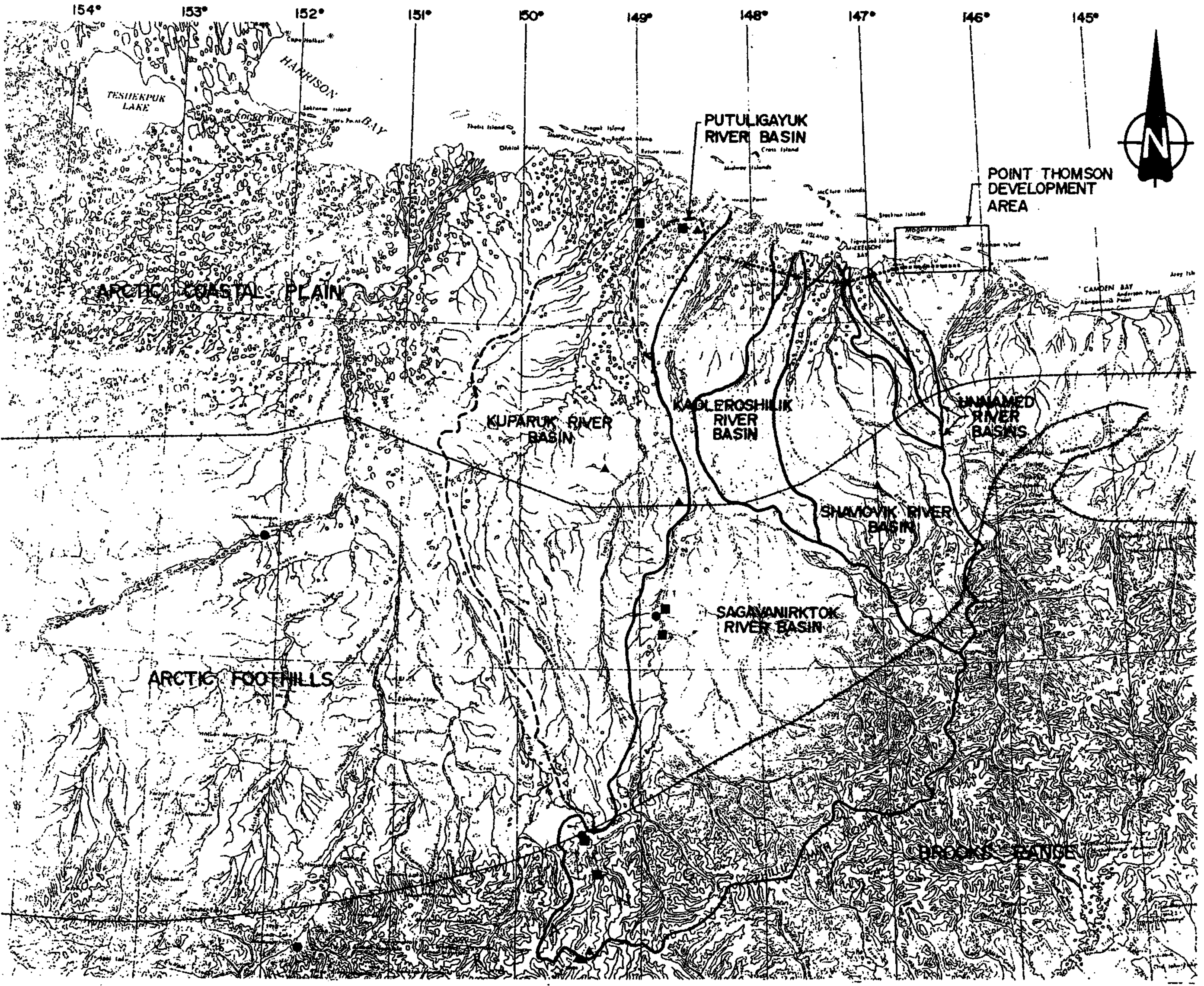
The general characteristics of watersheds located on the Arctic Slope of Alaska are described according to their runoff characteristics, climate, physiography, surficial geology and permafrost characteristics. Although the availability of site-specific information is limited, a description of these parameters on a regional basis is possible.

The most impressive hydrologic processes in the Arctic are snowmelt runoff and the resultant spring breakup. Spring breakup generally starts during the latter part of May or early June, and usually begins with runoff over bottom-fast aufeis. Although a single peak is most common, multiple peaks can occur if temperature variations occur.

Rivers flowing from the north side of the Brooks Range into the Arctic Ocean pass through one or more of the following physiograhic provinces: Brooks Range, Arctic Foothills and Arctic Coastal Plain. Each of these provinces and the surficial geology associated with it are briefly described below and are as shown on Drawing 3. The river profiles and basin elevations are depicted on Drawing 4.

The Brooks Range is rugged, with east-trending ridges. The elevation of the peaks range from 6000 to 8000 feet. The surficial geology of this area is described by Karlstrom et. al. (1964) as being primarily undifferentiated alluvium and slope deposits consisting of dominantly coarse rubble deposits with a high percentage of bedrock exposures.

The Arctic Foothills are made up of low mountains and rolling plateaus with intervening tundra plains. The northern part of the Foothills consist of broad east-trending ridges that vary in elevation from 600 to 1200 feet. The Foothills typically have undifferentiated glacial and glacio-fluvial deposits. The surficial geology has been described (Karlstrom et.al., 1964) as dominantly fine grained quaternary deposits associated with



## REGIONAL HYDROLOGIC MAP

0 50
Miles

**LEGEND**
- ▲ SNOW STATIONS
- ● TEMPERATURE / PRECIPITATION STATIONS
- ■ GAGING STATIONS
- × MAJOR STREAM CROSSINGS
- ┄ CENTERLINE OF PIPELINE AND ROAD CORRIDOR
- ― BOUNDARY BETWEEN PHYSIOGRAPHIC DIVISIONS (APPROXIMATE)

| | STATION | LOCATION LATITUDE | LOCATION LONGITUDE | PERIOD OF RECORD |
|---|---|---|---|---|
| SNOW STATIONS | ATIGUN CAMP | 68° 10′ N | 149° 26′ W | 1978 - 1982 |
| | ATIGUN CIRQUE | 68° 08′ N | 149° 29′ W | 1980 - 1982 |
| | ATIGUN PASS | 68° 08′ N | 149° 28′ W | 1982 |
| | BARTER ISLAND* | 70° 07′ N | 143° 39′ W | 1976 - 1982 |
| | JAGO RIVER* | 69° 42′ N | 143° 36′ W | 1977 - 1979 |
| | KAVIK | 69° 30′ N | 147° 00′ W | 1977 - 1979 |
| | PRUDHOE BAY | 70° 16′ N | 148° 34′ W | 1977 - 1982 |
| | SAGWON | 69° 26′ N | 148° 41′ W | 1977 - 1982 |
| | TOOLIK | 69° 38′ N | 149° 18′ W | 1977 - 1982 |
| TEMP/PRECIP. STATIONS | ANAKTUVUK | 68° 10′ N | 151° 46′ W | 1953 - 1975 |
| | BARROW* | 71° 18′ N | 156° 47′ W | 1921 - 1982 |
| | BARTER ISLAND* | 70° 08′ N | 143° 38′ W | 1952 - 1982 |
| | FRANKLIN BLUFFS | 68° 29′ N | 149° 29′ W | 1979 - 1982 |
| | GALBRAITH | 68° 29′ N | 149° 29′ W | 1974 - 1982 |
| | HAPPY VALLEY | 69° 10′ N | 148° 50′ W | 1974 - 1982 |
| | LONELY | 70° 55′ N | 153° 15′ W | 1978 - 1982 |
| | UMIAT | 69° 22′ N | 152° 08′ W | 1976 - 1982 |

## REGIONAL METEOROLOGICAL STATIONS

NOTE: SEE CLIMATIC DATA APPENDIX FOR SUMMARIES OF DATA.

* BEYOND MAP LIMITS SHOWN

| STATION NUMBER | STATION NAME | DRAINAGE AREA (sq. miles) | YEARS OF OPERATION | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1969 | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 |
| 15896000 | KUPARUK RIVER NEAR DEADHORSE | 3 130 | | | ▬ | ▬ | ▬ | ▬ | ▬ | ▬ | ▬ | ▬ | ▬ | ▬ | ▬ | ▬ |
| 15896700 | PUTULIGAYUK RIVER NEAR DEADHORSE | 176 | | ▬ | ▬ | ▬ | ▬ | ▬ | ▬ | ▬ | ▬ | ▬ | ▬ | | | |
| 15904900 | ATIGUN RIVER TRIBUTARY NEAR PUMP STATION 4 | 32.6 | | | | | | | | ▬ | ▬ | ▬ | ▬ | ▬ | ▬ | ▬ |
| 15905000 | GALBRAITH LAKE TRIBUTARY NEAR GALBRAITH CAMP | 7.55 | | | | | | | ▭ | ▭ | ▭ | ▭ | ▭ | | | |
| 15910000 | SAGAVANIRKTOK R. NEAR SAGWON | 2 208 | ▬ | ▬ | ▬ | ▬ | ▬ | ▬ | ▬ | ▬ | ▬ | ▬ | ▬ | | | ▬ |
| 15910200 | HAPPY CREEK NEAR HAPPY VALLEY | 34.5 | | | | ▭ | ▭ | ▭ | ▭ | ▭ | ▭ | ▭ | ▭ | ▭ | ▭ | ▭ |
| 15798700 | NUNAVAK CREEK NEAR BARROW | 2.79 | | | | ▬ | ▬ | ▬ | ▬ | ▬ | ▬ | ▬ | ▬ | ▬ | ▬ | ▬ |
| *10MD001 | FIRTH RIVER NEAR MOUTH | 2 240 | | | | ▬ | ▬ | ▬ | ▬ | ▬ | | | ▬ | ▬ | ▬ | ▬ |
| *10MD002 | BABBAGE RIVER BELOW CARIBOU CREEK | 582 | | | | | | | | | ▬ | ▬ | ▬ | ▬ | ▬ | ▬ |

**LEGEND**
- ▬ CONTINUOUS RECORDER
- ▭ CREST GAGE AND MISCELLANEOUS DATA
- * WATER SURVEY OF CANADA STATIONS

## PERIOD OF RECORD OF FLOW DATA

NOTE: SEE FLOW DATA APPENDIX FOR DAILY FLOW DATA.

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1970 | | | | | | | | | | | | | | | | | | | | | | | | | △ | | | | | | | | | | | | | | | | | | | | | | |
| 1971 | | | | | | | | | | | | | | | | | | | | | | | ○ | | | △ | | | | | | | | | | | | | | | | | | | | | |
| 1972 | | | | | | | | | | | | | | | | | | | | | | | | ○ | | | | | | | | | △ | | | | | | | | | | | | | | |
| 1973 | | | | | | | | | | | | | | | | | | | | | | | ○ | | | | | | △ | | | | | | | | | | | | | | | | | | |
| 1974 | | | | | | | | | | | | | | | | | | | ○ | | | | | | | | | | △ | | | | | | | | | | | | | | | | | | |
| 1975 | | | | | | | | | | | | | | | | | | | | | | | | | | | | ○ | | | | △ | | | | | | | | | | | | | | | |
| 1976 | | | | | | | | | | | | | | | | | | | | | | | | | ○ | | | | | | | | | △ | | | | | | | | | | | | | |
| 1977 | | | | | | | | | | | | | | | | | | | | | | | | | ○ | | | | △ | | | | | | | | | | | | | | | | | | |
| 1978 | | | | | | | | | | | | | | | | | | | | | | | | | | | ○ | | | △ | | | | | | | | | | | | | | | | | |
| 1979 | | | | | | | | | | | | | | | | | | | ○ | | | △ | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1980 | | | | | | | | | | | | | | | | | | | □ | | | | | | | | | | ○ | | | | | | | | | | | | | | | | | | |
| 1981 | | | | | | | | | □ | | | | | | | | ○ | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1982 | | | | | | | | | | | | | | | | | | ■ | | | □ | | ● | | | ○ | | ▲ | | | | | | | | | | | | | | | | | | | |
| | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
| | MAY | | | | | | | | | | | | | | | | | | | | | | JUNE | | | | | | | | | | | | | | | | | | | | | | | | |

**LEGEND**
- ■ MAIN CHANNEL, SAGAVANIRKTOK RIVER
- ▲ KADLEROSHILIK RIVER
- ● SHAVIOVIK RIVER
- □ WEST CHANNEL, SAGAVANIRKTOK RIVER
- △ PUTULIGAYUK RIVER
- ○ KUPARUK RIVER

## COMPARISON OF BREAKUP DATES

| REV. | BY | DESCRIPTION | DATE | APPR'D. |
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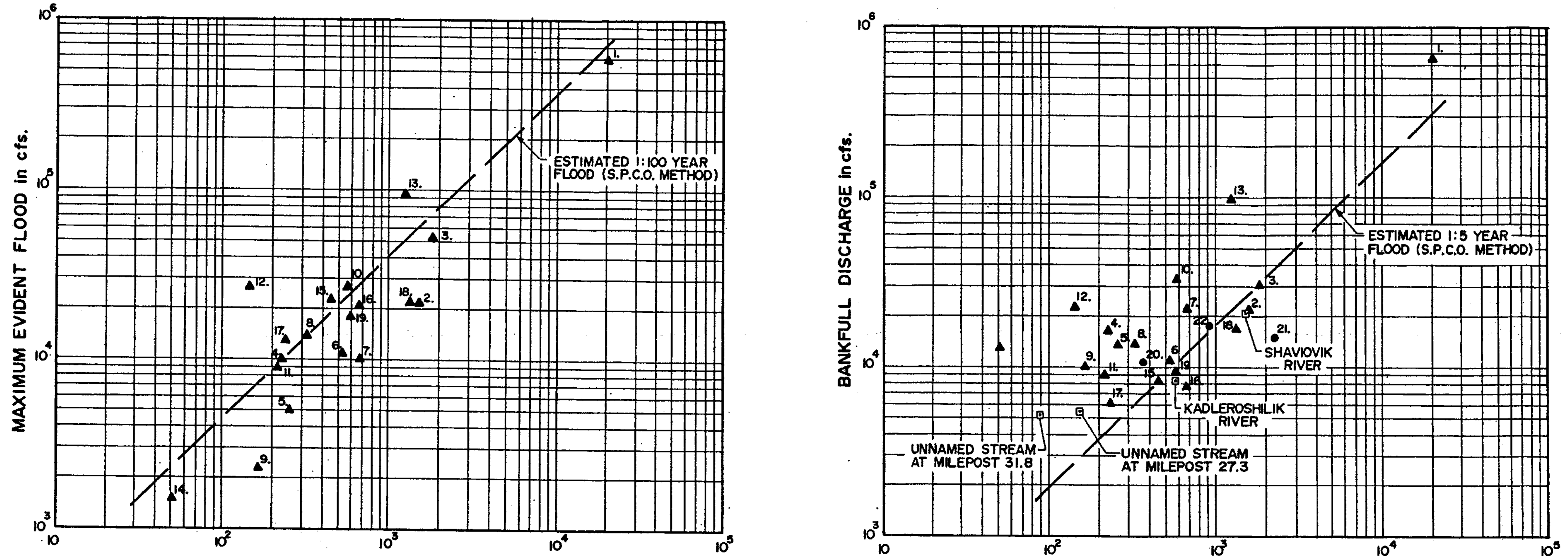


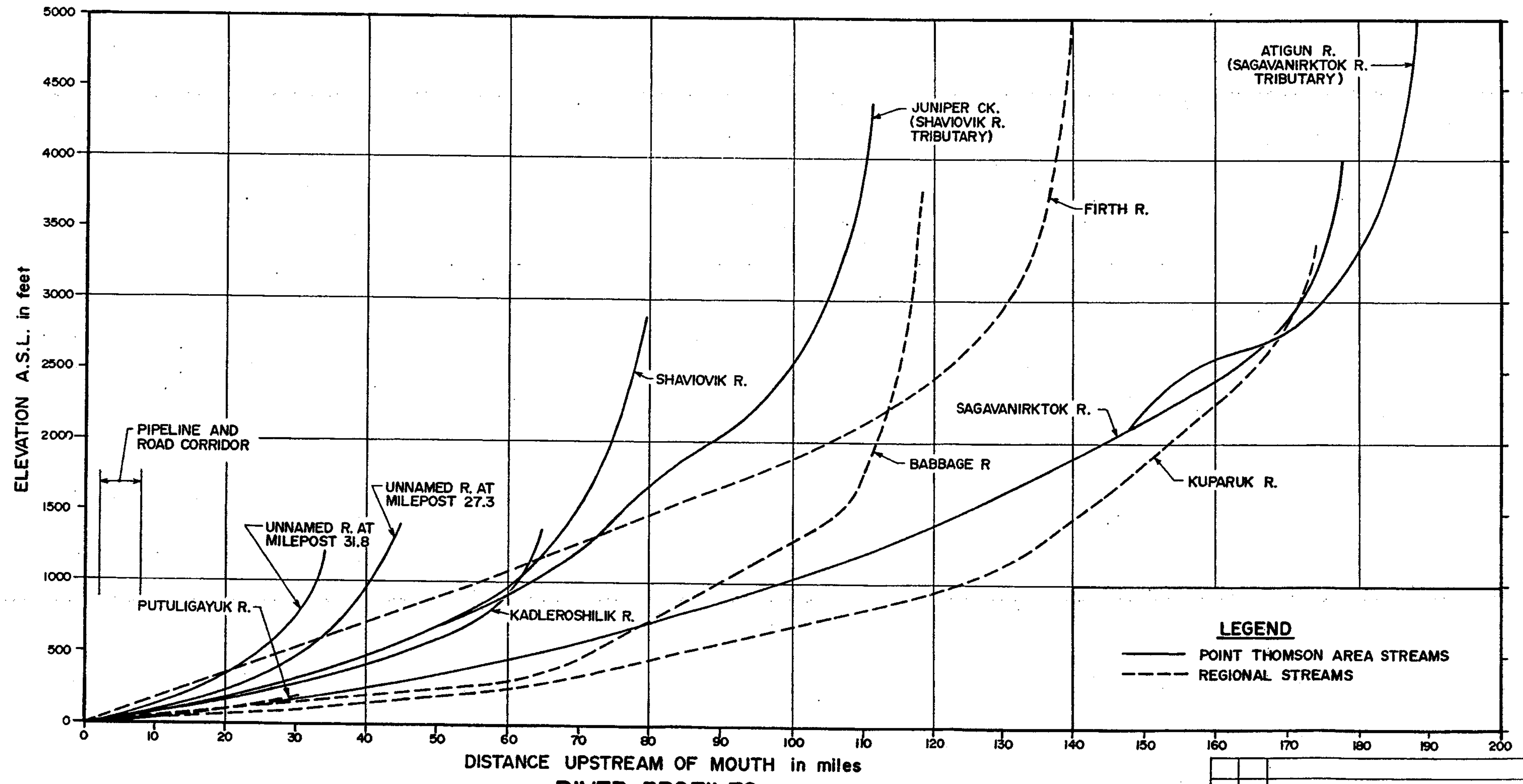
## REGIONAL FLOOD DATA

**LEGEND**

- ▲ ESTIMATED BY THE U.S. GEOLOGICAL SURVEY.
- ● ESTIMATED BY THE GEOLOGICAL SURVEY OF CANADA.
- ⊡ ESTIMATED BY HYDROCON.

1 COLVILLE RIVER
2 SHAVIOVIK RIVER (1977)
3 CANNING RIVER (1977)
4 KATAKTURUK RIVER
5 MARSH CREEK
6 SADLEROCHIT RIVER
7 HULAHULA RIVER
8 JAGO RIVER
9 OKEROKOVIK RIVER
10 AICHILIK RIVER
11 EGAKSRAK RIVER
12 EKALUAKAT RIVER
13 KONGAKUT RIVER
14 TURNER RIVER
15 KADLEROSHILIK RIVER
16 SHAVIOVIK RIVER (1973)
17 KAVIK RIVER
18 CANNING RIVER (1973)
19 MARSH FORK CANNING
20 MALCOLM RIVER
21 FIRTH RIVER
22 BABBAGE RIVER

**NOTE:** INFORMATION PRESENTED IS INCLUDED IN THE FLOW DATA APPENDIX.



## RIVER PROFILES

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sloping hills and exhibiting few bedrock exposures. Few lakes are present in the major valley bottoms.

The Arctic Coastal Plain extends from the Beaufort Sea to the Arctic Foothills. The Plain begins at the shoreline just a few feet above sea level and extends as high as 600 feet above sea level. The surficial geology has been defined by Karlstrom et. al. (1964) as consisting of older coastal deposits of inter-stratified alluvial and marine sediments, including local areas of geologic drift. The area has very poor drainage and contains numerous lakes which may or may not be connected to the main drainage courses.

All of the physiographic provinces are generally underlain by continuous permafrost. The thickness of the permafrost increases in a northerly direction and reportedly ranges from 1200 to 2000 feet. Along the Arctic Coastal Plain, the active layer is nearly completely frozen in early June, but may be as much as 3 or 4 feet in depth in late summer.

