

# Hydrologic Investigations along the Arctic Islands Pipeline Route

**J.H. Wedel**

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Hydrologic Investigations Along  
the Arctic Islands Pipeline Route

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Water Survey of Canada  
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This report presents concluding data and results obtained by Fisheries and Environment Canada for use by the Arctic Islands Pipeline Program. These investigations were carried out under the Environmental-Social Program, Northern Pipelines of the Government of Canada. While the studies and investigations were initiated to provide information necessary for the assessment of hydrocarbon transportation proposals, the knowledge gained is equally useful in planning and assessing other development projects.

Any opinions or conclusions expressed in this report are those of the author and are not necessarily shared by the Government of Canada.

## RÉSUMÉ

A la suite d'une étude hydrologique faite par un organisme indépendant, pendant trois saisons, dans la région qui s'étend de l'île Melville jusqu'au nord du Manitoba, pour évaluer la demande de Polar Gas de construire un pipe-line de gaz naturel à travers la région, on a obtenu certains renseignements concernant les processus fluviaux et géomorphologiques connexes. Les principaux processus étudiés étaient l'écoulement, la fonte des glaces, la glaciation et les mouvements des sédiments. Des évaluations des formes du relief fluvial ont été faites sur les lieux et d'après des photographies aériennes. On a pu se documenter, plutôt sur le plan qualitatif, sur les effets des mouvements de masse arctiques sur les versants et les fonds de vallées, ainsi que sur les chenaux des rivières. On s'est aperçu que l'avalasse printanière était responsable de la principale inondation annuelle, bien que les pluies d'un orage enregistrées en août 1960 dans les îles aient pu provoquer des écoulements plus importants que ceux dus à la fonte des neiges. Un écoulement important est aussi courant en fin d'été, en ce qui concerne les rivières Hayes et Murchison. On a déterminé que deux régions avaient un taux élevé de sédimentation: la région de Melville-Bathurst et celle des terres basses de Rasmussen, au sud de la baie Spence, la première étant une zone "in situ" d'actions météoriques d'écailles, de grès fissile à grain extrêmement fin, de grès très fin, et la dernière une vaste plaine marine. Le dérangement de fins matériaux situés sous les chenaux est néfaste au biome aquatique des systèmes d'eau claire du district de Keewatin et aux rivières plus au nord qui ont des lacs profonds, en particulier la rivière Union, certains systèmes à proximité du détroit Bellot et les régimes rivières-lacs de la baie Spence. L'érosion thermique et le pseudo-karst sont deux processus liés à la chaleur qui pourraient provoquer un ravinement et un manque de stabilité graves lors de la construction du pipe-line sur certains terrains. La construction de bermes ou de routes le long du parcours et les faibles températures de gaz pendant la phase d'exploitation provoqueront une hausse dans la table de permagel et entraveront le mouvement des eaux souterraines sur les versants, entraînant ainsi la formation d'étangs et de l'érosion, pouvant créer des problèmes. Si la température à la surface des chenaux tombait au-dessous de 0°C, à cause du refroidissement du pipe-line, il pourrait se former de la glace dans les rivières de Keewatin, où l'écoulement est faible au milieu de l'hiver, ce qui obstruerait encore plus le passage. Comme nous ne possédons pas suffisamment de données, il nous est impossible de faire des prévisions exactes en ce qui concerne l'importance des inondations et leur fréquence dans cette région.

*"And all experience is an arch wherethrough  
Gleams that untravelled world  
Whose margin fades forever and forever  
As we move...."*

*Alfred, Lord Tennyson*

North Knife River just south of 60°N.

Typical till plain river valley of southern Keewatin and northern Manitoba. (Note ice trim-line on far bank and fringe stand of heavy spruce and tamarack just above that. Behind tree fringe, on higher ground only isolated trees occur on shrubby tundra.)



Aston River:

Typical incised river reach on northern Somerset Island below 250 m elevation and above the braided coastal regimes.