### 5.1.2 Main Channel Sagavanirktok River

The Sagavanirktok River upstream of the Main Channel/West Channel bifurcation drains an area of approximately 5000 square miles. An additional 200 square miles of area drains directly into the Main Channel between the bifurcation and the proposed corridor area. As shown on Drawing 3, the river originates in the Brooks Range, flows north through the Arctic Foothills and the Arctic Coastal Plain, and discharges into the Beaufort Sea east of Prudhoe Bay via the Main and West Channels. The drainage area is divided almost equally between the three provinces, with slightly more area in the Brooks Range and slightly less area in the Arctic Foothills. The main tributary to the Sagavanirktok is the Ivishak River which joins it about 50 miles upstream from Prudhoe Bay.

As discussed and illustrated previously, the split in flow between the Main and West Channels can vary from year to year depending upon the extent and location of aufeis at the bifurcation and perhaps also on the positioning (in an east-west direction) of the initial breakup flow upstream of the bifurcation.

### 5.1.3 Kadleroshilik River

The Kadleroshilik River drains an area of approximately 586 square miles at the proposed pipeline crossing. It originates in the Arctic Foothills, flows north through the Arctic Coastal Plain, and discharges into Foggy Island Bay (see Drawings 2 and 3). Most of the drainage area is within the Arctic Coastal Plain.

### 5.1.4 Shaviovik River

The Shaviovik River drains an area of approximately 1555 square miles at the proposed pipeline crossing. It originates in the Brooks Range, flows north through the Arctic Foothills and Arctic Coastal Plain, and discharges into Foggy Island Bay (see Drawings 2 and 3). Most of the drainage area is in the Arctic Foothills, with only slightly less area in the Arctic Coastal Plains. The main tributary to the Shaviovik is the Kavik River which joins it about 10 miles upstream from its mouth.

### 5.1.5 Unnamed Stream at M.P. 27.3

The unnamed stream at M.P. 27.3 along the proposed pipeline drains an area of approximately 155 square miles. It originates in the Arctic Foothills, flows north through the Arctic Coastal Plain, and discharges into Mikkelsen Bay (see Drawings 2 and 3). The majority of the drainage is located in the Arctic Coastal Plain.

### 5.1.6 Unnamed Stream at M.P. 31.8

The unnamed stream at M.P. 31.8 along the proposed pipeline drains an area of approximately 88 square miles. It originates in the Arctic Foothills, flows north through the Arctic Coastal Plain, and discharges into Mikkelsen Bay (see Drawings 2 and 3). The majority of the drainage is located in the Arctic Coastal Plain.

### 5.1.7 Other Streams

The other minor streams previously illustrated in Section 4.3.3.6 and shown on Drawing 2 lie entirely within the Arctic Coastal Plain. Some drain a series of thermokarst lakes in a chain-like appearance, which is often referred to as a beaded stream pattern.

### 5.1.8 Canning - Staines Rivers

The Canning River drains an area of approximately 2150 square miles at its mouth. It originates in the Brooks Range, flows north through the Arctic Foothills and Arctic Coastal Plain, and discharges into the Beaufort Sea (see Drawings 2 and 3). Most of the drainage area is in the Brooks Range with significantly less area in the Arctic Coastal Plain and Arctic Foothills provinces. Three small glaciers are present in the headwaters of the Canning.

The Staines River is a distributary channel of the Canning River. It is located entirely within the Arctic Coastal Plain and flows out of the Canning River approximately 29 miles upstream from the mouth of the Canning.

## 5.2 AVAILABLE DATA

### 5.2.1 Streamflow

5.2.1.1 Point Thomson Area - Except for flow data at the U.S.G.S station at Sagwon on the Sagavanirktok River and the flow measurements taken in 1982 as part of this study, flow data for the Point Thomson study area is virtually non-existent.

The miscellaneous flow measurements are summarized on Table 5.1. Included is the West Channel of the Sagavanirktok River since it is useful as an indication of Main Channel flows.

Estimates of bankfull discharge and maximum evident flood have been made by the U.S. Geological Survey (Childers et. al, 1973 and Childers et. al., 1977) and are as summarized on Table 5.2 and illustrated on Drawing 4. The relevant data given in the Childers reports is also presented in the Flow Data Appendix.

5.2.1.2 Regional - Although on a regional basis there is considerably more flow data than in the Point Thomson area, the available information is still sparse and of short duration.

## TABLE 5.1

## FLOW DATA-POINT THOMSON PIPELINE CORRIDOR AREA

| Stream | Location | Date | Flow in C.F.S. | Source of Data |
|---|---|---|---|---|
| Sagavanirktok | | | | |
| .West Channel | ARCO's Bridge | 1970 | 20,000 | 1 |
| | | 1971 | 25,000 | 1 |
| | | 1972 | 23,000 | 1 |
| | | 1975 | 0 | 2 |
| | | 1976 | 8,480 | 2 |
| | | 1980 | 13,000 | 3 |
| | | 1981 | 20,000 | 3 |
| .Main Channel | Near Delta | 11/11/75 | 0 | 2 |
| | Near Delta | 5/28/81 | 20,000 | 4 |
| | Corridor | 7/15/82 | 3,150 | 5 |
| Kadleroshilik River | Corridor | 7/17/82 | 44 | 5 |
| Shaviovik River | Long 147°16'30" | | | |
| | Lat 70°05'07" | 8/13/75 | 335 | 2 |
| | Corridor | 7/17/82 | 358 | 5 |
| .Kavik River | ? | 8/13/75 | 0 | 2 |
| M.P. 27.3 Stream | Corridor | 7/18/75 | 3.5 | 5 |
| M.P. 31.8 Stream | Corridor | 7/14/82 | 2.0 | 5 |

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Notes

1. Estimates of peak spring breakup flow prior to construction of bridge.
2. Spot measurement by USGS.
3. Measurements made on behalf of ARCO Alaska Inc.
4. Estimate made during Hydrocon's previous studies in the area.
5. Present studies.

## TABLE 5.2

## FLOW CHARACTERISTICS - POINT THOMSON AREA STREAMS.

| Stream | Location | Drainage Area Sq. Mi. | Discharge in c.f.s. | |
|---|---|---|---|---|
| | | | Bankfull | Maximum Evident |
| Kadleroshilik[1] | Lat. 69°56'06"<br>Long. 147°51'15" | 451 | 8,400 | 23,000 |
| Shaviovik[1] | Lat. 69°52'21"<br>Long. 147°38'44" | 660 | 7,800 | 21,000 |
| Shaviovik[2] | Lat. 70°05'07"<br>Long. 147°16'30" | 1580 | 22,000 | 22,000 |
| Kavik[1] | Lat. 69°32'10"<br>Long. 146°39'44" | 237 | 5,200 | 13,000 |
| Canning[1] | Lat. 69°21'10"<br>Long. 146°02'31" | 1326 | 17,000 | 22,000 |
| Canning[2] | Lat. 69°50'38"<br>Long. 146°27'10" | 1871 | 31,000 | 53,000 |

Notes:

1. See Childers et. al., 1973. (data extracted in Flow Data Appendix).
2. See Childers et. al., 1977. (data extracted in Flow Data Appendix).
3. See Drawing 4 for a plot of the data.

In the early 1970's in response to the Prudhoe Bay development and the oil pipeline, flow stations were established by the U.S. Geological Survey on the Sagavanirktok, Putuligayuk and Kuparuk Rivers. The location and period of record of these stations is illustrated on Drawing 3. The Sagavanirktok River station was terminated in 1979 but was re-established in late 1982. Miscellaneous flow and crest data has also been collected in the Sagavanirktok River basin at Happy Valley Creek and on a tributary to Galbraith Lake. The location of these stations is as shown on Drawing 3. Beyond the immediate area, Nunavak Creek near Barrow has been gaged since 1971. Beyond the Alaska border, the Firth and Babbage Rivers in the Yukon Territory in Canada have been gaged by the Water Survey of Canada.

All flow data referred to above is presented in the Flow Data Apendix. Also included are extracts from the stream characteristic studies undertaken by the U.S.G.S. in 1973 and 1977 referred to above while Drawing 4 illustrates plots of the estimated bankfull and maximum evident floods versus drainage area for other streams within the region as a whole.

### 5.2.2 Climatologic

5.2.2.1 Point Thomson Area - There are no climatologic stations in the Point Thomson study area except at Prudhoe Bay and several in the southern regions of the Sagavanirktok River watershed. These are as shown on Drawing 3 with the data summarized in the Climatic Data Appendix.

For each of the climatic stations, the average monthly temperature and total monthly precipitation data collected since 1969 and as presented in the National Oceanic and Atmospheric Administration Annual Summaries are tabulated in the Appendix. Also included are summaries of the data for a number of temperature and precipitation parameters compiled either by the Arctic Environmental Information and Data Center (Becker, 1982) or by the National Oceanic and Atmospheric Administration, in the Annual Summaries. It should be noted, however, that the AEDIC summaries were compiled during the mid 1970's and thus do not include all available data. Data from the U.S. Soil Conservation Service snow stations is also tabulated in the Appendix. Due to the difficulties and cost of operating scientific equipment in the north, the data is often incomplete.

Some general observations can be made at this time. The mean annual precipitation of the Arctic Slope is between 5 and 10 inches. This low amount is primarily due to the desert-like conditions imposed on the region for much of the year by the ice-covered Arctic Ocean. Although poorly documented, mean annual precipitation on peaks at higher elevations in the Brooks Range is probably in the order of 40 inches per year. Mean annual precipitation increases in an easternly and southeasternly direction from the coast, probably as a function of elevation.

5.2.2.2 Regional - Other available climatic data in the region is as indicated on Drawing 3 and as summarized in the Climatic Data Appendix. Data for the northern portions of the Yukon Territories in Canada may also prove to be useful in future regional hydrologic studies. Stations that might be used are noted in the Climatic Data Appendix. Although not presented, climatic data is also available from the U.S. Air Force Distant Early Warning (DEW) stations. This must be obtained directly from the Air Force in Ashville, North Carolina, and is primarily applicable to the coast. Temperatures have been observed at the Alyeska Pump Stations since start of operation in 1977. Due to the time required to obtain this information and its limited usefulness at this time, it was not included in this report.

### 5.2.3 Aufeis

As discused and illustrated in Chapter 4, icings were observed and measured on the Kadleroshilik and Shaviovik Rivers during the 1982 breakup and at the Sagavanirktok River bifurcation. At the latter location, this has been a common occurrence since 1980. To determine the location of persistent icings, an indication of winter flow, Landsat imagery was analyzed. These are obtained by satellite, have an approximate scale of one to one million and are available for any given location once every 18 days. Only those photos containing less than 20 percent cloud cover taken in July or August for the 1975-1980 period were analyzed. Icings were observed on the Sagavanirktok, Shaviovik, Canning and the Staines Rivers.

On the Sagavanirktok River an icing located approximately 40 miles upstream from its mouth, was observed in photographs for each of several years. Other icings were observed in its headwaters and in the Ivishak River. A

U.S.G.S. report (Sloan et. al., 1975) indicated that during at least some of the years between 1969 and 1974, icings occurred as far north as Deadhorse. Childers' (1977) reconnaissance of the eastern streams noted icing locations as well. There are shown on a map with the extracted data in the Flow Data Appendix. Only one icing was observed in the Main Channel of the Sagavanirktok River, and it was located near the point of bifurcation.

## 5.3 RUNOFF CHARACTERISTICS

### 5.3.1 General

The knowledge of permafrost hydrology is still in its infancy stage. A general discussion of the difficulties involved is given by Carlson (1974) and is as presented below.

> Although a seemingly simple and straightforward subject, permafrost hydrology presents a great many difficulties in assessing the role of permafrost in the hydrologic system. Its most well known role is that of a geologic condition that presents a relatively impermeable barrier near the ground surface. The barrier, of course, is very temperature dependent and complex, especially in regions of sporadic permafrost where a great number of perforations exist under the larger lakes and streams. The presence of unfrozen water also occurs within the frozen zone.
>
> Characterization of permafrost hydrology is made more difficult by the existence of other agents in collaboration with permafrost, each of which offers a certain set of complexities. These include low temperature, high latitude, large elevation differences and an extremely sparse data network. Discussion of permafrost hydrology must take into account the roles of all five, permafrost itself as well as these four agents, in modifying the hydrologic system as it is normally found in northern regions. Each adds to the difficulty of studying permafrost hydrology and each should be addressed through a theory or model of understanding with full realization of the amount of data available to confirm the theory or model, and with a certain problem in mind.

### 5.3.2 Annual Flow Distribution

The annual flow distribution of rivers on the north slope is closely related to the physiographic provinces through which the rivers flow. Flow duration curves for the gaged streams, namely the Kuparuk, Putuligayuk and

Sagavanirktok Rivers are presented on Drawing 5 and are probably representative for streams in the Point Thomson area as discussed below. The average percentage of yearly flow occurring in each month of the year, on each of the three rivers, is presented in Table 5.3.

As noted from a review of the flow duration curves, high discharges occur for only an extremely short period. This is further illustrated in Table 5.3, where it can be seen, for example, that on the average, 88 percent of the total yearly flow in the Putuligayuk River occurs during the breakup month of June. An average of 73 percent of the total yearly flow in the Kuparuk River occurs during the month of June, whereas an average of 37 percent of the total yearly flow in the Sagavanirktok River occurs during the month of June. Over 90 percent of the yearly flow in each of the rivers occurs during the summer months of June, July, August and September.

---

The Putuligayuk River, which flows primarily in the Arctic Coastal Plain province, is not significantly affected by summer and fall precipitation. Therefore, spring snowmelt runoff is the dominant event both in terms of peak flows and volumes. The Kuparuk River, which is located primarily in both the Arctic Foothills and Arctic Coastal Plain provinces, is slightly more affected by summer and fall rainstorms and thus has a lower percentage of its runoff occurring during the breakup period. The stream gaging station on the Sagavanirktok River at Sagwon however is located at a point where the drainage is primarily in the Brooks Range and Arctic Foothills provinces. Moisture from the Beaufort Sea approaches the Brooks Range and can produce major late summer rainstorms. The result is that the percentage of total yearly flow occuring during breakup on the Sagavanirktok is considerably less than on either the Kuparuk or the Putuligayuk Rivers. It therefore follows that the percentage of total yearly flow occuring in the other summer months is larger than on either of the other two rivers. Representative annual hydrographs for the three area streams are shown on Drawing 5.

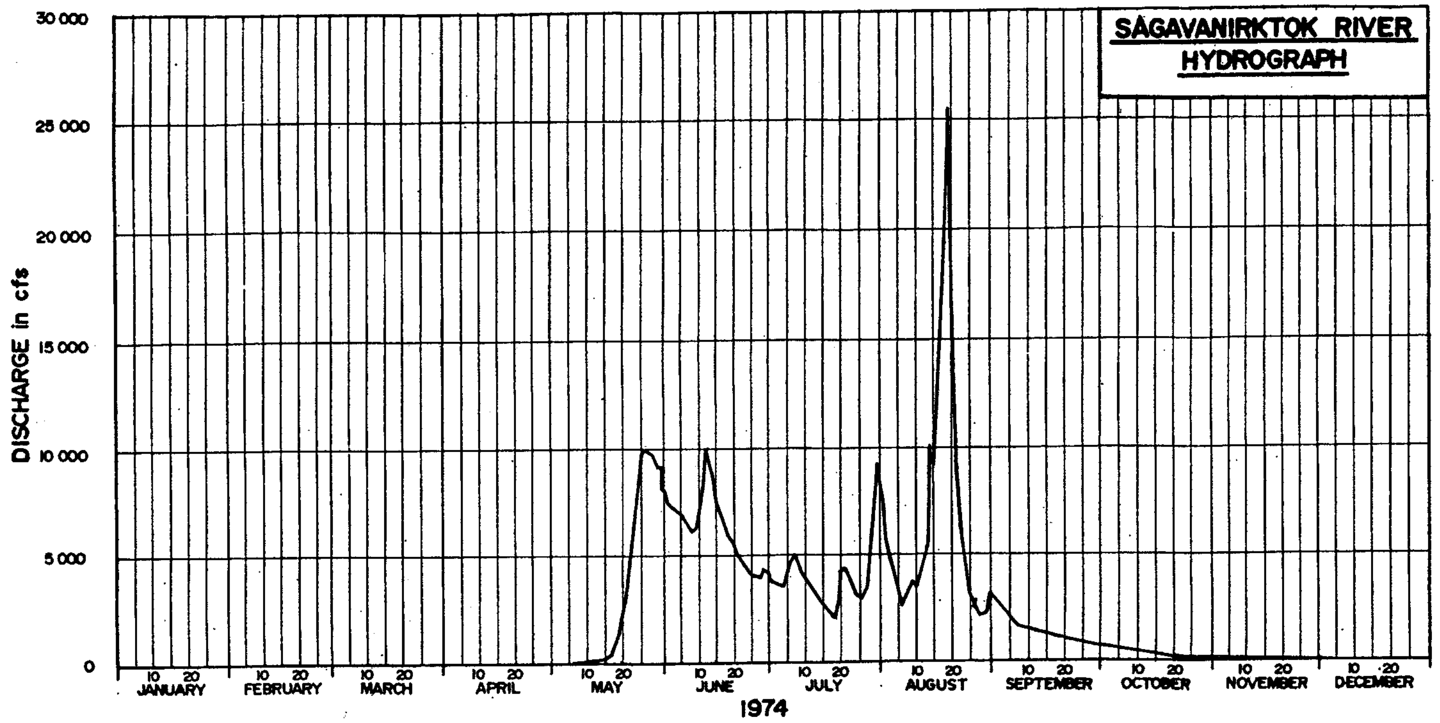
All the streams have little or no flow during the winter months. As a general rule, streams flowing out of the Brooks Range such as the Sagavanirktok River are likely to have higher winter flows since they are

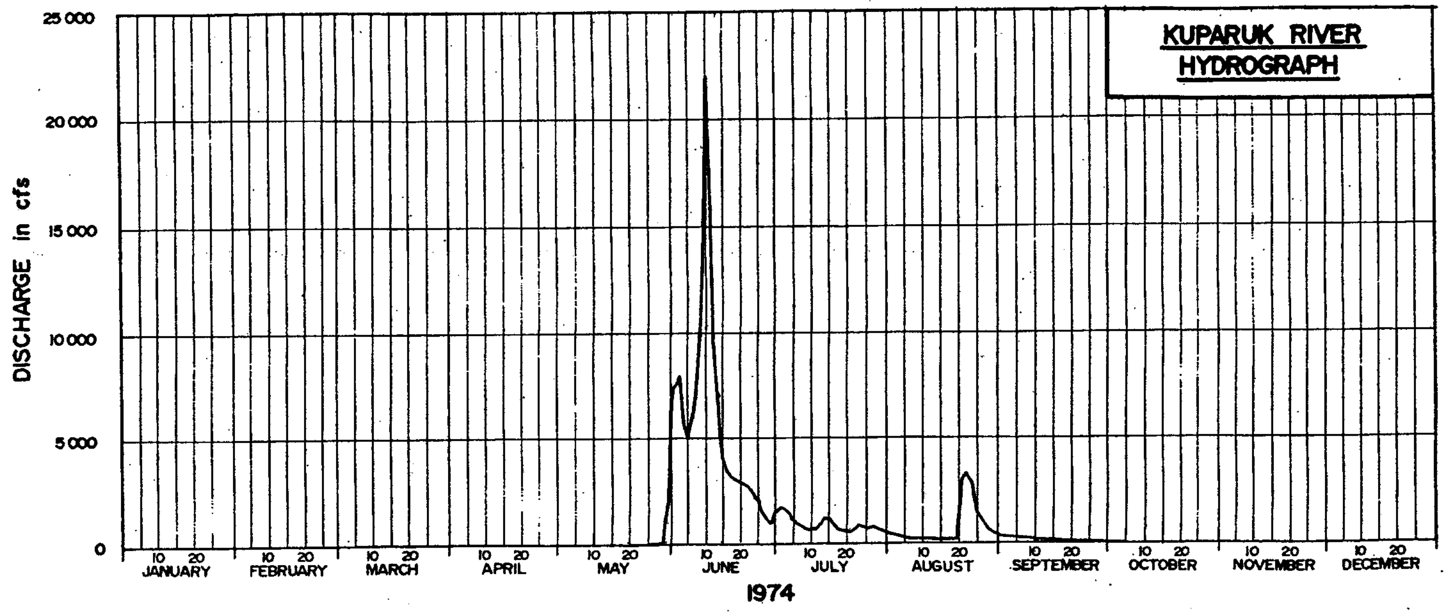
## TABLE 5.3

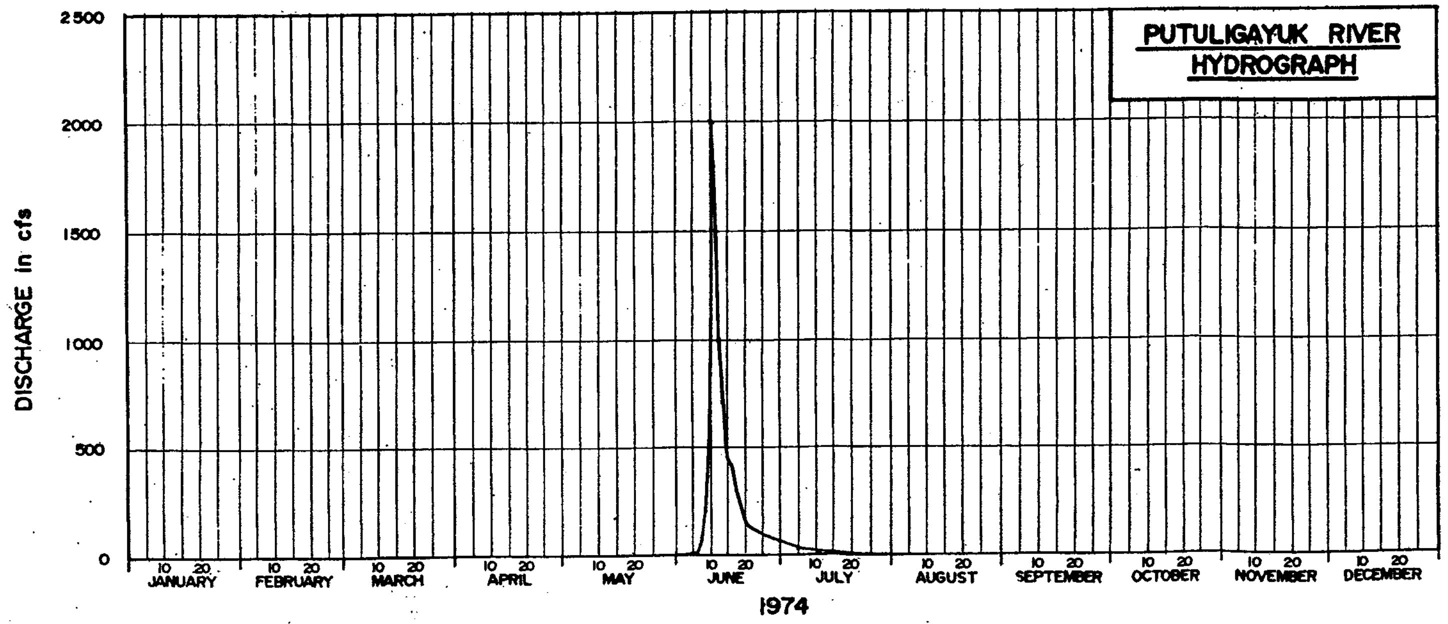
## DISTRIBUTION OF FLOW BY MONTH - SUMMARY

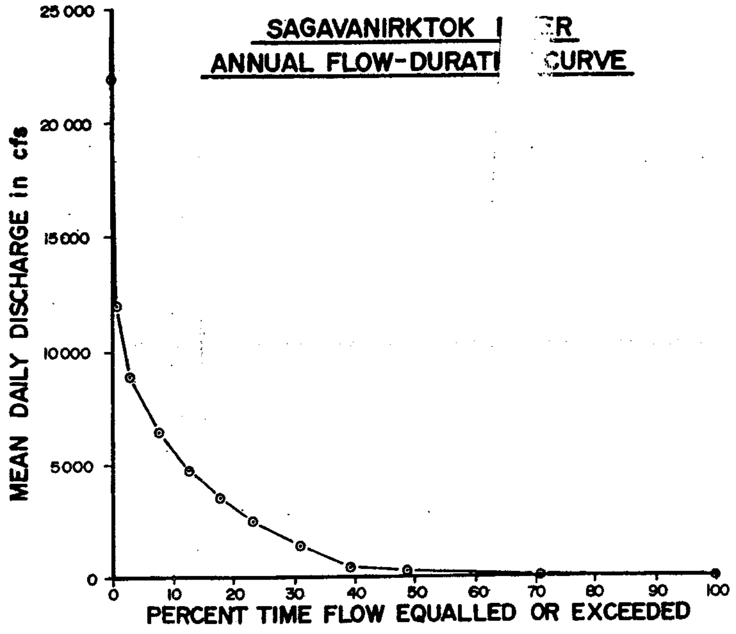
(Percent)

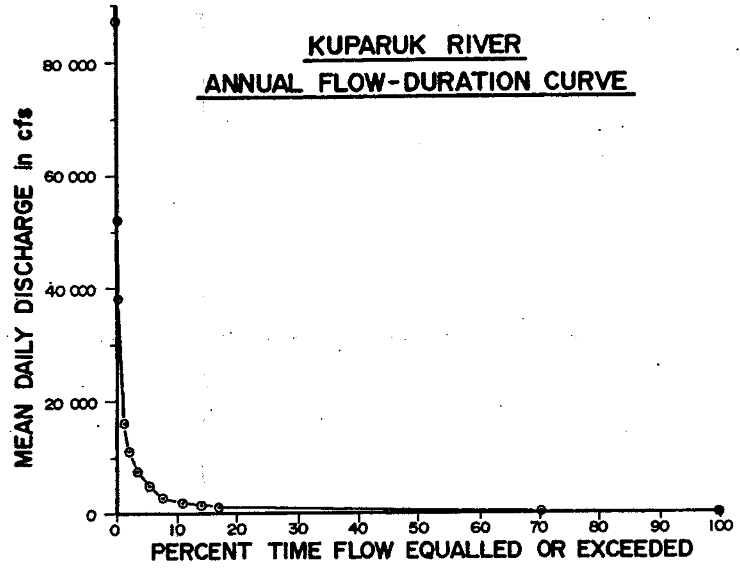
| | JAN. | FEB. | MAR. | APR. | MAY | JUN. | JUL. | AUG. | SEP. | OCT. | NOV. | DEC. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SAGAVANIRKTOK RIVER | | | | | | | | | | | | |
| Average | 0.02 | 0.01 | 0.01 | 0.01 | 5.5 | 37.0 | 25.0 | 21.0 | 8.5 | 2.0 | 0.6 | 0.1 |
| Standard Deviation | 0.02 | 0.01 | 0.01 | 0.01 | 5.3 | 9.1 | 5.2 | 6.3 | 2.6 | 0.6 | 0.4 | 0.1 |
| Maximum of Record | 0.07 | 0.04 | 0.04 | 0.04 | 14.0 | 49.0 | 32.0 | 31.0 | 13.0 | 3.0 | 1.0 | 0.3 |
| Minimum of Record | 0.01 | 0 | 0 | 0 | 1.1 | 25.0 | 17.0 | 15.0 | 4.5 | 1.0 | 0.2 | 0.03 |
| PUTULIGAYUK RIVER | | | | | | | | | | | | |
| Average | 0 | 0 | 0 | 0 | 2.6 | 88.0 | 5.0 | 1.0 | 4.0 | 0.4 | 0 | 0 |
| Standard Deviation | 0 | 0 | 0 | 0 | 7.1 | 12.0 | 3.0 | 2.0 | 6.0 | 0.8 | 0 | 0 |
| Maximum of Record | 0 | 0 | 0 | 0 | 20.0 | 98.0 | 10.0 | 4.0 | 17.0 | 2.0 | 0 | 0 |
| Minimum of Record | 0 | 0 | 0 | 0 | 0 | 58.0 | 1.0 | 0.2 | 0.3 | 0.01 | 0 | 0 |
| KUPARUK RIVER | | | | | | | | | | | | |
| Average | 0.02 | 0.02 | 0.02 | 0.02 | 3.2 | 73.0 | 7.4 | 8.8 | 6.2 | 1.0 | 0.2 | 0.03 |
| Standard Deviation | 0.04 | 0.04 | 0.04 | 0.04 | 7.6 | 19.0 | 3.1 | 8.6 | 5.2 | 1.0 | 0.3 | 0.05 |
| Maximum of Record | 0.10 | 0.10 | 0.10 | 0.10 | 23.0 | 89.0 | 13.0 | 26.0 | 15.0 | 4.0 | 0.8 | 0.10 |
| Minimum of Record | 0 | 1 | 0 | 0 | 0 | 29.0 | 4.0 | 1.0 | 1.0 | 0.1 | 0 | 0 |


**SAGAVANIRKTOK RIVER HYDROGRAPH**

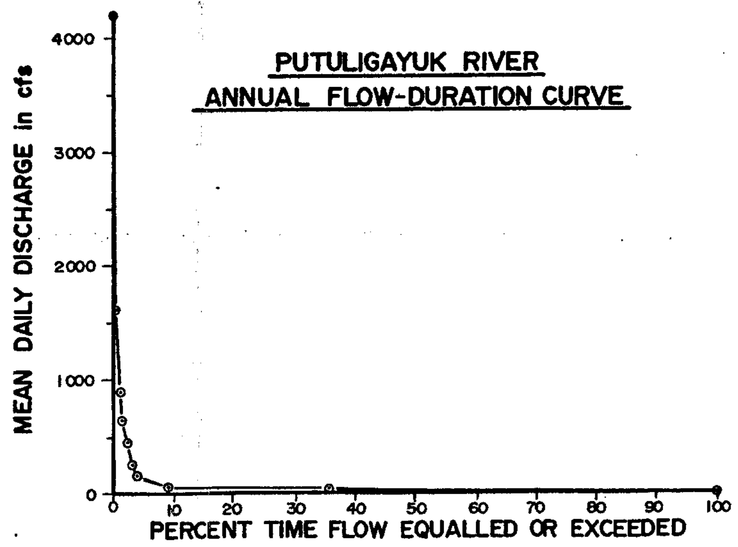

**KUPARUK RIVER HYDROGRAPH**


**PUTULIGAYUK RIVER HYDROGRAPH**


**SAGAVANIRKTOK [illegible]ER ANNUAL FLOW-DURATI[illegible] CURVE**


**KUPARUK RIVER ANNUAL FLOW-DURATION CURVE**

NOTE: HYDROGRAPHS SHOWN ARE TYPICAL FOR THE U.S.G.S. GAGING STATIONS.


**PUTULIGAYUK RIVER ANNUAL FLOW-DURATION CURVE**

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more likely to be spring fed. This being the case, they are also more likely to experience aufeis formations.

Relating the Point Thomson streams to the three gaged streams, the following general conclusions can be made. The flows in the Main Channel Sagavanirktok and Shaviovik Rivers are likely to be somewhat higher than the recorded flows at Sagwon for the month of June whereas July, August and September flows will be lower. The annual flow distribution of the Kadleroshilik River at the proposed pipeline river crossing is expected to be similar to that shown for the Kuparuk River at the U.S.G.S. stream gaging station. The annual flow distribution of the streams at M.P. 27.3 and 31.8 will probably be midway between the values shown for the Putuligayuk and Kuparuk Rivers. The other very minor streams will be comparable to the Putuligayuk River. The flow distribution of the Canning-Staines River is probably most similar to the Sagavanirktok River at the U.S.G.S. stream gaging station at Sagwon.

### 5.3.2 Flood Regime

Spring runoff as a result of snowmelt is the dominant hydrologic event in the Arctic Coastal Plain whereas streams originating in the Brooks Range, like the Sagavanirktok River, may experience summer and fall peaks due to rainstorms. Snowfall and temperatures affect the magnitude of spring breakup flows. Rainfall during this period can also significantly increase the magnitude of the peaks.

Table 5.4 is a summary of the timing and magnitude of annual peak flows on the Sagavanirktok, Putuligayuk and Kuparuk Rivers. It can be observed that of the three rivers, only the Sagavanirktok has experienced summer peaks during the period of record. The values shown are maximum annual instantaneous. The ratio of instantaneous to maximum ranges from 1.10-1.35, 1.00-1.15, and 1.03-1.18 for the Sagavanirktok, Putuligayuk and Kuparuk Rivers respectively.

In the Point Thomson area, the Kadleroshilik and minor unnamed streams would probably experience their major flood peaks during the spring breakup. The Shaviovik River could experience mid-summer peaks as well as high spring runoff. The Main Channel of the Sagavanirktok River would of course, like the U.S.G.S. gaging station upstream at Sagwon, experience its largest peaks during heavy summer and fall rains.

Minor streams draining the numerous lakes in the Arctic Coastal Plain can, as a result of sudden melting and release of ice at the outlet of the lake, experience an extremely high short-duration flow magnitude. This has been observed on a tributary to the Putuligayuk River where it crosses the workpad of the trans-Alaska oil pipeline.

## TABLE 5.4

## TIMING AND MAGNITUDE OF MAXIMUM ANNUAL INSTANTANEOUS FLOOD PEAKS

| Year | SAGAVANIRKTOK RIVER | | PUTULIGAYUK RIVER | | KUPARUK RIVER | |
|---|---|---|---|---|---|---|
| | Date | Peak in c.f.s. | Date | Peak in c.f.s. | Date | Peak in c.f.s |
| 1969 | Aug. ?? | 34,900 | | | | |
| 1970 | June ?? | 15,200 | June 7 | 1,900 | | |
| 1971 | June 8 | 19,300 | June 6 | 4,980 | June 5 | 77,000 |
| 1972 | June 2 | 22,200 | June 13 | 4,500 | June 11 | 45,800 |
| 1973 | July 24 | 24,700 | June 9 | 4,000 | June 6 | 82,000 |
| 1974 | Aug. 19 | 28,900 | June 10 | 2,000 | June 10 | 24,000 |
| 1975 | July 15 | 8,340 | June 14 | 2,000 | June 13 | 22,600 |
| 1976 | June 5 | 18,700 | June 17 | 3,130 | June 15 | 55,000 |
| 1977 | June 5 | 29,600 | June 10 | 1,800 | June 6 | 66,800 |
| 1978 | June 4 | 19,800 | June 11 | 4,630 | June 7 | 118,000 |
| 1979 | | | May 31 | 1,100 | June 1 | 24,300 |
| 1980 | | | | | June 12 | 40,500 |

### 3.3.4 Breakup

Available breakup data (defined as commencement of flow herein) for the Point Thomson and adjacent streams (Putuligayuk and Kuparuk Rivers and West Channel of the Sagavanirktok River) are as shown on Drawing 3. The following preliminary comments can be made at this time:

- the time lag between earliest and latest recorded breakup on any stream is in the order of two weeks.

- earliest commencement of flow on the Main Channel of the Sagavanirktok River - generally the first river in the area to breakup - is probably about May 15, 1982. The time lag between the Main Channel Sagavanirktok River and the Point Thomson area streams is approximately as follows:

| | |
|---|---|
| -Shaviovik River | 5 days |
| -Kadleroshilik River | 10 days |
| -unnamed coastal streams | 14 days |

- Climatic conditions which trigger breakup on the Sagavanirktok River - a warming trend in the Brooks Range - also create the commencement of flow on the Shaviovik River. To a lesser extent this is true for the Kadleroshilik River as more of its drainage area is contained in the Arctic Coastal Plain where weather conditions can be quite different from those in the Arctic Foothills and Brooks Range.

- as a general gule, the time lag between the various streams given above decreases as commencement of breakup becomes later.

The conditions depicted on the photographs of Chapter 4 are representative of spring breakup. Briefly the chronological order of events of a typical breakup is as follows:

- commencement of above-freezing temperatures in the Brooks Range and Arctic Foothills.

- maintainance of these warm temperatures (have been as high as the mid-70's in the upper Sagavanirktok River watershed) for a minimum of one week. This triggers sufficient runoff for it to reach the coastal area. The in-stream storage of the stream affects the time for the flow to reach the coast. For a given flow, the time is greater on the very wide and braided Sagavanirktok River than for a narrower and more well-defined channel such as the Kuparuk River.

- in aufeis-clogged rivers, the initial 4-5 days of flow is over the aufeis. The low temperature of the water results in little deterioration or downcutting of the ice during this period.

- when flows increase and/or the aufeis becomes sufficiently deteriorated, the ice lifts and moves downstream. The shallow depth and tortuous braided pattern of the Sagavanirktok River results in the stranding of most of the larger pieces of ice. On the Shaviovik River, some movement of ice could be anticipated. The high bed forms (and subsequently low average depth) on the Kadleroshilik River would probably result in the majority of its larger pieces of ice being stranded. There is probably little or no aufeis on the smaller unnamed streams since winter flows - a condition necessary to generate aufeis - are probably insignificant.

- if a cold spell occurs after the commencement of breakup, flows will dramatically decrease especially in the smaller streams which have low in-stream storage. A thin ice cover can be formed which becomes transported without difficulty when breakup resumes.

## 5.4 FLOOD FREQUENCY ANALYSIS

### 5.4.1 Methodology

The chief methods that can be used to compute flood flows are:

- multiple-regression equations which relate the magnitude of discharge for a specified frequency to the climatic and physical characteristics of a stream's drainage basins.

- hydrologic models, either snowmelt-runoff or rainfall-runoff to synthesize the hydrologic processes.

- analysis of physical evidences of flooding from highwater marks and geomorphic characteristics.

The optimum method depends in great part on available flow and meteorologic data and the hydrologic homogeneity of the streams in the Point Thomson study area to the gaged watersheds. In the development of multiple regression equations, the main question is the size of the region. In his study of flood characteristics of Alaskan streams, Lamke (1974) divided Alaska into only two areas. Although this increases the available flow and climatic data for the regression analysis, it groups watersheds of dramatically different hydrologic characteristics into a single region. A broad regional analysis was also developed by the State Pipeline Coordinator's Office (1980) for the Alaska Natural Gas Transportation System. The entire area north of the Yukon River was used. At the other end of the scale, multiple regression equations could be developed just for the gaged streams in the Prudhoe Bay area namely the Kuparuk, Putuligayuk and Sagavanirktok Rivers. The year to year variations in runoff even in this relatively local area can be illustrated by comparing annual peak flows for the Kuparuk and Sagavanirktok Rivers. The ratio of spring breakup maximum daily flow has varied from 8.66 in 1973 to 2.21 in 1972. Perhaps sophisticated multiple regression equations could explain these annual differences if sufficient climatic and hydrologic data is available.

A commonly-accepted although complicated hydrologic model is the U.S. Army Corps of Engineers' HEC-1 flood hydrograph program. Input data includes precipitation, snowpack, topography, temperature and loss parameters such as sublimation and infiltration. This model was, according to the report's authors, successfully calibrated to recorded flows and then used to generate flood data for the Kuparuk River road and pipeline bridges (unpublished report by consultants to ARCO Alaska Inc.). In an attempt to simplify the runoff modelling, particularly in view of the limited hydrometeorologic data available in the North Slope, the Institute of Water Resources, University of Fairbanks (Carlson, 1974) developed a snowmelt-runoff model. Although tested for only limited flow data (1970 and 1971) on the area streams, the model is a promising step forward towards the understanding and simulation of the hydrologic processes.

The relative flooding frequencies and potential flooding hazards have been mapped for the Canning, Shaviovik, Sagavanirktok, Kuparuk and Colville Rivers by Mortensen and Cannon (1981). From field verification of the relative flooding frequency and the geomorphic description of each floodplain unit, the flooding potential of each river was derived and mapped. The impact of aufeis on spring breakup levels as well as the relatively little physical effect of breakup on the floodplain and terrace levels (due to the frozen state of the active layer) were recognized as limitations to the application of this methodology to Arctic Rivers. An extension of this work could be the determination of the flood magnitudes, from the stream's hydraulic properties, necessary to cause flooding to the mapped limits.

Maximum evident floods, without an assigned return period, were computed by the U.S. Geological Survey (Childers et. al., 1973 and 1977) as previously tabulated on Table 5.2 and illustrated on Drawing 4. Although the accuracy of these results can be open to question because of the impact of aufeis, it can provide a check on computed hydrologic values.

The methods are therefore varied and each subject to various degrees of conjecture. In assessing the various approaches and determining the level of hydrologic effort necessary, the hydrologist should be cognizant of the following basic facts and limitations:

- .the North Slope region will continue to be relatively data-scarce in the immediate near future. This will most likely affect the method selected.
- .water levels, rather than the magnitude of flow, are probably the most important design consideration for major pipeline and road crossings.
- .flow magnitudes are probably more critical for minor culverted-road crossings.
- .the variable flow split at the Sagavanirktok River bifurcation presents a difficulty in estimating flow at the proposed crossing area, regardless of the hydrologic analysis used to compute the flow upstream of the split.

### 5.4.2 Design Floods

The order of magnitude of the design floods rather than the absolute values are presented in this section. This rather preliminary analysis is somewhat beyond the original scope of work outlined in Section 2.2.

To provide a rough comparison of the results of various hydrologic techniques, and to subsequently apply these results to the Point Thomson area streams, the hydrologic characteristics of the Kuparuk, Putuligayuk and

Sagavanirktok Rivers were analyzed with the results as shown on Table 5.5. The methods used were:

- the SPCO analysis of gaged streams north of the Yukon River.
- Lamke's (1974) multiple regression analysis of gaged streams.
- regression analysis of only the 3 gaged streams in the Prudhoe Bay area.
- flood frequency analysis of the recorded data.