## ABSTRACT

An overview of hydrologic activity in the region from Melville Island to northern Manitoba was obtained in three field seasons. This information was gathered from a position of independence in order to assess the application of Polar Gas to construct a natural gas pipeline through the region. Some understanding of fluvial and associated geomorphic processes was obtained. Specific processes studied were streamflow, ice-runs and icings, and sediment movement. Assessments of fluvial landforms were made in the field and from aerial photography. The effects of arctic mass-wasting processes on valley walls, valley bottoms and on river channels was documented, mostly in a qualitative sense. It was found that the spring freshet generated the dominant annual flood although the record rainstorm of August 1960 in the islands may have generated flows greater than those from snowmelt. On the Hayes and Murchison rivers, high late-summer runoff is also common. Two high-sediment-yield regions were defined: the Melville-Bathurst region and the Rasmussen Lowland south from Spence Bay—the former a zone of extensive *in situ* weathering of shales, siltstones and fine-grained sandstones, and the latter an extensive marine plain. Disturbance of fine-grained sub-channel materials will adversely affect the aquatic biome in the clear-water systems of the Keewatin District and those rivers farther north which have deep lakes—particularly the Union River, a number of systems near Bellot Strait and the river-lake regimes around Spence Bay. Thermal erosion and thermokarst are two heat-related processes that could lead to severe gullying and pipeline instabilities during construction over sensitive terrain. Berm or roadway construction on the right-of-way and low gas temperatures in the operating phase will create a rise in the permafrost table and impede the movement of near-surface groundwater on slopes. Ponding and erosional problems may result. In Keewatin streams which maintain a low volume of flow in midwinter, icing may result if channel surface temperatures drop below 0°C from the chilled pipeline, thus further restricting the passageway. Insufficient data exists to make accurate predictions of flood magnitudes and their recurrence intervals for this region.

## ACKNOWLEDGEMENTS

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Researchers who were active on behalf of the project were Jim Way, Enar Engstrom, Garry Thorne, Ole Larsen and Paul Baracos. Their diverse areas of expertise contributed immensely to the ultimate success of our study.

The drawings and figures in our in-house reports were done by Mavis Young, and the professional standard is evident. Typing of drafts and manuscripts was capably done by L. Ramm.

The writer wishes to thank the management of the project for encouragement and advice tendered, especially Mr. Joe Slater, coördinator for FP-1 projects; Mr. Peter Strilaeff, former District Engineer, Winnipeg office, now retired; and Dr. Andrew Macpherson, Director-General for Environmental Management Service, Western and Northern Region.

The staff of Glaciology Division, who conducted studies and contributed reports to our project, deserve a special thanks. Jerry Churylia, Bryan Grey, Keith Arnold and David Terroux have added much to the fund of northern hydrologic information.

Over the course of the study, the writer has much appreciated the friendly advice and helpful criticism provided by Dr. Terry Day of Terrain Sciences Division, Energy, Mines and Resources.

Contact throughout the study was maintained with Northwest Hydraulic Consultants, who conducted parallel investigations on behalf of Polar Gas. Exchange of scientific field data, principally through the good offices of Charlie Neill, proved to be invaluable to the writer. In this regard, the writer wishes to clarify some statements made in the FP-1-76-1 report where, by inference, the 25-year design flood criteria was ascribed to Neill's report. This, of course, is not the case, and the writer wishes to apologize for the poor composition which gave rise to that inference.

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## 1.0 INTRODUCTION

### 1.1 General Nature and Scope of Study

The terms of reference for the FP-1 study, spanning 1975 to 1977, required us to provide an overview of the freshwater hydrology in the Queen Elizabeth Islands and down the projected Polar Gas route through Somerset Island, Boothia Peninsula, and across the District of Keewatin, Northwest Territories (NWT), to latitude 60°N. Since little was known of river regimes in the High Arctic, the 1975 field season was spent on reconnaissance of Melville, Bathurst, Cornwallis, Prince of Wales and Somerset islands, and Boothia Peninsula. A fairly intensive study-reconnaissance of northern Somerset Island was conducted by Glaciology Division of Department of Fisheries and Environment (DFE). A further reconnaissance of Keewatin rivers and lakes was conducted by the same Division and accompanied by J.G. Cogley of Department of Geography, Trent University.

In 1976, several projects went forward simultaneously:

1. A site-intensive program on western Bathurst Island examined the temporal distribution of runoff, sedimentation and water quality and their relation to basin geomorphology and to precipitation inputs.
2. A detailed examination of selected river crossings in the District of Keewatin at spring freshet and in the late fall.
3. A site-intensive study of a small catchment, Airplane Lake Basin, near Baker Lake, to define water chemistry and its seasonal change.
4. An analysis of water quality at the study site (Snowbird Creek) on Bathurst Island, and along the Keewatin reconnaissance route.
5. Spring break-up observations of ice activity in the region about Baker Lake.