## TABLE 5.5
## COMPARISON OF HYDROLOGIC ANALYSIS FOR THE KUPARUK, PUTULIGAYUK AND SAGAVANIRKTOK RIVERS

| METHOD | KUPARUK Flow in cfs | | PUTULIGAYUK Flow in cfs | | SAGAVANIRKTOK Flow in cfs | |
|---|---|---|---|---|---|---|
| | 25 Yr | 50 Yr | 25 Yr | 50 Yr | 25 Yr | 50 Yr |
| SPCO | 80,000 | 98,400 | 5,010 | 6,160 | 57,200 | 70,300 |
| Lamke | 33,234 | 39,219 | 1,555 | 2,004 | 55,093 | 65,089 |
| 3-Stream Regression | N.C. | 112,000 | N.C. | 9,200 | N.C. | 83,000 |
| Flood Frequency Analysis of Recorded Data | 152,000 | 192,000 | 8,400 | 10,100 | 42,300 | 49,000 |

Notes:

1. N.C. - not computed.

The following observations or conclusions can be made at this time:

- the Lamke method appears to significantly underestimate the runoff from the Kuparuk and Putuligayuk Rivers whose drainage areas are located in the Arctic Foothills and Arctic Coastal Plain.

the unit runoff (cfs/square mile) for the Sagavanirktok River is less than half the other two streams. Thus when the Sagavanirktok River is grouped with the other two streams in the 3-stream regression analysis or in the broader regions employed by the SPCO or Lamke method, the Sagavanirktok River values appear to be on the high side.

Using the SPCO method*, flood frequency curves were computed for the Point Thomson area streams as shown on Drawing 6. To provide a check of these order of magnitude values, the 100 year** and 5 year*** floods were compared to the maximum evident and bankfull values respectively computed by the U.S.G.S. (Childers et. al., 1973 and 1977) as shown on Drawing 4. This rough comparison indicates that the SPCO values are probably the correct order of magnitude although on the basis of the results shown on Table 5.5, the values shown for all the streams except for the Main Channel of the Sagavanirktok River, may be somewhat low. It was assumed that the Main Channel conveyed 60 percent of the computed flow upstream of the bifurcation.

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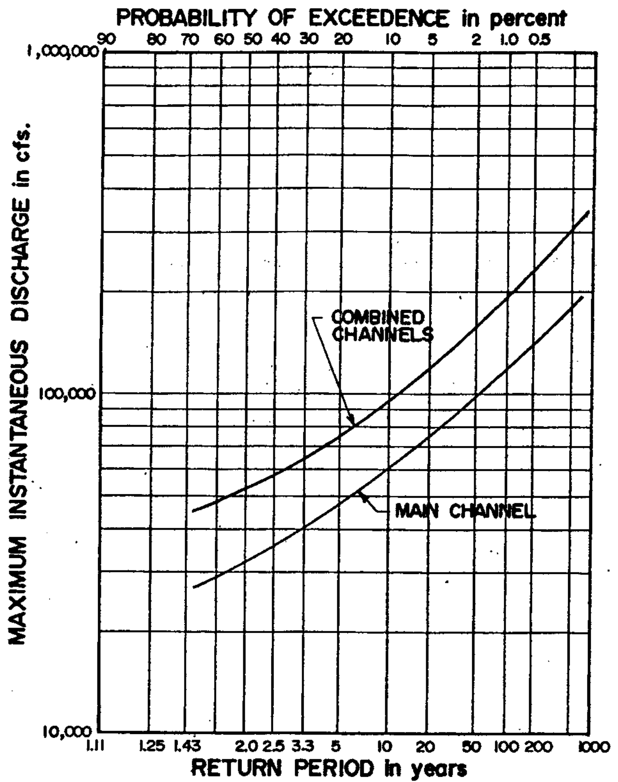
* The SPCO method uses expected probabilities. This methodology can be described as follows. The probability of exceedence of any given flood event must be inferred from random sample data. Therefore the true mathematical expectation cannot be computed exactly as errors due to uncertainty do not necessarily compensate. For example, if the estimate based on sample data is that a certain flood will be exceeded on the average of once in 100 years, it is possible that the true exceedence could be three or four times per hundred years.

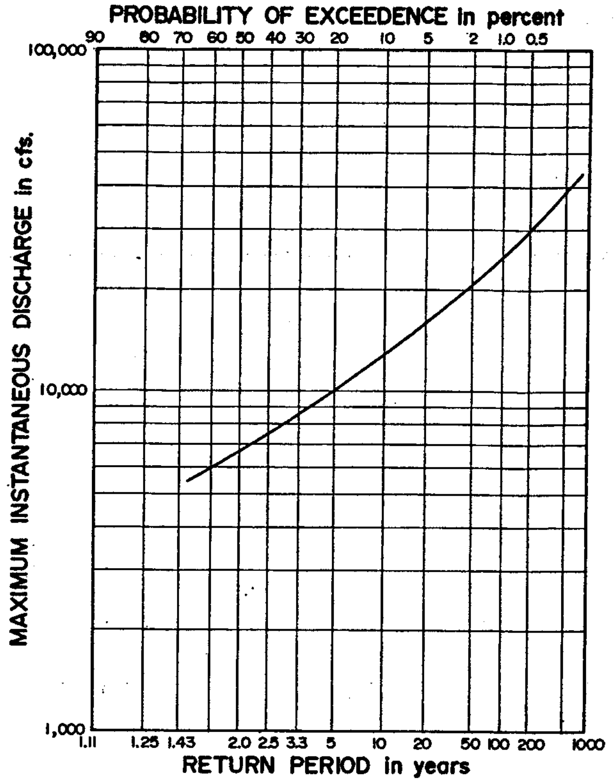
An expected probability adjustment is an attempt to incorporate the effects of such uncertainties in the application of the flood-frequency analysis. It represents the average of the true probabilities of all estimates for any specified flood frequency that might be made from a number of samples of a specified size.

** Selection of a 100 year flood versus say a 50 year flood is rather arbitrary. The premise of course is that the maximum evident flood is a rather rare event.

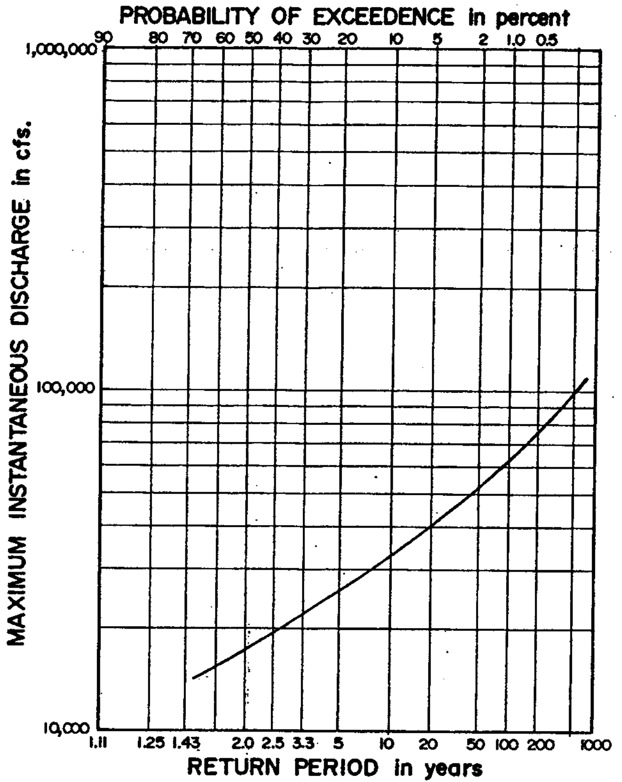
***Bankfull discharges may range from a 2 to a 10 year flood.



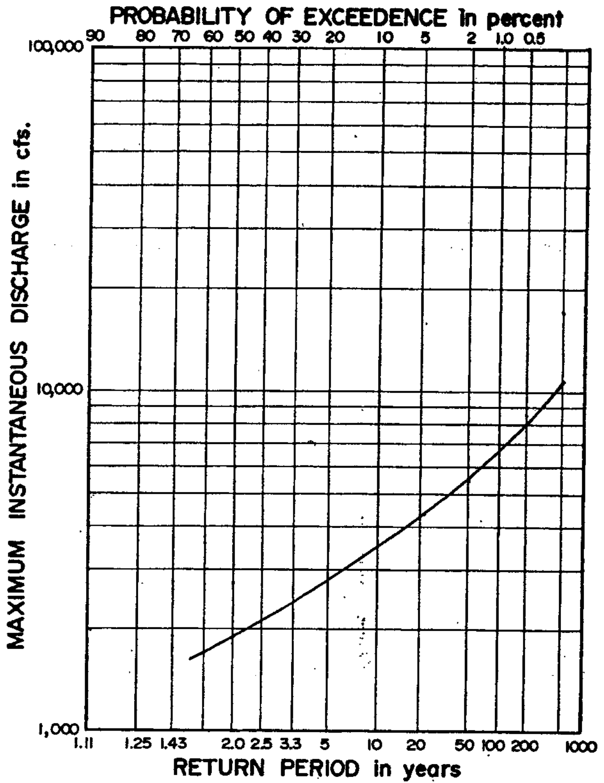
**SAGAVANIRKTOK RIVER**



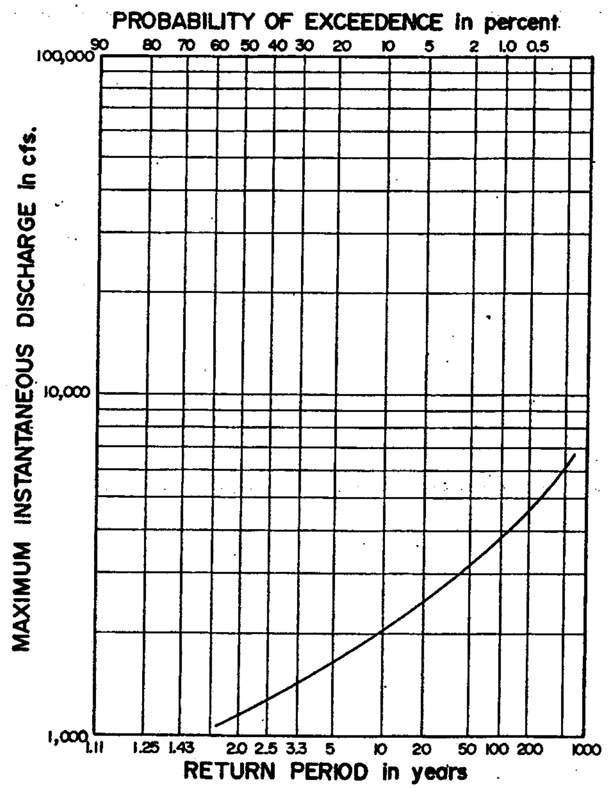
**KADLEROSHILIK RIVER**



**SHAVIOVIK RIVER**



**RIVER AT MILEPOST 27.3**



**RIVER AT MILEPOST 31.8**

NOTES:

1. FREQUENCY CURVES WERE DETERMINED USING THE S.P.C.O. METHOD AND INCLUDE AN EXPECTED PROBABILITY ADJUSTMENT FOR RETURN PERIODS GREATER THAN 5 YEARS.
2. SAGAVANIRKTOK RIVER MAIN CHANNEL FLOW BASED ON 60% OF COMBINED CHANNELS UPSTREAM OF BIFURCATION.
3. THESE CURVES ARE NOT TO BE USED AS DESIGN VALUES. THEY ARE PRELIMINARY ESTIMATES ONLY AND SUBJECT TO REVISION.

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CROSSING
TYPES

# 6.0 CROSSING TYPES AND DESIGN CRITERIA

## 6.1 PIPELINE CROSSINGS

### 6.1.1 General Hydrologic and Hydraulic Considerations

The design of pipeline river crossings requires a thorough consideration of many factors. For buried crossings, the basic objective is to minimize the potential for pipeline exposure. The sagbends and depth of burial of the pipe thus have to be determined by the river engineer. Processes that could result in exposure are riverbed scour and degradation, floodplain erosion and lateral channel migration or switching. On some rivers, these processes are affected by the occurrence of aufeis, river ice jams and accumulations of logs and other floating debris.

For aerial crossings, the design objectives are to minimize the potential for scour around structural foundations and abutments and to provide adequate clearance for flood water, ice and debris as well as navigation requirements.

The depth of burial for buried crossings is determined by the lowest level to which any portion of the riverbed or floodplain may be scoured. This scouring may be due to either local effects such as strong secondary currents at channel bends, turbulent eddies produced at the confluence of two or more subchannels or due to progressive channel profile degradation or a combination of both. The severity of scour at any particular point along a river is dependent on the flow conditions which produce the greatest hydraulic forces acting on the riverbed. For some rivers (usually deeply incised channels with banks too high to be overtopped) the greatest scour will generally occur during an extreme flood event. For others (usually channels with banks subject to overtopping) the potential for deep scour may be greatest at the bankfull stage. Therefore, a range of flow conditions must be analyzed and the results compared. A safety factor may also be added to the depth of burial depending on design uncertainties or regulatory stipulations.

The rate of erosion of a riverbank depends on the channel pattern (single, braided or split), the height of the bank, the type of bank material, the root system within the bank, the degree of curvature of the channel, the magnitude of the flows and sediment transported and the frequency of high flows. The presence of permafrost may also have a significant impact on erosion (Cooper, R.H. 1973). On wide streams, channel orientation to the wind may be a factor (Outhet, D.N., 1974). By charting the past behavior of a river channel by means of comparative aerial photographs, its most probable future behavior can be predicted within broad limits. The potential for drastic shifts in channel alignment or the development of overbank subchannels into major channels may also be dependent on the occurrence of aufeis, ice jams or accumulations of logs or other debris. Whether or not a new and larger channel is developed during overbank flows depends mainly on the duration and timing of the flow as well as the magnitude of the overflow. Overbank flows during breakup, when the bed material is still frozen, result in little or no change. However, a severe summer flood can cause dramatic and rapid changes in the size and location of overbank channels. The sagbend locations are determined from the anticipated bank erosion or channel shifting.

Scour and bank migration considerations also apply to the design of aerial crossings. Specifically these considerations are important in determining the type of piers, depth of footings or piles and the length of bridge and layout and extent of river training structures. The necessary bridge length is based on technical, economic, environmental and regulatory considerations. The design water level and presence and nature of ice and debris will govern the height of the bridge as well as required navigation clearances. During open water flood conditions, the design water level and thus the height of the bridge, is directly proportional to the size of flood selected. However during breakup on aufeis-laden streams, relatively low flows can produce water levels equalling or exceeding open-water design flood conditions. A range of flow conditions must thus be assessed. A safety factor may be added to the depth of footings or pilings depending on design uncertainties or regulatory stipulations.

The capability of a wide variety of river training and bank protection works to control channel migration is also a major consideration in the design of pipeline crossings. They are primarily used, where for either economic, geotechnical, environmental or construction reasons, deep burial or a bridge or main channel pilings are not the preferred construction mode across the entire width of an active floodplain.

The design of pipeline crossings still requires a great deal of professional judgement by qualified engineers particularly in view of the uncertainties associated with the data-scarce Arctic Slope streams.

### 6.1.2 Alternative Crossing Modes

The main crossing techniques are:

- deep burial for the entire width of the river,
- deep burial for a portion of the width with the remainder of the crossing in a shallow-buried mode and protected by river training structures,
- elevated crossing designed for main channel conditions for the entire width of the river,
- elevated crossing designed for main channel conditions for a portion of the total width with the remainder of the floodplain area, using mile-by-mile pile design, protected by river training structures,
- a roadway bridge/pipeline crossing combined with or without river training structures.

The crossing mode selected depends mainly on:

- economic considerations. The mode of the adjacent mile-by-mile design particularly affects the costs. It would probably be uneconomic to mobilize a river crossing spread for a small buried crossing in the midst of elevated mile-by-mile sections.
- technical constraints. A hot-oil pipeline can be buried only in thaw-stable material. A chilled gas pipeline may require specific modes to mitigate frost heave in frost-susceptible material.
- environmental requirements and constraints. The wildlife generally migrates during the summer to the coast via the river valleys. An elevated crossing could affect this movement. If used, it may have to be designed with a certain minimum "animal" clearance. A buried crossing generally results in a greater environmental impact during construction.

If the decision is in favor of an elevated crossing, various types can be used depending on economics, scour, ice forces and perhaps construction scheduling. Photos 38 to 40 illustrate the various types of crossings used in the Prudhoe Bay area.

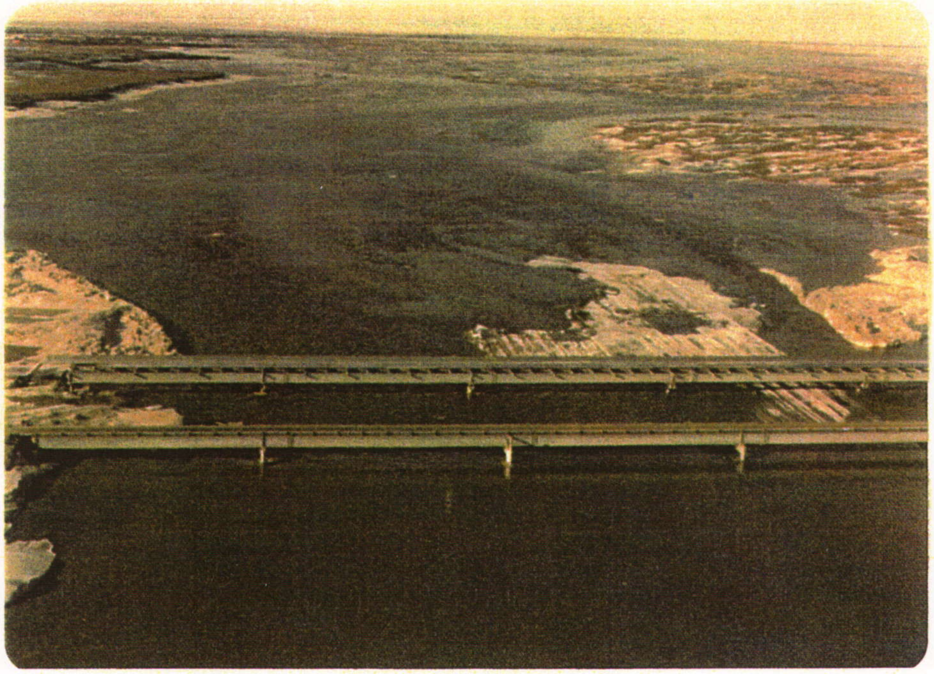

**PHOTO 38** **MULTI-SPAN PIPELINE BRIDGE**
Aerial view of ARCO's pipeline bridge (far structure) crossing the West Channel, Sagavanirktok River.
107-6-16A May 31, 1982

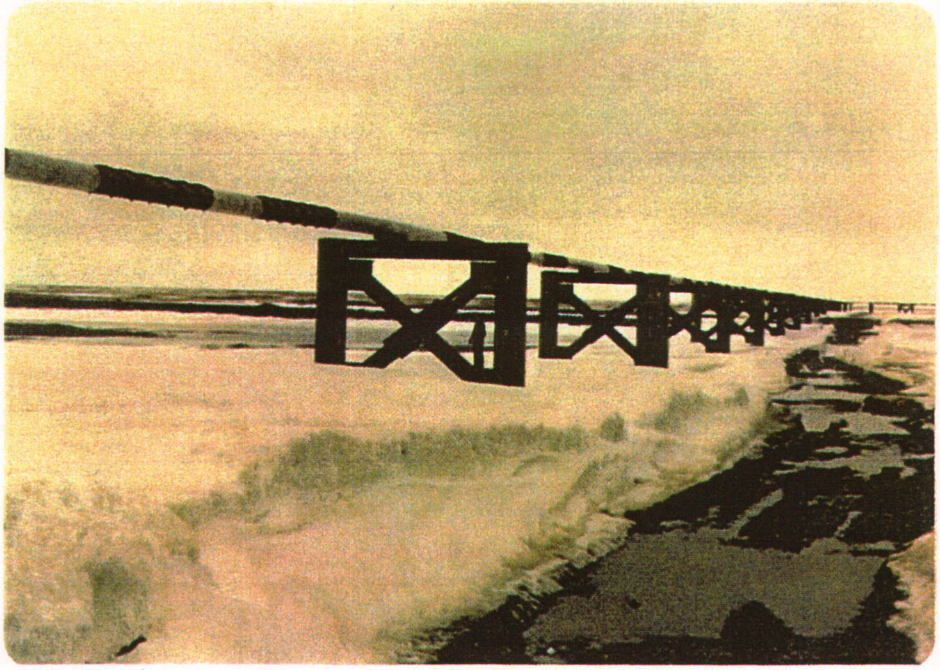

**PHOTO 39** **PILE-TYPE PIPELINE BRIDGE**
A massively-braced system of piles crossing the Kuparuk River. Note person for scale. Mile-by-mile piles are only 12 inches in diameter.
107-7-23 June 3, 1982

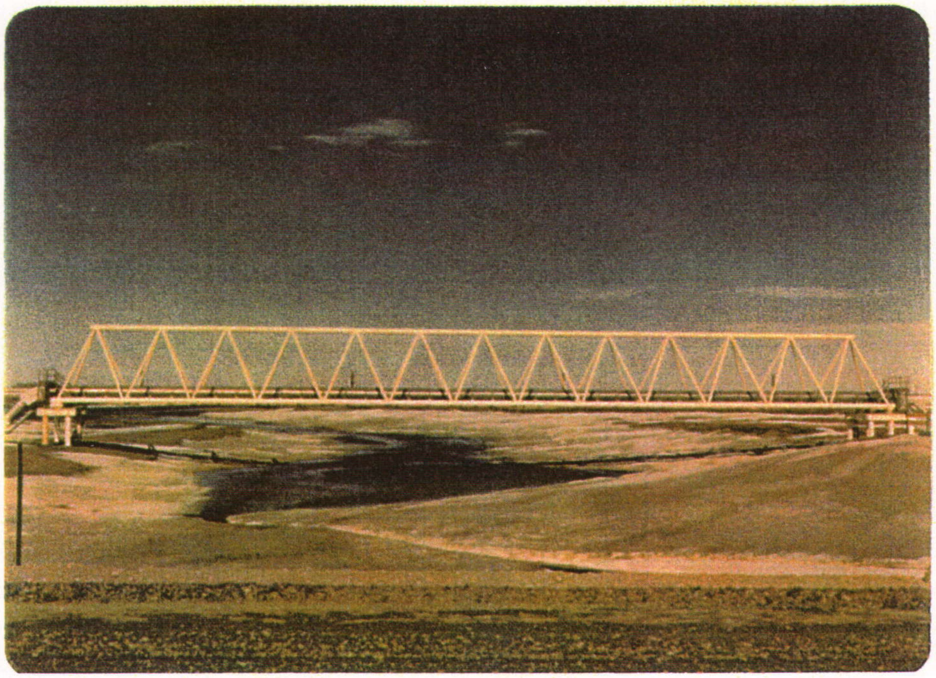

**PHOTO 40** **SINGLE-SPAN BRIDGE**
BP/SOHIO's crossing of the Putuligayuk River. Another crossing of the same stream further downstream uses regular mile-by-mile piles.
107-7-22 May 30, 1982

### 6.1.3 Design Criteria

6.1.3.1 Buried Crossings - The design flood selected for buried crossings will depend on economic, environmental and regulatory considerations. A safety factor may be added to the computed scour depths to account for uncertainties in computing both scour and design floods. In braided and low-banked streams such as the Main Channel Sagavanirktok, Shaviovik and Kadleroshlik Rivers, the most severe scouring conditions may occur at relatively low flood magnitudes, namely bankfull conditions, and thus the exact magnitude of the design flood may be rather academic. At an extremely rare event, flows are straightened by the valley walls and the individual subchannels are therefore a less dominant feature. At the bankfull depth of the subchannels however, the flows maintain the tortuous shape of the subchannels, and since bends and confluences of major subchannels experience the maximum local scour, this flow is generally the critical design condition. Depths of 4 to 5 times the normal depth of the channel have been observed in the field at confluences.

The fact a relatively frequent flood event (bankfull) can produce the most severe scour conditions would appear, at first glance, to be an unacceptable risk. However offsetting the relatively frequent nature of the design flood is the low probability of occurrence of two major subchannels forming right over the pipeline during the critical flow period.

A specific design criteria cannot be established for channel migration or channel switching. Yet it is these factors rather than flood-induced bed scour that lead more often to pipeline exposure and potential failure. Considering the maximum ultimate usable life of the pipeline (the more commonly used economic project life is often significantly extended as more oil is found or recovery techniques are improved), the pipeline should not become exposed due to a series of moderate flows combined with a single rare event. To ensure this, will require the analysis of channel behavior and past history by a qualified river engineer. Even then it should be recognized that periodic maintenance and construction of mitigative measure might be required.

Based on the above general discussion and recognizing the possible downtime if a failure occurred and the economic loss of such an event, a minimum design flood of 200 years is recommended at this time.

Generally either empirical methods based largely on field data and judgement or sediment/backwater computer models are used to compute scour. The proper application of both techniques requires experienced personnel. The appropriate scour method selected depends largely on the type of river, available cross-section and sediment data and the river conditions producing the most severe scour conditions. Field surveys should be undertaken with particular attention focused on bends and confluences. The surveys are most meaningful if undertaken at high flows.

6.1.3.2 <u>Elevated Crossings</u> - The preliminary proposed design criteria for the design flood, length, pile or pier spacing, elevation, ice loads and cofferdams for elevated crossings is as discussed below. Probably to a greater degree than even buried crossings, economic, environmental and regulatory considerations will play a large role in the determination of design criteria.

From a technical viewpoint, the recommended approach and philosphy is to establish acceptable limits of operation for the structure and then to ensure that under design conditions, the margins of safety against structural failure, either due to undermining or overtopping, are sufficient. This margin of safety should be established having regard to the reliability of the data on which the design values are based, to the probability of occurrence of greater values, to the consequences of failure and of course to economic and regulatory considerations previously discussed.

## Design Flood

In a pile-type crossing of a major (Photo 39) or minor stream, the incremental cost of selecting an extremely rare flood event may be very small. Pile "stick-up" height and depth of penetration would be affected to a minor degree by the flood size. The design flood however has a direct bearing on the width and therefore cost of a multi-span bridge as shown previously in Photo 38.

With regards to bed and bank scour, the probable duration as well as timing of large flows are significant. A moderate summer flood of long duration could result in significant river changes and scour whereas an extremely high spring breakup flow may have little impact on the crossing.

Selecting a design flood over bottom-fast ice or through a snow-constricted waterway opening (Photo 41) presents additional considerations. As flows and water temperature increase, deterioration and melting of the ice and snow commence. With ever increasing flows, the aufeis will lift and moves out while the snow is eroded or melted away.

The selection of a "design" aufeis level or snow-constricted opening should be in parallel with the flood selection process since the combination of relatively high breakup flow over aufeis or a snow-constricted waterway opening could be the critical design condition.

Based on the above discussion, the preliminary design criteria for elevated crossings are as given on Table 6.1.

**PHOTO 41** **EFFECT OF SNOW ON BRIDGES**
ARCO's West Channel Sagavanirktok River bridge in 1981. Dozer blade-wide paths were cleared prior to breakup. Height of snow relative to bridge is readily apparent, Snow had a significant impact on water levels during the early phases of breakup.
65-2-17 May, 1982

## Length

As discussed previously, a mile-by-mile pile-type crossing will be little if any affected by the necessary crossing length. Since the massive pile system for a major stream such as shown on Photo 39 is significantly more costly than a mile-by-mile design, it is very much affected by the length of the crossing. The same holds true for a multi-span bridge type crossing (Photo 38).

Factors to consider in determining the necessary bridge length are:

.impact of the bridge on water levels. If the banks are very low and extensive flooding is created by backwater effects, the waterway opening will have to be relatively large. Federal stipulations also require that the water levels during the 1:100 year flood are increased by not more than one foot above natural levels.

.impact on scour. A narrower opening will increase velocities and scour-factors which affect the design of piers and abutments.

- environmental considerations. As the crossing could alter the river's behavior or block an existing channel, environmental regulations could dictate minimum lengths or the location of bridges.

- economic considerations. In general a narrower opening will require deeper foundations or pilings and increased expenditure for river training structures. If the river width is too severely constricted, the additional capital and maintenance cost of the river training structures may in fact exceed the bridge structure savings realized.

Based on the above general discussion, the waterway length selected should ensure that during the 200 year open water design flood, natural water levels are increased by not more than one foot. This backwater effect could be increased, providing governmental stipulations concur, where the natural banks are sufficiently high and the backwater affected area is limited (see Table 6.1).

### Pile or Pier Spacing

The minimum spacing, from a hydraulic viewpoint, is usually dependent on debris or drift and ice floes. Lacking the presence of the former on the North Slope streams, ice is the only consideration. Based on the size of aufeis floes observed on the Sagavanirktok River since the mid-seventies, a minimum spacing of 100 and 60 feet is recommended for the named and unnamed streams respectively in the Point Thomson area.

### Elevation

Except where a bridge or pipeline is deliberately designed to be submerged, the appropriate clearance or freeboard between the design highwater level and the lowest part of the superstructure is dependent on:

- the thickness, orientation and projection of ice floes;

- the projection of logs or debris;

- statutory navigation requirements;

- liability of the superstructure to damage by water, ice or debris;

- bank height. If the riverbanks are low and flat and subject to overtopping, water level increases are limited even if the design conditions (flood size, aufeis or snow) are significantly exceeded.

.minimum clearance required for animal crossings.

Logs or debris are not a design concern on the Point Thomson streams. Ice floes up to 50X50 feet and 4 feet thick have been observed on the West Channel of the Sagavanirktok River. Similar floes could be experienced on the Main Channel and perhaps on the Shaviovik River. Little significant ice movement is expected on the Kadleroshilik and other minor streams due to their limited depth or lack of ice. The U.S. Coast Guard would probably

## TABLE 6.1

## DESIGN CRITERIA - ELEVATED PIPELINE CROSSINGS

| Condition | Criteria |
|---|---|
| Design Flood | .200 year open water<br>.20 year breakup flow over maximum recorded aufeis levels<br>.for a multi-span bridge, use a 20 year breakup flow over and through a snow-constricted waterway opening. This is not a design consideration for a pile-type crossing remote from a road bridge. |
| Length | .depends on technical, economic, environmental and regulatory considerations. As length is decreased, cost of river training structures, foundations and pilings increase. To minimize potential changes to the characteristics of the river and increases in water levels, environmental and regulatory requirements may dictate a minimum bridge length. |
| Pile or Pier Spacing | .100 foot minimum on the Main Channel Sagavanirktok, Shaviovik and Kadleroshilik Rivers.<br>.60 foot minimum on the unnamed streams. |
| Elevation | .the highest of the following criteria:<br>-200 year open water flood + 4.0 feet<br>-20 year breakup flow over aufeis + 4.0 feet<br>-20 year breakup flow over snow + 4.0 feet<br>-2 year flood + 7.0 feet (for navigation)<br>-as specified for animal crossings. |
| Ice | .to be determined |
| Temporary Structures | .depends on timing and duration of the structures and economic considerations by the owner and contractor. |

classify all the named streams as being navigable. The recommended clearance criteria is as given in Table 6.1.

### Ice

The design criteria for ice forces will have to be determined by structural engineers. The unique nature of aufeis and the fact it generally does not move until it has reached a deteriorated state, should be recognized by the designer. Strong arguments could be presented to reduce commonly-used ice strengths developed from competent and thermally-generated ice covers. Other possible design considerations are the potential velocities and pile-up against the piers. With a bridge over a wide low-banked braided stream - typical of the major Point Thomson crossings - the magnitude of the potential head build-up as a result of an ice jam is very limited. This is in contrast to a crossing of a deeply incised valley where significant forces could be transmitted to the bridge structure as a result of an ice jam.

### Temporary Structures

Cofferdams and diversions may be required to construct the crossings. The layout and design of these facilities will be very dependent on economic, environmental and risk considerations. Economics and bridge design may dictate the location of the structures and thus the constriction they impose on the natural river channel. Environmental dictums may specify the maximum constriction percentage or the maximum allowable velocity increase for a given flood size. These of course relate to concerns about fish passage. The owner and contractor are usually both involved in determining an acceptable risk of overtopping of temporary structures. The owner wishes to ensure the start-up of the project is not delayed while the contractor is concerned about damages and costs incurred as a result of construction delays. The timing and duration of the temporary work will play a large part in the selection of the design flood.

## 6.2 ROAD CROSSINGS

### 6.2.1 General Hydrologic and Hydraulic Considerations

The hydrologic and hydraulic factors affecting the design of elevated pipeline crossings, as outlined in Section 6.1.1, are applicable as well to road crossings. The major difference between the two types of crossings is that whereas the elevated pipeline beyond the main channel crossing (either bridge or pile-type structures) creates little obstruction to the floodplain flows, the roadway embankment or causeway across the floodplain can have a significant impact on water levels.

Economic and access considerations will have a major impact on the type and size of crossing selected and these, rather than hydrologic or hydraulic considerations, may be the dominant factors in the design process. Should the bridge and causeway provide access for any and all flood conditions or will periodic overtopping of the roadway and thus temporary loss of access be permitted? What are the bridge design loads? Normal maintenance and/or construction traffic or modules?* These are considerations in assessing the infrastructures and logistics for the development.

Whether roadway sections are designed to be overtopped or not, a section of the roadway embankment in the floodplain should always, if possible, be at or somewhat below the theoretical design water level. This will ensure that if unforeseen conditions occur, (a severe flood or ice or snow constrictions), adequate freeboard at the bridge will be maintained without the integrity of the bridge being compromised. If the river valley is very narrow, designed low sections may not be possible if reasonable road grades are to be maintained.

The emergency overflow sections can either be non-armored gravel sections which erode during sustained periods of overtopping (Photos 42 and 43) or they can be, based on the 1982 breakup, successfully designed to be non-erodable by paving the surface and armoring the upstream and downstream faces of the embankment (Photo 44). Concrete blocks on the downstream side only of the roadway fill have been used elsewhere in the Prudhoe Bay area (Photo 45) although they have not yet been tested by overflows. If the

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* Since ARCO's bridge at the West Channel of the Sagavanirktok River is not designed for modules, it is assumed that modules would have to be transported in the winter if Prudhoe Bay is the docking area. If Point Thomson is the docking area, the modules would not have to cross the streams discussed herein.

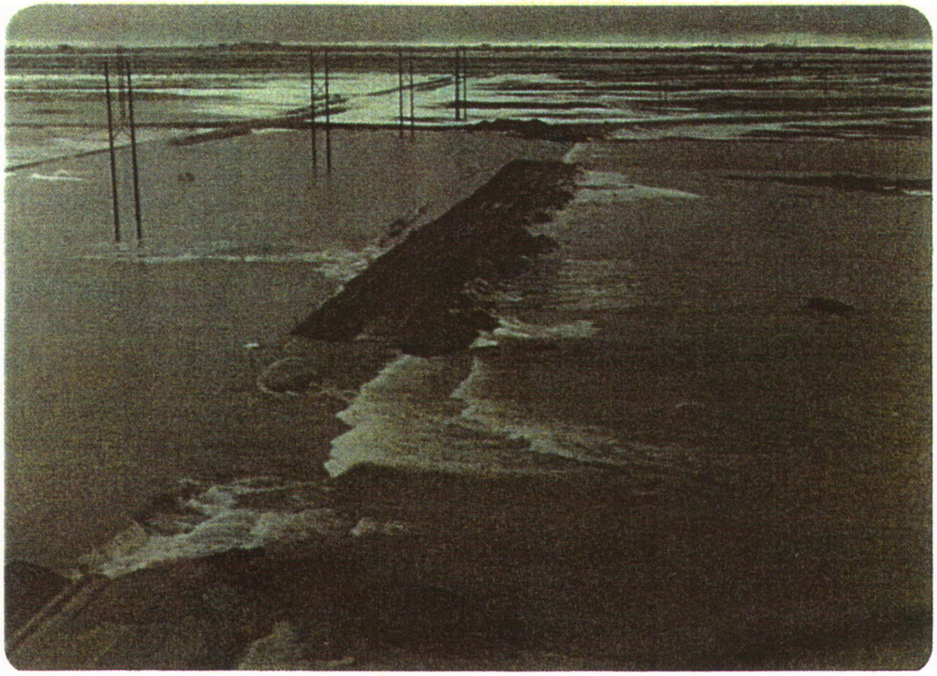

**PHOTO 42** **WEST CHANNEL SAGAVANIRKTOK RIVER**
Looking at gravel roadway sections (crossing overflow channels from the West Channel) overtopped by the 1981 breakup flows. Culverts in between the overflow sections have inadequate capacity.
65-7-0 May 1981

**PHOTO 43** **WEST CHANNEL SAGAVANIRKTOK RIVER**
Close-up of washout of gravel roadway sections shown above.
65-6-25 May 1981

**PHOTO 44** **KUPARUK RIVER**
View of designed overflows. "Armorflex" articulated concrete blocks (12" X 12") on upstream and downstream faces of embankment and a concrete driving surface.
65-14-10 July 1982

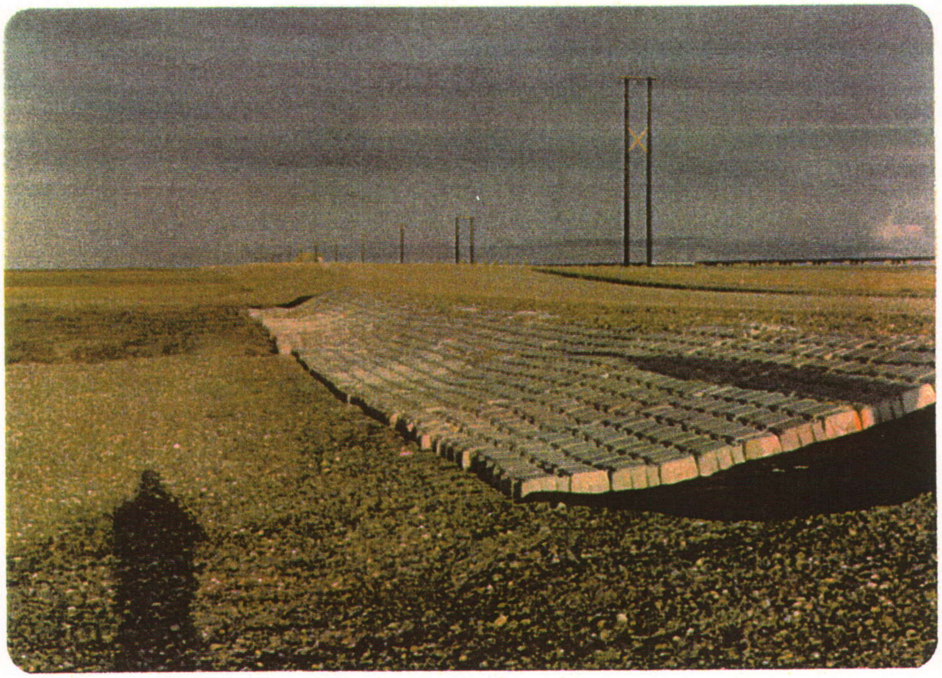

**PHOTO 45** **WEST CHANNEL SAGAVANIRKTOK RIVER**
"Armorflex" concrete slope protection used on downstream face of repaired overflow sections shown on Photos 42 and 43.
107-14-6 July 1982

driving surface is paved like the Kuparuk River causeway, access is uninterrupted except at extremely high flows. The type of overflow design selected depends on the frequency and magnitude of overtopping, access requirements during "minor" overtopping events as well as the availability of granular material to repair the washed-out sections.

### 6.2.2 Alternative Crossing Types

The main choice is between a bridge or culverts. Factors affecting the selection process are size of stream, bank height, presence and nature of ice, river channel stability, sediment transport, environmental requirements, and economic and construction considerations. The size of stream and thus design flow will determine the bridge width or number of culverts. If the banks are relatively low at a major stream, it may not be physically possible to provide an adequate waterway opening using culverts. Aufeis formations and a highly mobile bed such as the Kadleroshilik River are hydrologic factors favoring a bridge over culverts. Maximum allowable velocities to permit upstream passage of fish may also dictate the use of a bridge. Although economics could initially favor culverts, their annual maintenance cost (mainly snow clearing) could in the long term favor a bridge. Even with bridges like ARCO's across the West Channel of the Sagavanirktok River, experience has shown that a snow clearing program may still be necessary to reduce breakup water levels. The proximity and number of bridges at this location could be a factor in the snow depositional processes.

Construction considerations also play a role in the selection process. Fill compaction for culverts is difficult to attain during freezing conditions. Summer construction activities may be limited on some streams due to environmental considerations.

### 6.2.3 Design Criteria

The proposed design criteria for roadway bridges should be as recommended for elevated pipeline crossings (see Section 6.1.3.2 and Table 6.1) except the open water design flood can be reduced from 200 years to 100 years. For culverts, the maximum depth of water upstream should not exceed 1.5 times the height of the culvert at design flow conditions and to facilitate cleanout, a minimum culvert diameter of 4 feet is recommended. Partial snow and/or ice blockage should be assumed in determining the capacity of culverts during spring breakup. Culverts can be set at varying elevations in icing areas. The invert of the culvert will generally have to be set below the natural streambed to meet fish passage requirements. Therefore a portion of the culvert's area will be ineffective. Culvert capacity is also a function of downstream water levels which may also be affected by the presence and extent of snow. A firm commitment to a snow clearance program could significantly reduce the capital cost of culverts. Culverts will generally require inlet and outlet sections to improve their hydraulic efficiency and reduce seepage which could lead to eventual failure.

## 6.3 ALIGNMENT OF ROAD VERSUS PIPELINE

At the major crossings such as the Main Channel Sagavanirktok, the Shaviovik and Kadleroshilik Rivers, proximity of the road to the pipeline is advantageous from a hydraulic viewpoint as discussed in the next chapter. Assuming that the road bridges, for economic reasons, span only a portion of the main channels, river training structures will be required to protect the abutments. By placing the pipeline bridge immediately next to the roadway bridge, a single set of structures can be used for both crossings. The upstream and downstream extent of the structures is mainly a function of bridge length and thus will need to be only incrementally increased to serve as protection for both bridges.