Field data and some conclusions from them are found in seven interim reports of project FP-1, Arctic Islands Pipeline Project (AIPP). Field projects in 1977, an on-site inspection of island river crossings and aerial colour photography provided additional information.

## 1.2 Research Objectives

Specific objectives for freshwater research which were thought to apply to a gas pipeline were cited in our terms of reference. We were requested to assemble information along the projected pipeline corridor on water quality, river discharge (particularly flood flows), sediment transport, groundwater regimes, streambed percolations, icings, ice-runs, valley walls, valley plain and floodplain, and channel banks.

Particular attention was to be paid to landforms and riverine instabilities thought to have a bearing on pipeline design, construction and maintenance. Specific landform or geomorphic activities that we attempted to document were slides, slump, creep, solifluction (or the periglacial expression, gelifluction), ground ice, thermal or dynamic river bank erosion, aggradation and channel migration.

In sum, the purpose of FP-1 investigations was to provide government with sufficient in-house expertise in matters of freshwater hydrology in the Queen Elizabeth Islands and the Keewatin District, NWT, to assess the Polar Gas application properly and to provide such baseline data as we might assemble to associated disciplines such as Fisheries.

## 1.3 Relationship of This Study to Pipelining Concerns

The effects of a chilled, buried, gas pipeline should be negligible on surface runoff regimes in regions of shallow, continuous permafrost such as underlies most of the study area, *ie*, it should not seriously alter the runoff regime and therefore sediment patterns. If, however, the rivers to be crossed are considered to be in equilibrium with their environment, then it follows that any disturbance to the drainage basin surface will bring about alterations, some of temporary nature, to the hydrologic system. Just as agricultural use of lands in the south generates higher sediment loads in rivers, so also will the terrain disturbance caused by pipelining activity increase sediment discharges. The magnitude of this new sediment load is closely related to the erodibility of disturbed soils and to the fraction of drainage basin area of disturbed soils and to the fraction of drainage basin area disturbed. The sediment load increase would thus be greatest in small basins with fine, uncohesive soil texture. The effects of erosion and increased siltation of rivers and lakes would have adverse aesthetic impacts, could present engineering problems to pipeline construction and operation and could harm the aquatic resources of affected systems. Other items of concern are

the degradation of water quality and restrictions imposed on natural flow pathways within the active layer and in streambeds by the creation of a frost-bulb around the chilled pipe.

This report does not contain a summary for material related to water quality. That data will be reported upon separately.



## 2.0 RÉSUMÉ OF CURRENT KNOWLEDGE

The current hydrologic data base, especially in the high arctic lowland regions, is clearly inadequate for an assessment of pipeline effects. Two agencies have been largely responsible for any existent data in the High Arctic.

Glaciology Division of DFE, as their name implies, have assisted many scientific investigations concerned with run-off and sedimentation rates from proglacial systems in the arctic highland regions of Baffin, Devon, Axel Heiberg and Ellesmere islands. For the most part, river regimes in these mountainous regions are sufficiently different to make extrapolation of this data to the Queen Elizabeth Islands untenable. Orographic precipitation patterns of the highlands, the seasonal advance of snowmelt and glacial ablation, all of which are dependent on altitudinal differences, clearly make these hydrologic regimes substantially different from those found in the lowlands. Notwithstanding this incompatibility, the extant body of literature cited in Wedel *et al* (1977) does describe numerous hydrologic and geomorphic processes common to both regions of the Arctic.

Terrain Sciences Division of Department of Energy, Mines and Resources (EMR), is another organization which has become involved in arctic hydrology for the simple reason that intimate relationships exist between surficial landforms and river activity, particularly so in the North. In addition, some of their studies, such as the ongoing investigations of geomorphic-hydrologic processes on Banks Island, are in regions of physiography similar to our interests, and therefore have direct application to our studies. McLaren (1975), in his study of coastal processes on eastern Melville Island, provided the first hard data on sediment in the Queen Elizabeth Islands of which the writer is aware. This information, plus the data for 1976 from western Bathurst Island (Wedel *et al* 1977), constitutes the entire data set for river sediment discharges in the central High Arctic.