At minor crossings, where either river training structures are not required at the road crossing or where they are not significant, proximity of the two facilities is not as important from a hydraulic viewpoint. The pipeline crossing may be similar to mile-by-mile elevated design with the piles designed for the increased "stick-up" height to account for scour and design water level. The design and cost would thus be affected, little if any, from proximate roadway and pipeline alignments.

Where the lines are proximate, it is recommended that the pipeline be located downstream of the roadway. The road embankment across the floodplain thus protects the proximate floodplain pipeline segments from main channel flows, scour and ice. Furthermore, if water levels are higher than anticipated due to unexpected snow or ice conditions, freeboard at the pipeline crossing will not be affected. Offsetting this latter advantage however is the potential backwater created by the roadway bridge. This could result in high velocities and scour at the pilings or piers of the pipeline bridge located downstream.

CROSSING
DESIGNS

# 7.0 CONCEPTUAL RIVER CROSSING DESIGNS

## 7.1 DESIGN BASIS AND APPROACH

The preparation of preliminary or conceptual river crossing designs was not included in the scope of services outlined in Section 2.2. However to better assess the need for and scope of future hydrologic studies, an important component of the work, conceptual designs were prepared for road and pipeline river crossings of the Main Channel Sagavanirktok, Kadleroshilik and Shaviovik Rivers and unnamed streams at Mileposts 27.3 and 31.8. The designs were not based on quantitative hydrologic and hydraulic analysis but rather are preliminary qualitative assessments based on Hydrocon's experience with river crossings in Alaska (several years of breakup reconnaissance on the Sagavanirktok River and Prudhoe Bay area streams, the design and construction of the river crossings for the trans-Alaska oil pipeline and design review of river crossings for the Northwest Alaska gas pipeline) as well as general experience with pipeline and road crossings of gravel-bed streams.

More specifically the qualitative assessments were based on the following considerations:

- bridge elevations were generally selected to be equal to or greater than the combined width of the major subchannels.
- bridge height is a function of design water level. The design water level was estimated from the surveyed highwater marks plus a 1-2 foot allowance for backwater due to the bridge. For the crossings of the Main Channel Sagavanirktok, Shaviovik and Kadleroshilik Rivers, which have wide, flat and very low floodplain areas, the design water level for natural conditions was estimated to be about 2 ± feet above the observed highwater mark. The low steel elevation for elevated crossings was set at 4 feet above the design water level.
- the elevation of the emergency roadway overflow sections was generally set at approximately the elevation of the surveyed highwater marks. On some streams such as the Shaviovik River, the required minimum thickness of embankment (for structural reasons) will probably require a higher elevation for the overflow area. At Milepost 31.8, the narrow width of the stream did not permit an overflow. The length of overflow

was generally maximized assuming a maximum road grade of 6% and horizontal sections (50 to 100 feet long) leading out from the bridge abutments.

- scour depths for the deep buried sections were estimated from other scour studies of gravel-bed streams. In floodplain areas, a minimum cover of 5 feet was assumed below the lowest existing floodplain elevation.

The following data and assumptions were used in the preparation of the conceptual design drawings:

- cross-sections as surveyed in July 1982 using assumed datums.
- highwater marks as obtained during the July, 1982 surveys.
- comparative aerial photographs from July, 1955 and 1980 or 1981.
- the road and pipeline crossings are proximate at the 3 major named rivers. At the unnamed streams, alternate designs are shown for widely separated crossings.
- the pipeline is located downstream of the road.
- burial, from a geotechnical viewpoint, is an option to an elevated pipeline crossing.
- a minimum of 4 feet of gravel was assumed for the mile-by-mile roadway design.

The centerline of the road and pipeline corridor is depicted on the aerial photos. Although the surveyed cross-sections are within the corridor width used in the present study (2 miles), their locations do not necessarily coincide with either the location or orientation of the centerline of the corridor shown. The ground profile shown on the conceptual design drawings matches the topography surveyed at cross-section 1.

To proceed to the preliminary crossing design phase requires detailed hydrologic, hydraulic and river engineering studies to determine flood magnitudes, bridge length and height and scour depths respectively.

## 7.2 MAIN CHANNEL SAGAVANIRKTOK RIVER

### 7.2.1 River Behavior

The 1955 and 1980 aerial photos are as shown on Drawing 7. Low level helicopter photos of the crossing area during open water conditions are as previously shown in Photos 19 to 21.

Few changes have occurred in the corridor area since 1955. The easternly subchannels of the main channel have reduced in size somewhat since 1955 while another subchannel has formed immediately adjacent to the high eastern bank. The western subchannel appears to have become slightly enlarged.

Flows could increase in the western subchannel in the future if the gravel bar, which partly constricts its entrance (see Photo 20), is eroded away. Dramatic flow changes are not expected however. Alternatively, flows could be reduced if additional material is deposited on the bar. The subchannels of the eastern main channel (Photo 19) may change in their location and size within the floodplain however significant erosion of the main banks is not expected. This is particularly true for the high frozen eastern bank where permafrost will retard bank migration.

As shown on Drawing 7, the west subchannel is relatively deep compared to the main channel. The surveyed cross-section is located at a slight bend on the subchannel. The frozen non-erodible nature of its east bank combined with the curvature of flow, accounts for its depth. If one of the subchannels in the main channel became entrenched against the high and relatively non-erodible eastern bank, its depth could become comparable to the west subchannel.

### 7.2.2 Alignment

The crossing alignment is virtually on a straight line from the West Channel of the Sagavanirktok River to the Shaviovik River; the latter being a possible control point on the overall alignment of the Point Thomson pipeline as discussed in Section 7.4. Future design refinements will no doubt optimize the crossing location for both the main and west subchannel crossings. From an economic viewpoint, there would be advantages in blocking

AIR PHOTO DATE: 24 JULY, 1955

AIR PHOTO DATE: 17 JULY, 1980

## AIR PHOTO COMPARISON

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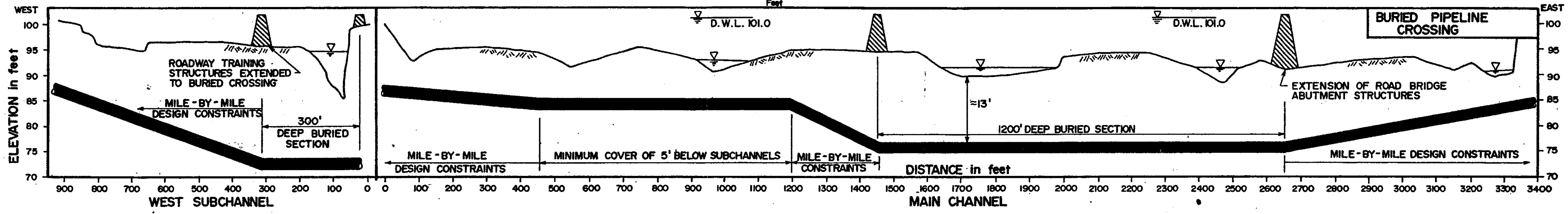

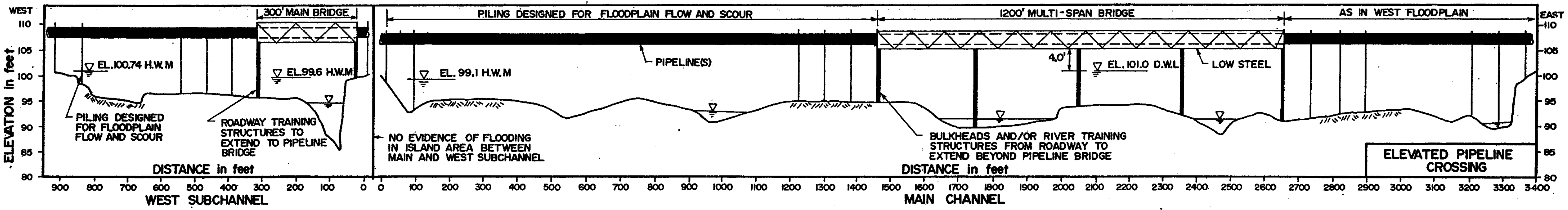

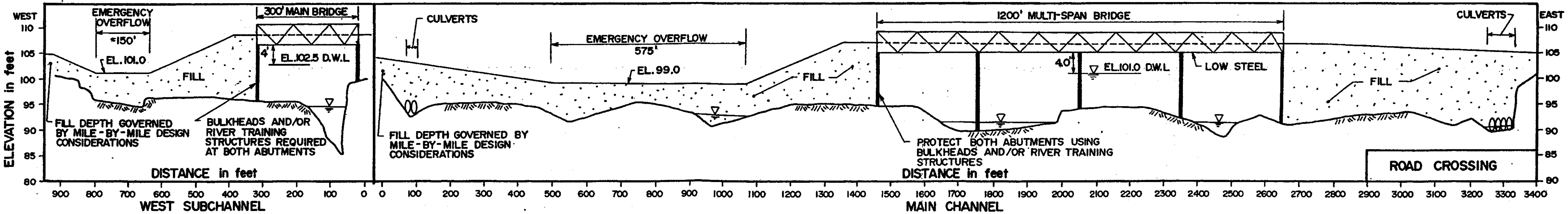

## CONCEPTUAL CROSSING DESIGNS

NOTES:

1. CROSS SECTION BASED ON HYDROCON SURVEY DATED JULY 15, 1982. SECTION ILLUSTRATED IS NUMBER 1.
2. ELEVATIONS ARE BASED ON ASSUMED DATUMS.
3. ▲----▲ INDICATE SURVEY LIMITS.
4. SURVEY OF WEST SUBCHANNEL NOT TIED INTO MAIN CHANNEL SECTION.
5. "HWM" SIGNIFIES HIGH WATER MARK AS DETERMINED FROM DEBRIS AND/OR GRAVEL REMNANTS.
6. "DWL" SIGNIFIES DESIGN WATER LEVEL AND IS ESTIMATED ONLY.
7. THE DESIGNS, INTENDED TO SHOW CONCEPTS ONLY, ASSUME THE PIPELINE CROSSING IS LOCATED IMMEDIATELY DOWNSTREAM OF OR IS CONCURRENT WITH THE ROAD CROSSING. THUS ONE SET OF RIVER TRAINING STRUCTURES WOULD SUFFICE FOR BOTH CROSSINGS. IF THIS IS NOT THE CASE, EITHER SEPARATE RIVER TRAINING STRUCTURES WILL BE REQUIRED OR DEEP BURIAL OR BRIDGE LENGTH INCREASED. THE CONCEPTUAL DESIGNS ASSUME THE CROSSING IS LOCATED AT SECTION 1. REALIGNMENT WOULD ALTER THE LOCATION OF THE COMPONENTS BUT PROBABLY NOT THE GENERAL DIMENSIONS. MAIN CHANNEL PILING IS AN OPTION TO THE PIPELINE BRIDGE.

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SUBJECT SAGAVANIRKTOK RIVER - MAIN CHANNEL
AIR PHOTO COMPARISON AND
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the west subchannel and thus eliminating the western 300-foot long bridge. Provided the fill across the west subchannel and the island between the west and main channels is sufficiently high (at least 5 feet), all the flow could be diverted from the west into the main channel.

If this were to be considered, and the option might be ruled out almost immediately as it would significantly decrease the fish habitat, the road alignment across the west channel would have to be shifted approximately 1000-1500 feet further upstream to facilitate diversion of the flow into the main channel.

### 7.2.3 Roadway Crossing Design

Drawing 7 illustrates the conceptual design of the road crossing. Features of the design are:

- a multi-span bridge approximately centrally located in the eastern main channel area.

- river training structures and/or vertical abutments protecting the bridge and aligning the flow through the waterway opening. Guidebanks will be required upstream of the bridge to ensure the efficient utilization of the entire waterway opening during floods. Without guidebanks, excessive gravel deposition and scour could occur in the bridge opening.

- an emergency overflow west of the bridge set at several feet below the design water level. If future breakup reconnaissances indicate that the highwater levels experienced during 1981 (at or near bankfull) is a relatively frequent occurrence, the overflow elevation would have to be increased. This could in turn necessitate an increase in bridge length.

- culverts near both banks of the main channel. Although not required for hydraulic capacity reasons, they may be desirable or necessary to prevent ponding and permit fish passage. The culverts might be eliminated, from a technical viewpoint, if the roadway embankment overflow area is at least 5 feet above the floodplain levels and the floodplain subchannels are interconnected to the main channel the latter to prevent ponding.

- a single or multi-span bridge across the west subchannel. The bridge would be centered over the present channel.

- an emergency overflow west of the west subchannel bridge.

### 7.2.4 Pipeline Crossing Design

Drawing 7 illustrates the conceptual design of an elevated and buried pipeline crossing. Features of the elevated design are:

- a multi-span bridge or main channel piling in line with and adjacent to the roadway bridge. River training structures for the latter would be extended for the pipeline bridge.
- pilings designed for floodplain flow for the remainder of the crossing length.
- a multi-span bridge or main channel piling in line with and adjacent to the roadway bridge across the west subchannel. Pilings beyond the bridge and for the remainder of the channel width would be designed for floodplain flows and scour.

In the case of a buried crossing, deep burial would be required below the roadway bridges. In the floodplain areas affected by the roadway overflows, a minimum cover of 5 feet would be necessary. River training structures from the roadway bridge would be extended across the buried crossing to limit the length of deep burial to that of the roadway bridge. If for geotechnical reasons the east bank transition to an elevated mile-by-mile design (assuming it is elevated), is located within the floodplain limits, a river training structure may be required to protect it unless full reliance can be placed on the adjacent roadway fill.

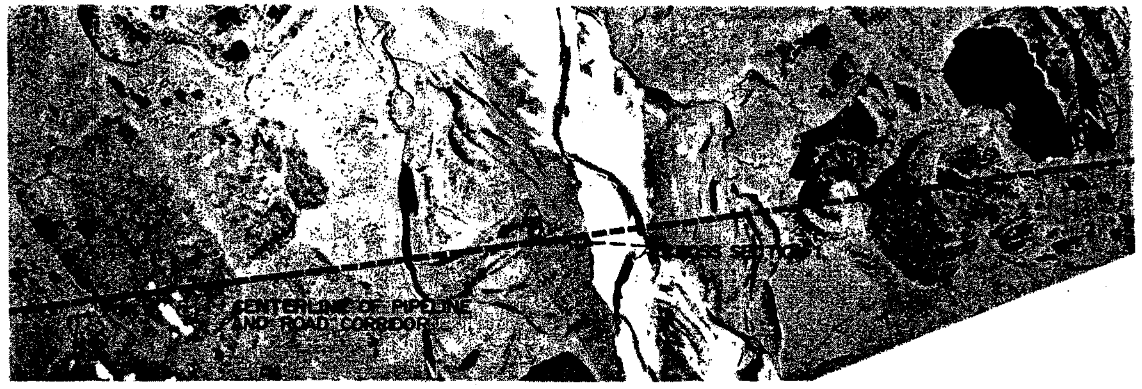
## 7.3 KADLEROSHILIK RIVER

### 7.3.1 River Behavior

The 1955 and 1981 air photos are illustrated on Drawing 8. Very few if any changes are noticeable within the corridor area. Even the subchannels within the non-vegetated floodplain exhibit little change.

The most dramatic feature of the Kadleroshilik River is its large bedforms and local scour holes as shown in Photo 23 of Section 4.3.3.2. The forms are generally indicative of high bedload transport although, based on comparative airphotos of the last 25 years, the transport has apparently done little to change the pattern of the stream - a somewhat surprising conclusion. Another unusual feature is that there is little evidence of

AIR PHOTO DATE: 24 JULY, 1955



AIR PHOTO DATE: 15 JULY, 1981

## AIR PHOTO COMPARISON

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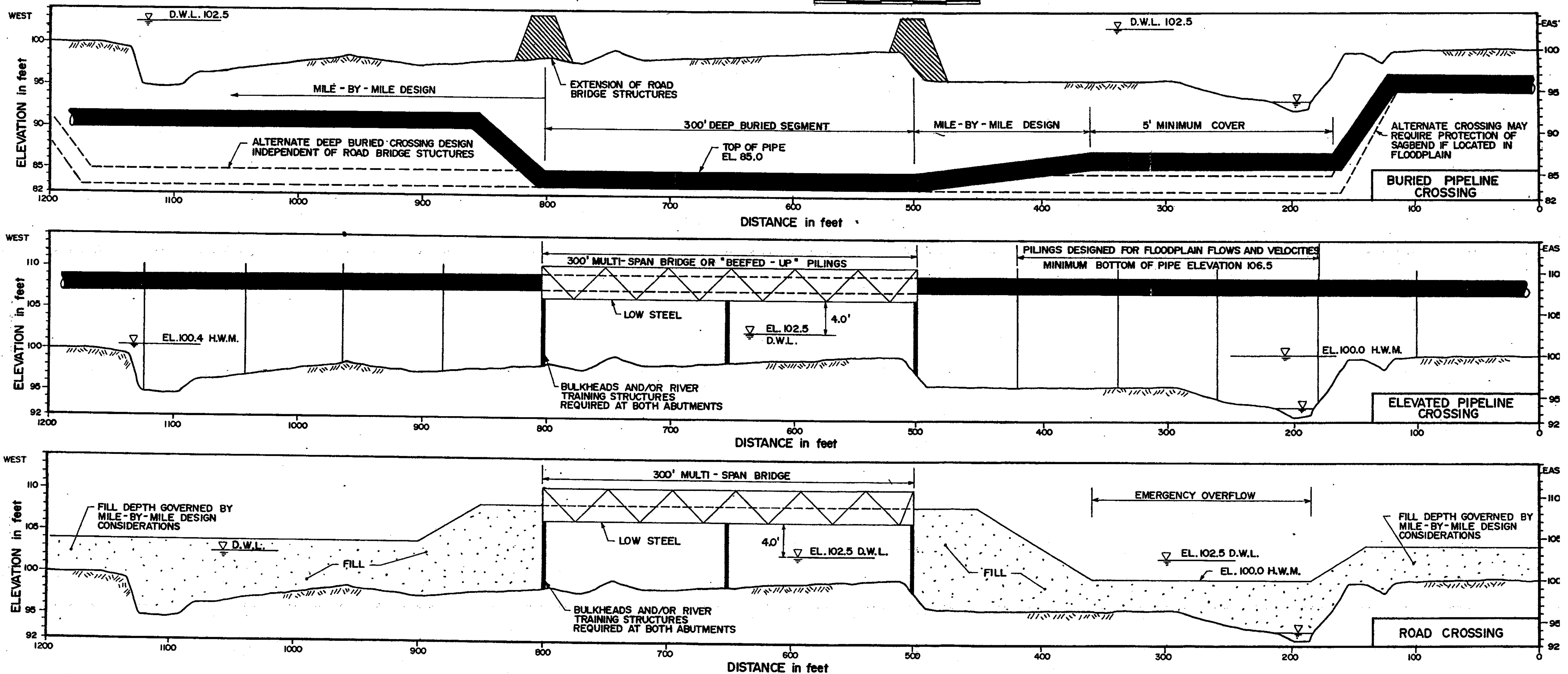

## CONCEPTUAL CROSSING DESIGNS

NOTES:
1. CROSS SECTION BASED ON HYDROCON SURVEY DATED JULY 18, 1982. SECTION ILLUSTRATED IS NUMBER 1.
2. ELEVATIONS ARE BASED ON ASSUMED DATUMS.
3. ▲——▲ INDICATE SURVEY LIMITS.
4. "HWM" SIGNIFIES HIGH WATER MARK AS DETERMINED FROM DEBRIS AND/OR GRAVEL REMNANTS.
5. "DWL" SIGNIFIES DESIGN WATER LEVEL AND IS ESTIMATED ONLY.
6. THE DESIGNS, INTENDED TO SHOW CONCEPTS ONLY, ASSUME THE PIPELINE CROSSING IS LOCATED IMMEDIATELY DOWNSTREAM OF OR IS CONCURRENT WITH THE ROAD CROSSING. THUS ONE SET OF RIVER TRAINING STRUCTURES WOULD SUFFICE FOR BOTH CROSSINGS. IF THIS IS NOT THE CASE, EITHER SEPARATE RIVER TRAINING STRUCTURES WILL BE REQUIRED OR DEEP BURIAL OR BRIDGE LENGTH INCREASED. THE CONCEPTUAL DESIGNS ASSUME THE CROSSING IS LOCATED AT SECTION 1. REALIGNMENT WOULD ALTER THE LOCATION OF THE COMPONENTS BUT PROBABLY NOT THE GENERAL DIMENSIONS. MAIN CHANNEL PILING IS AN OPTION TO THE PIPELINE BRIDGE.

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gravel deposition on the vegetated floodplain, although it is nearly at the same elevation as the mid-channel bedforms in the surveyed area. The aufeis formations and resultant ice pressure ridges may affect the channel processes on this stream. Similar scour holes have been reported on the Babbage River* in a similar physiographic region in the Yukon Territories of Canada.

### 7.3.2 Alignment

The crossing is virtually on a straight line between the Main Channel of the Sagavanirktok River and the Shaviovik River. Cross section 1 is the narrowest main channel width in the corridor area and with a minor realignment to eliminate its skew, would be the optimum crossing location from a hydrologic viewpoint.

### 7.3.3 Roadway Crossing Design

Drawing 8 illustrates the conceptual design of the road crossing. Features of the design are:

- realignment of the present subchannels to approximately the middle one-third of the active floodplain width. Excavated material could be used to construct the roadway embankment.

- a multi-span bridge centrally located. Bulkheads and/or river training structures (guidebanks) would be required to protect the bridge abutments and roadway fill and to increase the hydraulic efficiency of the waterway opening.

- an emergency overflow east of the bridge at an elevation slightly below the observed highwater mark and the adjacent main banks. If the terrain is very flat for a considerable distance beyond the main banks, the overflows may have to be lowered further to prevent excessive flooding of the adjacent terrain. Alternatively, the overflow elevation could be increased, however this may require additional raising of the bridge.

- culverts are not expected to be necessary to prevent ponding and would probably be difficult to keep open in view of the possible sediment transport and aufeis. They are not necessary for hydraulic capacity reasons.

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* "Rivers of the Yukon North Slope". C.P. Lewis and B.C. McDonald, in Fluvial Processes and Sedimentation, Proceedings of Hydrology Symposium, University of Alberta, May 1973.

### 7.3.4 Pipeline Crossing Design

The conceptual designs of an elevated and buried crossing are illustrated on Drawing 8. Features of the elevated design are as follows:

- a multi-span bridge or pilings designed for main channel flow and scour. It is assumed the bridge would be located immediately proximate to the roadway bridge and would thus utilize the same river training structures. If pilings are used, the main channel general scour plus the local pile scour combined with the design water level and freeboard would govern the "stick-up" or unsupported length of piling. A sleeve or sacrificial section of pipe could be used around the pilings if damage due to bedload movement is a concern.
- the pilings downstream of the roadway overflow would be designed for floodplain flows and scour.
- the pipeline would be set at a minimum of 4 feet above the design water level for the entire width of the crossing.

If a buried crossing is technically feasible and economically desirable, it would consist of a deep buried segment for the width of the road bridge and a minimum cover of 5 feet in the areas adjacent to the roadway overflow sections. River training structures for the roadway would be extended to limit the length of deep burial. The burial depth for the remainder of the crossing would be governed by mile-by-mile design considerations. If the east transition to an elevated mile-by-mile design is located within the floodplain area (necessary if the bank material is not thaw stable), a river training structure may be required to protect it. If the pipeline alignment is not proximate to the roadway, deep burial across the entire width of the floodplain would probably be most desirable as illustrated.

The variability of bed levels at the crossing dictates that design burial depths be specified by an elevation rather than a cover depth. The design elevation for a buried crossing would be based on a realigned channel through the proposed roadway bridge opening.

## 7.4 SHAVIOVIK RIVER

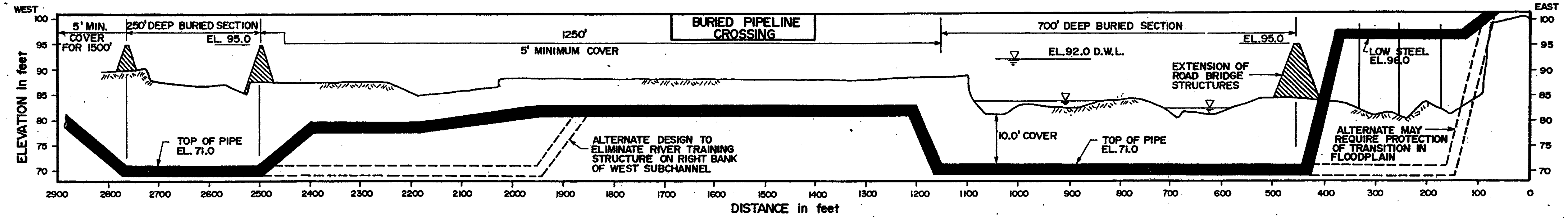
### 7.4.1 River Behavior

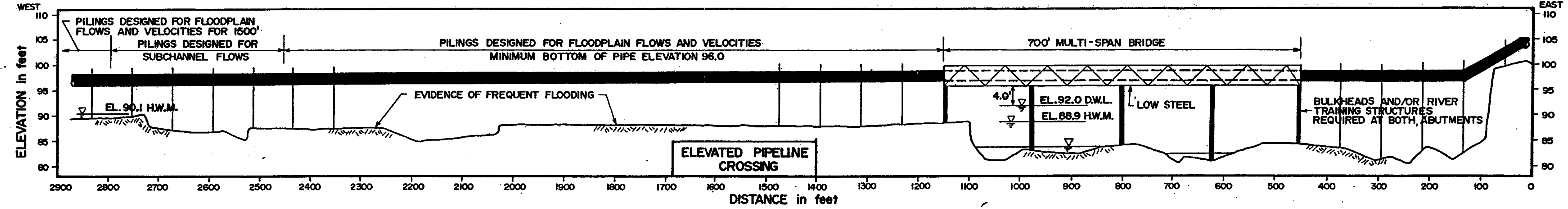
The 1955 and 1981 comparative aerial photos are shown on Drawing 9. As in

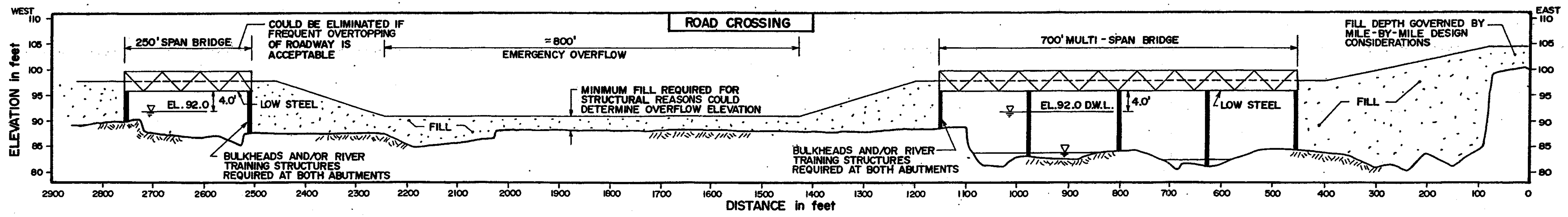
AIR PHOTO DATE: 24 JULY, 1955

AIR PHOTO DATE: 15 JULY, 1981

## AIR PHOTO COMPARISON







## CONCEPTUAL CROSSING DESIGNS

NOTES:
1. CROSS SECTION BASED ON HYDROCON SURVEY DATED JULY 16, 1982. SECTION ILLUSTRATED IS NUMBER 1.
2. ELEVATIONS ARE BASED ON ASSUMED DATUMS.
3. ▲——▲ INDICATE SURVEY LIMITS.
4. "HWM" SIGNIFIES HIGH WATER MARK AS DETERMINED FROM DEBRIS AND/OR GRAVEL REMNANTS.
5. "DWL" SIGNIFIES DESIGN WATER LEVEL AND IS ESTIMATED ONLY.
6. THE DESIGNS, INTENDED TO SHOW CONCEPTS ONLY, ASSUME THE PIPELINE CROSSING IS LOCATED IMMEDIATELY DOWNSTREAM OF OR IS CONCURRENT WITH THE ROAD CROSSING. THUS ONE SET OF RIVER TRAINING STRUCTURES WOULD SUFFICE FOR BOTH CROSSINGS. IF THIS IS NOT THE CASE, EITHER SEPARATE RIVER TRAINING STRUCTURES WILL BE REQUIRED OR DEEP BURIAL OR BRIDGE LENGTH INCREASED. THE CONCEPTUAL DESIGNS ASSUME THE CROSSING IS LOCATED AT SECTION 1. REALIGNMENT WOULD ALTER THE LOCATION OF THE COMPONENTS BUT PROBABLY NOT THE GENERAL DIMENSIONS. MAIN CHANNEL PILING IS AN OPTION TO THE PIPELINE BRIDGE.

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the case of the previous crossing, there is little noticeable change in the limits of the active channel in the corridor area. In the eastern half of the corridor centreline however, a major subchannel has formed since 1955. There is no significant noticeable change in the west overflow channels (located 1000 feet west of the main channel) since 1955. The potential enlargment of these subchannels is however a major design consideration particularly for the roadway bridge.

### 7.4.2 Alignment

It was assumed that the North Slope Borough Conservation Zone as shown on Drawing 2 governs the alignment at the Shaviovik River crossing. If this is the case, the pipeline corridor shown, just north of a lake on the east bank, is probably the optimum location from a hydrologic viewpoint. It provides for the minimum main channel width. Shifting the pipeline and road northward into the Conservation Zone would shorten their mile-by-mile lengths but would increase the length of the river crossing. This may however not add substantially to the crossing cost as the necessary bridge (pipeline and roadway) lengths or deep buried segments would probably remain the same. Only the floodplain segments adjacent to the main crossing would increase in length. Roadway embankment quantities would increase however at the downstream location.

Only by shifting the alignment even further south, and thereby increasing the length of the pipeline and roadway could the western overflow channels, from a hydrologic and hydraulic viewpoint, be closed off completely. This would eliminate the need for a bridge across the west subchannel. At this upstream alignment (located just downstream of the bifurcation of the main and west channels), the west channel could be diverted into the main channel by means of the roadway embankment.

### 7.4.3 Roadway Crossing Design

Drawing 9 illustrates the conceptual design of the road crossing. Design features are:

- multi-span bridges over the main eastern channel and the west subchannel. River training structures (guidebanks) and/or bulkheads would be used to protect the bridge abutments and roadway fill and to maximize the hydraulic efficiency of the waterway opening. The design shown is predicated on the assumption that the western subchannels will not become dramatically enlarged in the near future. If this is shown not to be the case in the final design analysis, bridges of nearly equal size might be required on the main channel and the west subchannel.

.an emergency overflow section between the bridges across the vegetated floodplain. The elevation of the overflow might be governed by the minimum roadway fill required over the floodplain area for structural and thermal integrity reasons. The overflow is made as long as possible to minimize the depth of overflow and thus the extent of bridge backwater-induced flooding beyond the main and west channels.

.culverts are not expected to be required. The multi-span bridge will prevent ponding in the main channel area whereas the west subchannel probably carries little or no flow except during major flood events and spring breakup.

### 7.4.4 Pipeline Crossing Design

The conceptual designs of an elevated pipeline crossing and an alternate buried crossing are illustrated on Drawing 9. Features of the elevated crossing are:

.a multi-span bridge or main channel piling adjacent to the roadway bridge. The river training structures or bulkheads at the roadway bridge would be extended for the pipeline bridge.

.pilings designed for floodplain flows and scour extending westward across the vegetated terrace and western subchannels. By utilizing pilings rather than a bridge across the west subchannels, the roadway and pipeline would not need to be proximate. If the pilings are designed for main channel scour depths, their design would not be affected by an increase in flow in the west subchannels.

The buried crossing would have a deep buried section downstream of the roadway bridge and similarly a deep section across the west subchannels. The buried design shown on Drawing 9 assumes that flows in the west subchannel are not substantially increased. Depending on the location of the transition to an elevated mode at the eastern bank, river training structures may or may not be required to protect the transition.

## 7.5 UNNAMED STREAM, M.P. 27.3

### 7.5.1 River Behavior

Comparative air photos taken in 1955 and 1981 are shown for this stream on Drawing 10. The crossing is located approximately one mile east of the Shaviovik River and again, few if any noticeable river changes were observed from the airphotos within the corridor area. The channel is meandering in nature but well confined by relatively high banks. Valley wall to valley wall widths vary from about 300 to 1000 feet.

A potential cutoff across the east floodplain exists just upstream of the surveyed corridor although sustained high-magnitude summer flows would probably be required for it to form.

### 7.5.2 Alignment

The alignment at this stream is largely governed by the alignment selected for the Shaviovik River as previously discussed. The surveyed area, which is located just downstream of the centerline of the corridor, is near optimum from a hydrologic and hydraulic viewpoint. The meander loops upstream should be avoided since potential cutoffs could substantially increase the required length of deep burial.

As described in subsequent sections, the conceptual design of the elevated pipeline crossing is not dependent on the proposed design or proximity of the roadway crossing. The buried crossing might benefit from a proximate roadway alignment.

### 7.5.3 Roadway Crossing Design

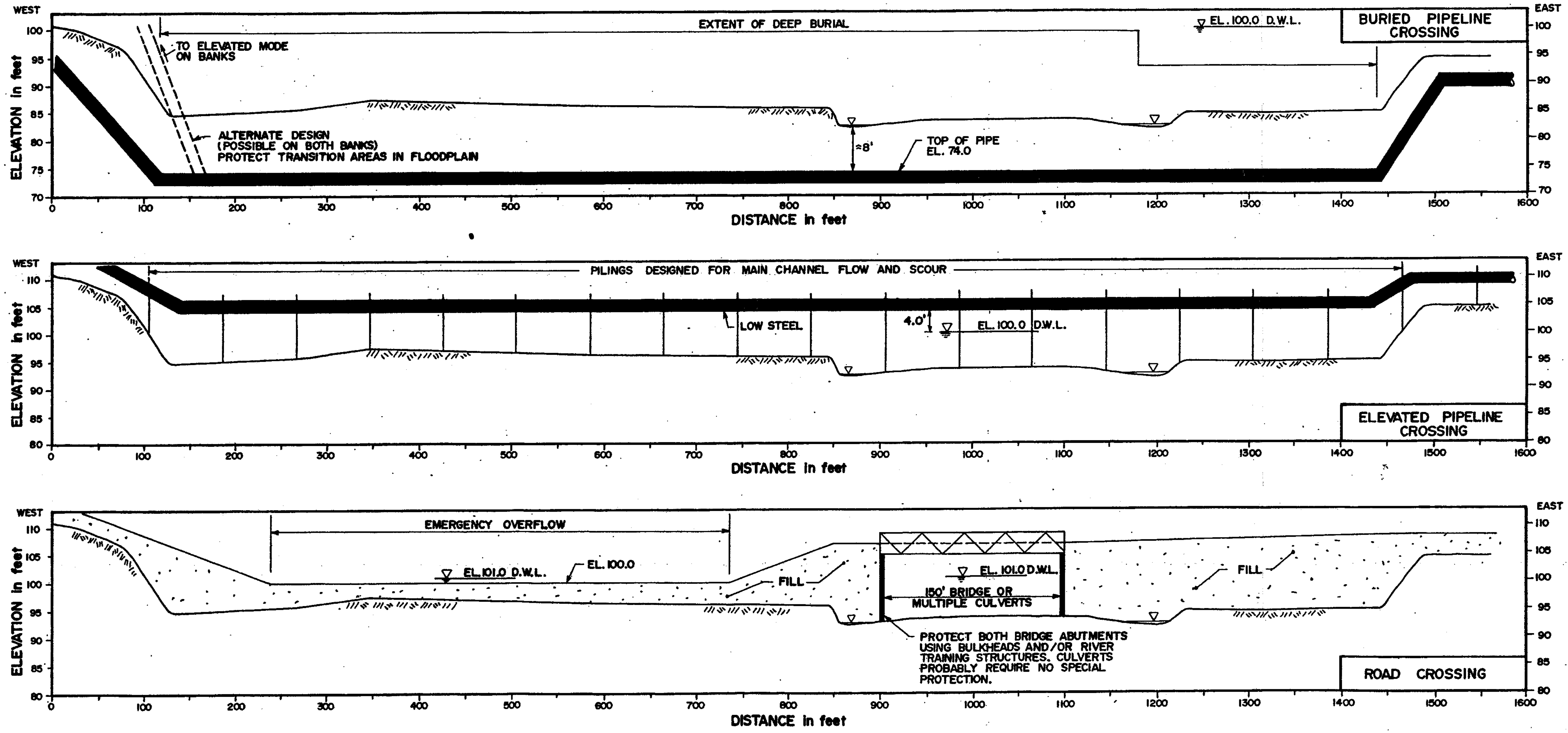
The conceptual design as shown on Drawing 10 consists of a single span bridge or multiple culverts across the main channel and an emergency overflow in the roadway to the west. The high banks, by limiting the area flooded due to backwater, will permit some constriction of the flow thus enabling a reduction in the size of bridge or culverts and a relatively high roadway overflow section. The bridge abutments and roadway fill would have to be protected by bulkheads and/or river training structures. Culverts, except for typical upstream and downstream end sections, would probably not require any river training structures.

AIR PHOTO DATE: 24 JULY, 1955

AIR PHOTO DATE: 15 JULY, 1981

## AIR PHOTO COMPARISON

0 5000
Feet



## CONCEPTUAL CROSSING DESIGNS

NOTES:
1. CROSS SECTION BASED ON HYDROCON SURVEY DATED JULY 17-18, 1982. SECTION ILLUSTRATED IS NUMBER 1.
2. ELEVATIONS ARE BASED ON ASSUMED DATUMS.
3. ▲——▲ INDICATE SURVEY LIMITS.
4. "DWL" SIGNIFIES DESIGN WATER LEVEL AND IS ESTIMATED ONLY.
5. THE DESIGNS ARE INTENDED TO SHOW CONCEPTS ONLY. THE CONCEPTUAL DESIGNS ASSUME THE CROSSING IS LOCATED AT SECTION 1. REALIGNMENT WOULD ALTER THE LOCATION OF THE COMPONENTS BUT PROBABLY NOT THE GENERAL DIMENSIONS.

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CLIENT EXXON COMPANY U.S.A.
PROJECT POINT THOMSON - HYDROLOGIC STUDIES
SUBJECT RIVER AT MILEPOST 27.3
AIR PHOTO COMPARISON AND
CONCEPTUAL CROSSING DESIGNS
HE HYDROCON ENGINEERING (CONTINENTAL) LTD

| DRAWN BY | DESIGNED | APPROVED | DATE | | JOB No | DWG No | REV. |
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| DRL | WMV | Wmw | 9/82 | | 107-40.2 | 10. | 0 |

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### 7.5.4 Pipeline Crossing Design

As noted previously, the proposed elevated pipeline crossing illustrated on Drawing 10 is not dependent on the design and location of the road crossing. The pilings would be designed for main channel flow and scour from valley wall to valley wall. The design is thus not dependent on river training structures. With the buried crossing, deep burial would be used across the entire width of the floodplain with the sagbends located in or adjacent to the high banks. If the sagbends are located near the high banks, the transitions to the mile-by-mile elevated mode would probably have to be protected by river training structures (guidebanks or dikes) particularly if the pipeline is not proximate to the road crossing. If the roadway is proximate, separate training structures would probably not be required.

## 7.6 UNNAMED STREAM, M.P. 31.8

### 7.6.1 River Behavior

As only the 1981 air photo was available for this unnamed stream crossing (see Drawing 11), its changes if any with time are unknown.

The stream is meandering within relatively low banks. Bank-to-bank widths vary from 200 to 800 feet. The active floodplain is non-vegetated. Mid-channel bars are low permitting ready movement of the subchannel within the full width of the floodplain.

### 7.6.2 Alignment

The optimum hydrologic and hydraulic alignment is in a straight and narrow reach of the stream some distance away from tortuous meander bends. Locating the crossing in such a location will obviously minimize its length and thus costs.