In both studies, annual sediment transport was computed by conventional means, *ie*, by relating individual samples to streamflow. Clearly, then, the first need to assess sedimentation parameters is to assemble streamflow data. Traditionally, this has been the responsibility of Water Survey of Canada (WSC), a branch of DFE.

Examination of the record reveals that WSC data is of inadequate length to permit conventional statistical analysis, if it is accepted that a minimum of 10 years of record is essential for the prediction of a 25-year event with some confidence, for parameters such as annual floods.

Meteorological data for northern Canada is the only hydrological parameter of sufficient length to permit conventional statistical analysis to be made. Incorporation of arctic precipitation data into water budgets for specific basins as performed by Cogley & McCann (1975) on the Mechem River, by March (1976) and Wedel *et al* (1977) in the region about Resolute Bay, suggest that snowfall data as recorded by Atmospheric Environment Services (AES) under-estimates its water content by a factor of two. If the precipitation data is recalculated as outlined in Wedel *et al*, it becomes hydrologically compatible to other inputs in a water budget. It appears that such an approach applied to the regions of interest will permit investigators to progress beyond the description of unique northern hydrologic and associated geomorphic processes and to approximate the temporal distribution of the magnitudes of these parameters.

University research projects on Ellesmere, Axel Heiberg, Baffin and Devon islands have contributed substantially to northern hydrologic knowledge. Of great interest to the writer is the ongoing research by Woo & Marsh in a basin just north of Resolute Bay airport on Cornwallis Island. Hydrologic aspects being investigated are snow-water content, evaporative processes, runoff, sedimentation, and supra-permafrost, interflow regimes. The last area of investigation has not heretofore been properly addressed and promises to have significant application in the timing of construction projects which involve the disturbance of the active layer (Marsh pers. comm. 1977).

Finally, pipelining activity in the western Arctic (Alaska, Mackenzie Valley and the Yukon) have defined precisely those processes in hydrology and related geomorphology of concern to industrialization. Essentially, this system of identification has given our central arctic group a "leg up". What remains to be done is to place the expressed concerns of the western Arctic into the geographic context of the Queen Elizabeth Islands and the District of Keewatin.

## 3.0 STUDY AREA

### 3.1 Geographic Area

Outline maps of the area (Fig. 1 and 2) illustrate the regions investigated. The island portion of the route is shown in Fig. 1, and Fig. 2 depicts the mainland segment north of 60°. Sites which were studied and the existing hydrometric network are identified.

### 3.2 Geology and Physiography

In the sense that surface rock facies influence river channel formation, a discussion of geology is pertinent to this report. Fundamentally, the study region may be divided into two areas: that of intrusive rocks—generally granitic or gneissic and of great age (Pre-Cambrian), and that of depositional rocks of the northern islands. The northern depositional rocks have undergone varying degrees of tectonic modification and metamorphosis. Characteristic surface rock facies thus permit identification of geologic regions which in turn influence physiographic riverine features. Progressing along the pipeline route in a south-easterly direction from Sabine Bay represents a trip backwards through geologic time.

Physiographically, the river morphologies have been greatly modified by glacial activity. Identifiable landforms with a glacial history such as ice-contact deposits (kames and eskers), outwash materials (fans and valley trains), and meltwater channels are found throughout the regions. Since glacial times the coastal river regimes have been modified further by the effects of isostasy and eustasy.

A brief discussion of the geologic provinces follows.

#### 3.2.1 Sverdrup Basin

In the region of interest, this geologic province is found on Sabine Peninsula. Except for isolated pockets of Quaternary rocks on Bathurst, Cornwallis and Somerset islands, this region contains the youngest parent rock found along the route. On Sabine Peninsula, rock exposures from north to south ranges through Tertiary, Cretaceous, Jurassic, Triassic and Permian periods. Principal rock types are shaly sandstone, siltstone and shale. The northern Tertiary rock strata are marked by two prominent piercement domes of gypsum anhydrite. Tectonic activity associated with the Melvillian orogeny preceded deposition of these parent rocks,

thus they unconformably overlie older strata. The bands of Permian rock across the neck of Sabine Peninsula are predominantly sandstones, and most of these surface rocks remain in fairly horizontal bedding planes.