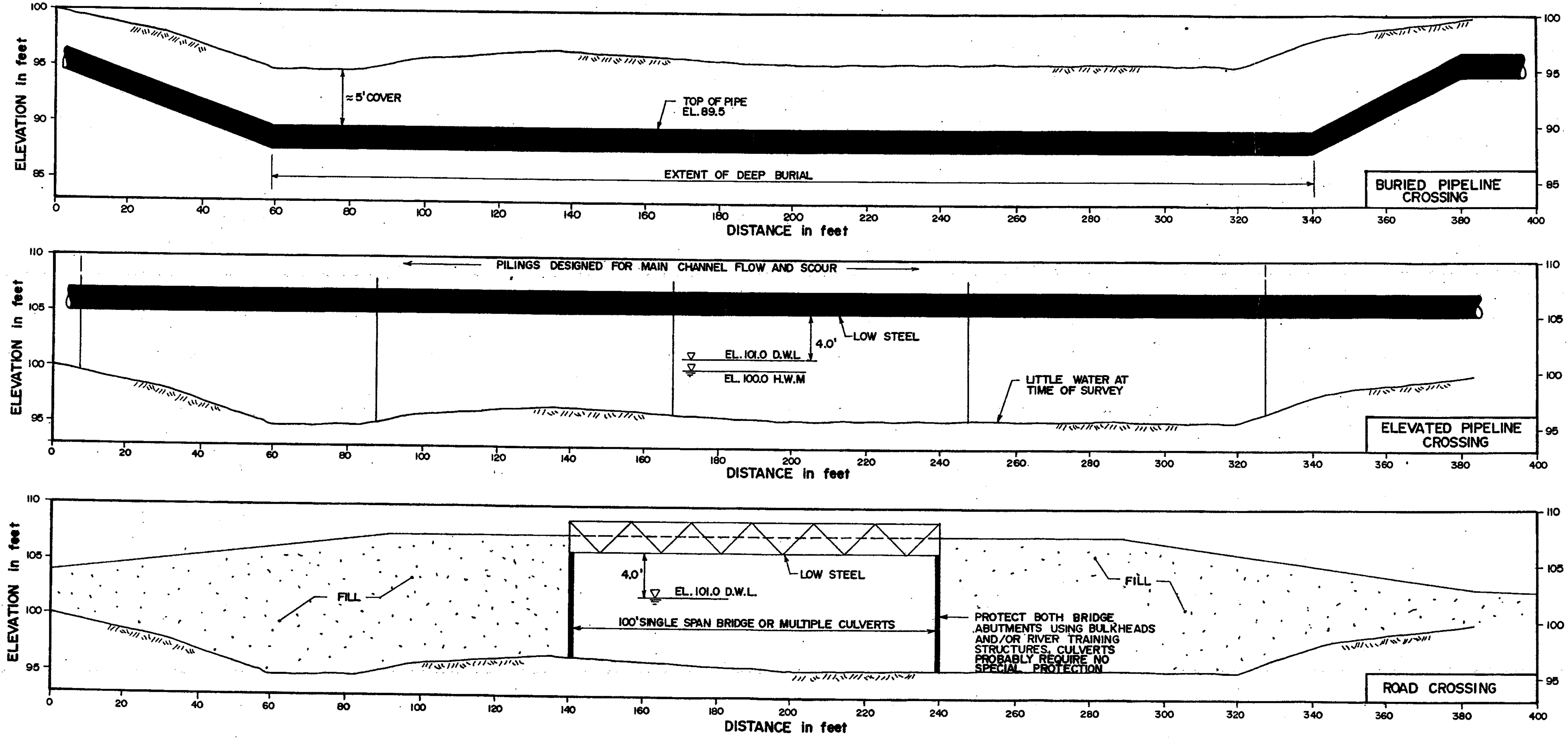
### 7.6.3 Roadway Crossing Design

In the design shown on Drawing 11, either a single span bridge or multiple culverts would be used to cross this unnamed stream. Emergency overflow sections are probably not possibly because of the relatively narrow width of the stream. If this is the case, the bridge length or number of culverts may have to be increased to minimize the degree and extent of

1955 AIR PHOTO NOT AVAILABLE

AIR PHOTO DATE: 15 JULY, 1981

## AIR PHOTO COMPARISON



## CONCEPTUAL CROSSING DESIGNS

NOTES:
1. CROSS SECTION BASED ON HYDROCON SURVEY DATED JULY 14, 1982. SECTION ILLUSTRATED IS NUMBER 1.
2. ELEVATIONS ARE BASED ON ASSUMED DATUMS.
3. ▲——▲ INDICATE SURVEY LIMITS.
4. "HWM" SIGNIFIES HIGH WATER MARK AS DETERMINED FROM DEBRIS AND/OR GRAVEL REMNANTS.
5. "DWL" SIGNIFIES DESIGN WATER LEVEL AND IS ESTIMATED ONLY.
6. THE DESIGNS ARE INTENDED TO SHOW CONCEPTS ONLY. THE CONCEPTUAL DESIGNS ASSUME THE CROSSING IS LOCATED AT SECTION 1. REALIGNMENT WOULD ALTER THE LOCATION OF THE COMPONENTS BUT PROBABLY NOT THE GENERAL DIMENSIONS.

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PROJECT POINT THOMSON - HYDROLOGIC STUDIES
SUBJECT -RIVER AT MILEPOST 31.8
COMPARATIVE AIR PHOTOS AND
CONCEPTUAL CROSSING DESIGNS
HE HYDROCON ENGINEERING (CONTINENTAL) LT

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DP 002 A1 HEL

overtopping of the low channel banks. A bridge would probably require a bulkhead or armoring to protect the abutments and roadway fill.

### 7.6.4 Pipeline Crossing Design

The conceptual designs for a buried and elevated crossing are as shown on Drawing 11. In the case of the elevated mode, the pilings would be designed for the main channel flow and scour for the entire width of the floodplain. The same design philosophy would be used for the buried crossing. If the transition from the buried to the elevated mile-by-mile mode is located in the floodplain and the pipeline alignment is not proximate to the roadway fill, river training structures may be needed to protect the transition area.

## 7.7 OTHER MINOR STREAMS

### 7.7.1 River Behavior

The nature of the other minor streams to be crossed by the Point Thomson road and pipeline are as previously illustrated by photos shown in Section 4.3.3.6. Some general comments on the nature of these streams are:

- single channels having a plan shape varying from straight to very tortuous.
- some signs of bank overtopping.
- evidences of bank erosion and sloughing.
- cross-sections of variable width probably due to local erosion accelerated at times by thermal processes. Some of the streams link a series of shallow thermokarst lakes in a bead-like fashion.

### 7.7.2 Alignment

Due to the small size of these streams, it is very doubtful whether the alignment of either the roadway or pipeline would be affected by the hydrologic and hydraulic characteristics of the streams.

### 7.7.3 Roadway Crossing Design

The road crossings would most likely utilize culverts. The number and size would depend on the width of the stream, bankfull height, fish migration requirements, if any, and of course the design flow. Regarding the design flow, experience on a tributary of the Putuligayuk River indicates that severe short duration floods can occur when the outlets of lakes upstream suddenly melt during spring breakup. A prudent design would thus, if at all possible, involve an emergency overflow adjacent to the culverts. Culverts will require a firm committment to annual cleanout prior to breakup. A minimum culvert diameter of 4 feet is recommended to facilitate snow and ice removal.

### 7.7.4 Pipeline Crossing Design

The pipeline crossings would be similar to the mile-by-mile elevated design. The pilings should be designed for general and local scour. If thermal degradation affects the depth and width of the streams, as it appears from the photographs, this would also be a design consideration. In most cases the pilings can probably be spaced to avoid in-stream placement.

CONCLUSIONS

# 8.0 CONCLUSIONS

## 8.1 ROUTE

- A two-mile wide corridor was selected from the West Channel Sagavanirktok River to the Point Thomson development area.

- The enforcement of the North Slope Borough's Conservation Zone particularly at the Shaviovik River could impact the corridor's alignment. If it is not enforced, the corridor can virtually follow the shortest possible route.

- Optimum river crossing locations will have to be selected within the corridor limits. Mile-by-mile alignment considerations as well as future hydrologic studies will affect the locations chosen. An alternative crossing location of the Main Channel Sagavanirktok River which is located just upstream of its delta is not recommended for further study. It offers no apparent hydrologic or hydraulic advantages and would add considerably to the length of the proposed roads and pipelines to the Point Thomson area.

## 8.2 FIELD STUDIES

- On the basis of previous reconnaissance work in the area, the 1982 breakup was rather undramatic. The Main Channel of the Sagavanirktok River was the first to commence flowing followed by the Shaviovik and Kadleroshilik Rivers and finally the unnamed streams.

- Extensive aufeis formations were observed at the bifurcation of the Sagavanirktok River and on the Kadleroshilik River. The ice at the former location probably affects the flow split between the Main and West Channels of the Sagavanirktok River in varying degrees from year to year. Ice at the latter location could be a reason for the large and unusual bedforms and scour holes observed near the crossing area.

- Cross-sections and highwater mark surveys and hydrometric measurements were undertaken during the summer to provide data for the conceptual crossing designs and support information for the hydrologic studies. Flow at the time of the surveys in July was relatively low.

## 8.3 HYDROLOGY

- The watersheds of the rivers draining into the Point Thomson area can be classified into three physiographic regions, namely the Brooks Range, the Arctic Foothills and the Arctic Coastal Plain. Watersheds originating in the Brooks Range are characterized by earlier commencement of breakup and higher summer floods than those draining the nearly desert-like conditions of the Arctic Coastal Plain. The hydrologic processes on the Arctic Plain are dominated by high, short duration spring breakup peaks as a result of snowmelt.

- The majority of runoff occurs during spring breakup, particularly on those streams draining the Arctic Coastal Plain and the Arctic Foothills. All streams have little or no flow during the winter. Rivers originating in the Brooks Range or Arctic Foothills, such as the Sagavanirktok, Kadleroshilik and Shaviovik Rivers have minor winter flows sustained probably mainly by springs. Aufeis, an indicator of the presence and magnitude of winter flow, is developed when the flow surfaces and freezes.

- Hydrologic data in the Point Thomson area is very limited. Data from the U.S.G.S. gaging station on the Sagavanirktok River at Sagwon - the only continuously recording station in the watersheds draining into the Point Thomson area - probably cannot be extrapolated using a drainage area relationship to the Main Channel crossing of the Sagavanirktok River. This is due to the ungaged and unknown contribution from the Ivishak River and the variable flow split at the bifurcation into the West and Main Channels. On a regional basis, more hydrometeorologic data is available.

- To compute design flows for the Point Thomson area streams requires hydrologic correlations and comparisons with available hydrometeorologic data from the North Slope area. The size of the region used and thus the number of streams included in these regional studies, requires thorough hydrologic analysis of all the available data. Various techniques are available to compute the design flows. The results of these studies can have a wide scatter particularly when both the technique and study are a variable.

- The method or methods selected to compute the design floods depends greatly on the available data. A regional analysis developed previously by Hydrocon's staff for the hydrologic review of the the Northwest Alaska gas pipeline was applied to the Point Thomson area streams. The ready availability of this particular methodology rather than its superiority over other methods was the chief reason for its implementation. Substantially more work will be required, as outlined in the conclusions, to select the optimum methodology and to apply it to refine the very preliminary values presented herein.

## 8.4 CROSSING TYPES

### 8.4.1 Roadway

- Roadway crossings can be either via bridges (single or multiple-span) or culverts. The size of the stream, aufeis formations, and sediment transport as well as economic and environmental considerations will be factors to consider in the selection process.

- As a general rule, emergency overflow sections should be incorporated into floodplain roadway embankment sections. This will ensure the integrity of the bridge is not endangered if flows exceed the design capacity or if unforeseen hydrologic or hydraulic conditions occur. The overflow could, if sufficiently low and long like those used on the Kuparuk River road crossing, reduce required bridge length and thus costs. The need for continuous access will govern the design details of the overflows. They can be designed to be non-erodible and to enable normal vehicular traffic at all but the largest floods.

- If culverts are selected, a committment must be made to an annual snow and/or ice cleanout program.

### 8.4.2 Pipeline

- Elevated pipeline crossings may consist of either multi or single span bridges, pilings designed for main channel or floodplain flow and scour conditions, or combined with the roadway bridge. Economic, technical and environmental factors will determine the choice.

- Minor elevated crossings will probably utilize the typical mile-by-mile elevated design.

- Buried crossings may be technically feasible at some locations. Whether or not they are used will depend on the mode of the adjacent mile by-mile segments and technical and environmental considerations. If only the river crossing segment is buried and the transition to the elevated mode is located in the floodplain (for geotechnical reasons), river training structures may be required to protect the transition area.

## 8.5 PROXIMITY OF ROADWAY TO PIPELINE

- Assuming river training structures are used at major roadway crossing to confine the flow to a reasonably-sized waterway opening, locating the pipeline immediately next to and downstream of the roadway will probably offer the maximum hydraulic and economic advantages. In this configuration, the pipeline segment, (whether elevated or buried) designed for main channel attack, corresponds to the roadway bridge length with the remainder of the floodplain area protected by the roadway river training structures extended over the pipeline at a low incremental cost.

- Pipeline segments, in either the elevated or buried mode, located adjacent to the floodplain roadway embankment can be designed for floodplain rather than main channel conditions.

- At minor elevated crossings where the typical mile-by-mile design will probably be adequate, the proximity of the roadway to the pipeline will probably not affect the cost of the crossing.

## 8.6 DESIGN CRITERIA

- Preliminary hydrologic and hydraulic design criteria are presented for both pipeline and road crossings. The magnitude of flow, aufeis and snow will affect both the length and elevation of the elevated pipeline crossings and roadway bridges. Navigation and environmental considerations may also have an impact. Although the return period of the design flood for pipeline and roadway bridges may be stipulated by the

State and Federal regulatory authorities, the bridges should be designed to have adequate freeboard for the 200 and 100 year floods respectively.

- To prevent excessive overbank flooding due to bridge-induced backwater effects, the low-banked major streams will require relatively long roadway bridge spans. The emergency overflow areas can be utilized to reduce bridge lengths and thus costs if the frequency, duration and impact of the overtopping is considered acceptable from access and maintenance viewpoints.

## 8.7 CROSSING DESIGNS

- Conceptual crossing designs are presented for the roadway and pipeline crossings of three major named and two minor unnamed streams. The designs are based on the assumptions and design criteria as previously outlined in the report.

- The major road crossings will require multi-span bridges, river training structures, floodplain embankments and emergency overflow sections. Culverts, if used in the floodplain areas, will be generally for environmental rather than technical reasons. Minor crossings can be achieved by culverts. A minimum culvert size of 4 feet is required to facilitate cleanout of snow and ice - probably an annual requirement.

- Elevated pipeline crossings of the major streams will consist of either pilings designed for main channel flow and scour conditions or multi-span girder bridges. The choice is one of economics. Across the floodplain areas beyond the main channel crossing, typical elevated mile-by-mile designs can be utilized. Buried crossings will need to be deep buried next to the roadway bridges. Floodplain burial will be relatively shallow. Minor elevated crossings will probably utilize a pile design similar to the typical mile-by-mile mode.

# RECOMENDATIONS

# 9.0 RECOMMENDATIONS

The recommendations arising from this study with regards to alignment, field studies, hydrology and crossing concepts are as essentially discussed in the conclusions of the previous section. Recommended future studies are outlined herein. This work should go hand-in-hand with mile-by-mile studies, economic and environmental assessments as well as preliminary discussions with the appropriate Federal and State authorities to assess the applicable design and environmental stipulations.

The recommended studies are intended to address the hydrologic problem areas and data and design deficiencies identified in the the present work. The field data collection program is recommended for immediate implementation in 1983 whereas the office studies can be scheduled as budget or time permits and in accordance with the overall schedule of the project.

## 9.1 FIELD DATA COLLECTION PROGRAM

The program as outlined below is recommended for implementation during the 1983 open water period. The intent of the program is to obtain field data, which in combination with regional hydrologic analysis, will enable refinement of design flows for the Point Thomson Area. The program assumes that the Kuparuk and Sagavanirktok River gages will be operational in 1983 (by the U.S.G.S.) and that miscellaneous flow data can be obtained from either ARCO Alaska Inc. or BP/SOHIO for the Putuligayuk River at Prudhoe Bay.

A comprehensive field program consists of qualitative and quantitative observations and measurements respectively. General channel processes, river behavior and the impact of overbank flows on the development of subchannels can only be assessed in a qualitative fashion by an experienced river engineer. This is done by means of visual observations and photographs supported perhaps by some spot measurements. Quantitative data consists of flow and water level information, ice thickness and size of floes and water level slopes.

In view of the time lag during breakup between the Point Thomson area streams and the gaged streams of the area, spot flow measurements have little value. For example a discharge measurement on the unnamed stream at M.P. 31.8 coincident with the occurrence of peak flow on the Putuligayuk River would not necessarily guarantee that the peak flow had been measured on the former. Thus continuous data on strategically located streams is necessary. The number of streams selected for monitoring is essentially one of economics. The continuous water level recorders are relatively expensive to purchase and install in the remote Point Thomson area. Shelters are required to protect the equipment. Included in the total cost estimate should be an allowance for an adequate number of flow measurements to enable the preparation of a water level-discharge relationship. Without this committment, the data is only incrementally more valuable than miscellaneous water level measurements from manual staff gages. It may be possible to jointly maintain and operate the stations with either the U.S. Geological Survey or the Department of Geological and Geophysical Surveys, State of Alaska or alternatively, Exxon's field personnel can be trained to operate the equipment and obtain flow measurements.

At this time, continuous recorders are recommended for an Arctic Coastal Plain watershed and one draining both the Arctic Foothills and the Arctic Coastal Plain. These would be comparable to the physiographic regions drained by the Putuligayuk and Kuparuk River gages respectively. The value of installing a continuous water level recorder on the Main Channel Sagavanirktok River, which drains the two aforementioned regions plus the Brooks Range, is rather questionable because of the variable flow split at the bifurcation plus the ever-changing multi-channelled nature of the crossing.

Crest gages can provide an accurate indication of maximum water level attained. If two are installed some distance apart to obtain an accurate water level slope and the hydraulic characteristics of the stream known, the maximum discharge attained during the monitoring season can be computed. Staff gages of course provide on-the-spot and instantaneous water level measurements.

The recommended field program, to start about 5 days after commencement of flow on the Main Channel, Sagavanirktok River, is as follows:

- establish permanent staff and crest gages at the Main Channel Sagavanirktok and Kadleroshilik River, the unnamed stream at M.P. 27.3 and at one other representative minor coastal stream. Install a second crest gage (tied in by surveys to the first gage) about 1-3 stream widths upstream or downstream of the first gage at each location. The gages should be installed near the centerline of the corridor or in the optimum hydraulic location. Install temporary bench marks in all locations in the event a gage is lost.

- install continuous water level recorders at the Shaviovik River and unnamed stream at M.P. 31.8. The nitrogen bubbler system with a Stevens Recorder is probably the preferred method. Although more expensive than the recorder mounted over a wet well, it requires no heavy equipment to install. Install crest gages at the recorder sites and 1-3 stream widths upstream or downstream.

- during the breakup period, the recommended monitoring program is as follows:

  - measure discharge at least three times at the continuous recorder locations. Note the presence and extent of ice and snow during the measurements.

  - measure discharge once at the other streams. The timing should be as concurrent as possible with the measurements at the continuous recorders.

  - check continuous recorder and note water level at all gages at least every second day.

  - record highwater marks from the crest gages at all locations.

  - measure the magnitude of suspected scour holes. Flow confined by ice next to a high and non-erodible bank would be a prime potential scour location. The confluence of two major subchannels would be another possible measurement site. As the relative depth of the scour holes to the normal channel depth upstream or downstream is the important factor, the surveys would be very local and would not need to be tied into the temporary bench marks at the crossing.

- qualitatively observe and document the nature and size of ice floes, the magnitude and rate of deterioration of aufeis during the breakup period, impact of aufeis on flow distribution, impact of overbank flows on the development of subchannels, and the nature and location of bank erosion. Factors affecting the flow into the west subchannels at the Sagavanirktok and Shaviovik River crossings would be particularly assessed.
- following breakup, arrange with on-site field personnel to maintain the stations and measure flows on a monthly basis.

## 9.2 HYDROLOGIC ANALYSIS

The recommended program is as follows:

- evaluate the various hydrologic techniques discussed in the report. Factors to consider are:
  - availability of hydrometeorologic data compared to data required by the various methods.
  - comparison of Point Thomson area streams to the gaged regional streams. Factors to consider are shape and elevation of the watershed, percentage of area draining into lakes, the magnitude of non-contributing drainage areas, density of the drainage networks and volume of in-stream storage. This is best done by following the 1983 field data collection program.
- obtain (if possible) and review the hydrologic data collected by ARCO Alaska Inc. during the last several years on minor streams west of the Kuparuk River.
- decide on the methodology to use for final design and determine changes, if any, to future data collection programs.
- from the preferred method, compute preliminary flood design values. Indicate the confidence limits associated with this value.

## 9.3 CROSSING DESIGNS

The following studies are recommended to refine the conceptual designs presented herein:

- .following mile-by-mile alignment studies, refine the location of the crossings. Interface with the mile-by-mile designers to select the optimum overall alignments.

- .a general study of river stability of the North Slope streams. Review all available comparitive air photos over a broad region to determine the magnitude and types of changes possible. Of particular importance is the development and enlargement of subchannels and how these might impact particularly the Main Channel Sagavanirktok and Shaviovik River crossings.

- .determine preliminary bridge lengths from the computed flow values and an assessment of channel behavior and stability.

- .determine preliminary layout of the river training structures and conduct a review of the performance, availability and economics of alternative armoring techniques. This would include riprap, gabions, articulated concrete blocks, concrete and fabriform.

- .review the performance of the roadway overflow sections used in the Prudhoe Bay area.

- .initiate discussions with regulatory agencies regarding the required hydrologic design criteria, the navigability of streams and possible environmental and construction constraints.

- .study the behavior of the Kadleroshilik River and its impact on design. Field observations during an open water high flow period would especially provide valuable data. If uncertaintites remain as to its behavior, the impact of these unknowns will have to be considered in the final design.

- .assess, in conjunction with the mile-by-mile design group, potential floodplain granular material sites. This should be done in conjunction with the crossing designs to avoid potentially negative impacts.

For example, although a floodplain site in a normally-dry subchannel may be an excellent and economic source of granular material, it could significantly alter flow conditions and thus the design and cost of the crossings.

- assess possible techniques to reduce snow drift accummulations at bridges and review the snow clearing and ice cutting program initiated by ARCO Alaska Inc. at their West Chanel Sagavanirktok River bridge during the last several years.