Physiographically, this region lies in the Sverdrup Plains' subdivision of the Innuitian region (Bird 1972). If the two piercement domes are omitted, maximum relief is less than 150 metres. Valleys are generally shallow and sediment supplies plentiful. Estuarine and early-stage arcuate deltas and braided streams are common. Drainage patterns are structurally uncontrolled of a dendritic pattern. There are no lakes on Sabine Peninsula.

### 3.2.2 Franklinian Miogeosyncline

In the area of interest, this geologic province extends from west to east across central Melville and Bathurst islands and is abruptly terminated by the complex western border of the north-south trending province of Boothia Uplift. The uppermost facies of parent rock are mainly of upper and middle Devonian age. Hecla and Griper Bay formations, mainly composed of sandstones, dominate (Thorsteinsson & Tozer 1972). The region is characterized by extensive folding of the Ellesmerian orogeny of Mississippian age. Some bedrock materials are overlain by unconsolidated deposits of till and marine silts and sands of later Tertiary and Quaternary age.

Since record of substantial ice movement does not exist, it is currently thought that the Innuitian sheet in this region was essentially stagnant and upon retreat formed small ice caps over each island, which eventually melted. Till and seashell deposits on Melville and Bathurst containing strata of peat have been dated at approximately 35,000 years before the present. These, together with alluvial deposits underlying the peat layers, suggest more extensive glaciations in pre-Wisconsinian times. Some tills and marine deposits have been identified as late Tertiary materials, although most of them are thought to belong to the Beaufort formations of Quaternary age.

The highest elevations on eastern Melville Island, known as the Spencer and Baldwin Walker ranges, are found in the Weatherall Bay region of northeastern Melville Island. Local relief is in excess of 300 metres. Physiographically, this region has been described by Bird (1972) as the Parry Fold Belt in the Innuitian region. Some structural control on drainage patterns is evident, more so on Bathurst than on Melville. The plateau surface of southeastern Melville

seems to have been domed by proglacial runoff from remnant Wisconsin ice and by subsequent periglacial fluvial activity. Fairly deep valleys drain topography more adequately described as hill terrain.

On western Bathurst Island, underlying geologic structure determines the topography and drainage pattern and has been described by Roots (1963) in Kerr (1974) as a ridged upland with broad folds, the folding decreasing in amplitude from north to south (Kerr 1974). Selective erosion has created surface inversion of the underlying rock structures so that today the original synclines appear as relatively smooth ridges plunging westwards. Stream valleys are carved into the softer bedrock. Glaciation and marine submergence have infilled river valleys with substantial deposits of clayey silts, sandy silts and gravels. Braided streams are common on coastal reaches.

### 3.2.3 Boothia Uplift

This geologic province is a narrow, finger-like intrusion of the Pre-Cambrian shield northward into the arctic sedimentary basins. Gneissic and metamorphic rocks are exposed on Boothia Peninsula and Somerset Island. North of Parry Channel, the uplifted zone continues but is overlain by sedimentary limestones and dolomites of Ordovician age (Thorsteinsson & Tozer). Since much of this uplift preceded the Ellesmerian orogeny, the northern portion of Boothia Uplift behaved as a buttress and separated into eastern and western sections the folding of the Franklinian Miogeosyncline. Kerr (1974) suggests that three periods of uplift occurred, the intervening eras being marked by erosion in periods of emergence and by deposition when submerged. The western boundary between Boothia Uplift and the Parry Island Fold Belt occurs in eastern Bathurst Island and is noted for its complex geologic structure with exposure of lower formations of shales and siltstones such as the Eids shales. Later Tertiary and Quaternary glaciations have modified the surface further and many of the off-plateau drainages on Cornwallis and eastern Bathurst are described as meltwater channels (Thorsteinsson in Kerr 1974). Interior Cornwallis Island topography is that of a gently rolling, monotonous plateau. Stream channels become sharply incised near the coast and provide most of the local relief of the island. Braided channels are common in the regions near the coast where deposition of upland sediments occurred. Maximum marine submergence of 100 metres in Wisconsinian period left many relic beaches and near-shore marine plains such as are found at Trafalgar Lakes on the south coast of Cornwallis Island.

A rugged upland hill region of Pre-Cambrian gneissic and sedimentary metamorphics characterizes western and southern Somerset Island and northern Boothia Peninsula. In the region around Bellot Strait many fault structures trending east-west contain narrow, deep mountain lakes. Waterfalls and rapids are numerous and local relief is severe. South from Creswell Bay, a narrow coastal plain on the eastern shore contains tundra ponds and unstructured drainages. Some of these streams are quite turbid.

#### 3.2.4 Churchill Province

South central Boothia is rolling plateau-like terrain, bounded on the east and west by Pre-Cambrian hill country. South from Sanagak Lake the region about Spence Bay is known as the Rasmussen Lowlands and contains many lakes. Channel substrates under gravel-cobble surface materials contain marine clay-silt strata, some of which tend to structural collapse upon disturbance. South from Spence Bay the recently-emerged plain borders Chantrey Inlet. Materials are mostly unconsolidated sand, silt and clay, and the terrain has little relief. Numerous thaw lakes, large areas of patterned ground and unstructured drainage networks characterize the surface. To the east, hill terrain with much morainal till is apparent. Outcrops of Pre-Cambrian rocks in the east display the typical rounded shapes common to the severely glaciated regions of the shield.

South from Hayes River the physiographic region of Wager Plateau is characterized by numerous exposures of granites, gneisses, and metasediments of very old rocks last thought to have been modified by the Hudsonian orogeny, *circa* 1,750 million years before the present (Stockwell *et al* 1972). Post-orogenic Aphebian sandstones known as the Thelon Formation become the dominant surface expression of ancient rock structures in the region west and south of Baker Lake. Quartz sandstone and conglomerates in a sand matrix are typical of this region and appear to be of fluvial origin. These parent rock materials are dominant in many river channels of the region. The Thelon and Pitz river channels are good examples on the pipeline route. Farther south, gneissic rocks again dominate. The entire region appears to have been subjected mostly to erosion since Hudsonian times. The result is described as an extensive peneplain. In the fluvial sense, this has left the rivers of the region with low levels of geomorphic energy. Physiographically, the region has been last modified rather extensively by Pleistocene glaciation. In between rock outcrops, extensive till plains exhibit irregular, poorly-defined

drainage networks. Drumlin fields and moraines exert structural control on present watercourses, and innumerable lakes dominate the landscape. Marine submergence up to 200 metres has left numerous relic beaches considerable distances inland and are especially noteworthy along the pipeline route in the vicinity of Baker Lake.



## 4.0 SOURCES OF DATA AND METHODS

### 4.1 Sources of Data

Principally, the data used as the basis for the summary contained herein is derived from the series of FP-1 funded interim reports summarizing field research conducted in 1975, 1976 and 1977. The paucity of hydrologic-morphologic data in the Keewatin and Queen Elizabeth islands demanded initial reconnaissance be made of the pipeline route prior to site selection for detailed study. Interim reports of AIPP FP-1 projects are as follows:

#### 4.1.1 1975 Field Work

##### 4.1.1.1 *River Crossings along a Projected Polar Gas Pipeline Route, Churchill to Baker Lake.* J. Graham Cogley.

This report summarizes an aerial survey in August of the following river crossings: Thlewiaza, Tha-Anne, Maguse, Kogtok, Kognak, Noomut, Kazan, Thelon and "Anigaq". No landings were made, but the report provides a concise, qualitative overview of some of the fluvio-geomorphic problems.

##### 4.1.1.2 *Hydrologic Reconnaissance: Somerset Island, District of Franklin.* Bryan J. Grey.

This report describes the physiography of riverine features of Somerset Island, north of Creswell Bay. Data was obtained from helicopter traverses of northern Somerset. In addition, the Hunting River was studied out of the base camp from June 26 to July 27. For this period, runoff values are listed, qualitative assessments of sediment regime are made and the recession of snowbeds is documented. Off-plateau, long-river channel characteristics are analysed.

##### 4.1.1.3 *Interim Report (1975), Hydrologic Regimes - Eastern Arctic Islands Pipeline Project, Spence Bay to Sabine Peninsula.* J.H. Wedel & J.G. Way.

Essentially, the report catalogues the field party's impression of 31 specific sites visited twice in the runoff season of 1975. Qualitative assessments of valley walls, bank stability and channel configurations were made. Flow and suspended measurements were taken. Some data on bed material and active layer depths is tabulated as well. Rudimentary channel hydraulic characteristics are tabulated.

An ancillary report on water quality is included as Appendix C (p. 293), and contains water quality analysis based on samples collected by the field parties in July and August. Its title is, "Water Quality of High Arctic Streams" (Wm. D. Gummer & G. Dunn).

#### 4.1.2 1976 Field Work

##### 4.1.2.1 *Project FP-1-76-1: Site-Intensive Hydrologic Study of a Small Catchment on Bathurst Island.* J.H. Wedel, G.A. Thorne & P.C. Baracos.

Data necessary to the calculation of a water budget for a high arctic drainage was collected and analysed. Sediment movement was sampled and computed. Mass movement on slopes and slushflow transport was sampled. An experimental relationship was developed between water content of snow on the ground prior to runoff and snow-water equivalents of the weather record at Resolute Bay.

##### 4.1.2.2 *Project FP-1-76-3: Reconnaissance of Polar Gas Route River Crossings in Keewatin District, NWT.* J.G. Way & G.A. Thorne.

This report is a geographic extension of selected site reconnaissance initiated in 1975. It lists some hydraulic, sediment and water quality data and a qualitative geomorphic assessment for 22 sites from Spence Bay south to Churchill. In addition, some generalized statements of regional hydrologic characteristics are made, based on data from the hydrometric network in place in Keewatin District.

##### 4.1.2.3 *Project FP-1-76-4A: Snowmelt Runoff, Airplane Lake Basin, June 1976.* J.P. Churylia.

Variability of water chemistry as it relates to snowmelt progression and midsummer recession flows is the chief concern addressed in this report. The basin studied is 12.3% lakes with total area of 21 km<sup>2</sup> and lies just to the northeast of Baker Lake settlement.

##### 4.1.2.4 *Project FP-1-76-4B: Spring Break-up Observations at Polar Gas Proposed Pipeline Crossing Sites of Keewatin Rivers, 1976 - A Progress Report.* Bryan J. Grey.

The report documents the observations made of ice-runs on two major river crossings near Baker Lake: on the Kazan and Thelon rivers. Observations were from the ground and by helicopter traverses. Documentation was by aerial and time-lapse photography.

4.1.2.5 *Project FP-1-76-4C: 1976 Aerial Photography.* D.A. Sherstone.

Photo coverage, generally at 1,500 m above sea level, was provided for selected river-crossing reaches in early June 1976 for the region between Spence Bay and Baker Lake. The flight lines are documented; the negatives are on file in the National Air Photo Library in Ottawa.

4.1.2.6 *Project FP-1-76-5: Water Quality Survey of Snowbird Creek Basin, Bathurst Island, NWT, 1976.* R.A. Guilbault & V.T. Chacko.

The sampling and analysis of Snowbird basin freshwater from four sites on a regular basis for the duration of runoff complemented study 76-1 above. The study points out relationships between increased sediment loading, temperature regimes and biological activity.

4.1.3 1977 Field Work

4.1.3.1 Project FP-1-77-1:

Defined Polar Gas crossing sites on Melville, Bathurst, Cornwallis and Somerset were visited. Approach slopes, channel materials, sediment loads and streamflow were assessed to provide correlations to earlier studies in the region.

4.1.3.2 Project FP-1-77-2:

In conjunction with the ground truthing of project 77-1, medium-level colour aerial photography was flown over the same region. Stereotriplets were the minimum coverage obtained at the selected sites.

4.1.4 Other Sources

4.1.4.1 Northwest Hydraulic Consultants

This firm acted as hydrologic investigator to the proponent, Polar Gas, and it followed that much of their research paralleled ours. Raw data from field studies was exchanged on an *ad hoc* basis. Their two summary reports were made available to us.

4.1.4.2 Hydrologic Investigations, Geologic Survey of Canada

Two research studies have provided much necessary information useful to our project. The basin study conducted at Consett Head on Melville Island in 1975 to assess marine sedimentation rates allowed for comparison of data with in-house project 76-1. The ongoing research of Banks

Island hydrology and geomorphology has provided much information useful to our region of interest in these disciplines.

#### 4.1.4.3 McMaster Research in the Vicinity of Resolute Bay

This multi-year study addresses the water budget of high arctic catchments. Of particular interest is the data on snow measurement and interflow.

#### 4.1.4.4 Water Survey of Canada

Flow records from the region of interest are incorporated into this summary report in extreme-value flow analysis.

#### 4.1.5 Atmospheric Environment Service

Temperature and precipitation data is used to develop a relationship between those hydrologic parameters and streamflow.

### 4.2 Methods

Principally, this report is a summation of the research conducted both in-house and by other agencies in the last three years. Summary results and their implications will be presented in two ways: by region or zone and by process. New analysis of flood-flow magnitudes is also presented. This particular analysis should be termed experimental since it relies on a rather tenuous relationship between snow precipitation and runoff. Another hypothesis put forward as a result of photographic analysis discusses the current rates of erosion-deposition in northern braided streams.

## 5.0 RESULTS

The accumulated data will be described in this section from two viewpoints:

1. On a regional basis, those items of interest in the hydrologic-morphologic sense will be described. It is proposed to divide the pipeline route into the following sections:
  - a) Melville and Bathurst islands.
  - b) Cornwallis and Somerset islands north of Stanwell-Fletcher Lake.
  - c) south Somerset and Boothia Peninsula to approximately 70°N.
  - d) Sanagak Lake to Hermann River region.
  - e) Wager Plateau from Hermann River to Thelon River.
  - f) Thelon sandstone region to Kazan River.
  - g) southern Keewatin region.

The reader is referred to Fig. 3 defining these zones of interest.

2. The second approach to define fluvio-morphologic characteristics will deal with individual form and/or processes and describe those findings of the last three years of investigation thought to be pertinent. Topics to be described are as follows:
  - a) river discharge
  - b) sediment transport
  - c) groundwater regimes
  - d) streambed percolations and icings
  - e) ice-runs
  - f) valley walls
  - g) valley plain and floodplain
  - h) channel banks

Some of the principal concerns are located on a colour map (Fig. 4).

## 5.1 Results by Region

### 5.1.1 Melville and Bathurst Islands

*In situ* weathering of sandstones, siltstones and shales have produced a plentiful supply of easily eroded material. As a result, sedimentation rates are relatively high. McLaren (1975) tabulates maximum suspended sediment at Consett Head in east Melville of 3500 ppm in 1975. Wedel *et al* (1977), lists values of 1500 ppm in west Bathurst in 1976. Spot sampling in 1975 on Sabine Peninsula (Wedel & Way 1976), well after the peak flow period, show values up to 164 ppm.

Valley walls are largely of unconsolidated materials and many examples of arctic mass-wasting processes may be observed. On steeper slopes, rill and gully development is prevalent. Almost without exception, the coastal reaches of streams consist of extensively braided river systems. Exposures of massive ground ice were noted along currently active channel banks within the estuarine deltas. In the near-shore marine plains, ground ice as tabular lenses or as ice wedges in patterned ground is felt to be prevalent. Many channel substrate soil materials are clearly frost-susceptible. Considerable portions of the lowland marine plain are well vegetated wetlands with thermokarst ponds. Two of the larger wetland regions are found at the head of Sabine Bay on the west coast of Sabine Peninsula and in Polar Bear Pass on Bathurst Island. Both of these regions are important wildlife habitats. Many of the valley floors of the interior regions of these islands are also extensively vegetated along terraces and abandoned floodplains. Patterned ground in such reaches indicates the presence of ice-wedge polygons. From west to east, mean annual runoff in this region is thought to be in the order of 100 to 150 mm. These values are derived from data at Consett Head in 1975 (McLaren) and Snowbird Creek runoff in western Bathurst in 1976 (Wedel *et al*). Based on extreme-value analysis, the two years fall near the long-term mean precipitation values at Resolute and Mould Bay weather stations and, on an annual basis, the relation between precipitation and runoff is held to be valid. Except for some lakes in the Polar Bear Pass region, the gas pipeline route is devoid of lakes which do not freeze solid in the winter. No fish were noted in the streams of this region in three field seasons. Sketch maps (Fig. 5 and 6) of the two islands, locate a few of the more pertinent findings of the investigations of 1975 and 1977.

### 5.1.2 Cornwallis and Northern Somerset Region

The interior of both Cornwallis Island and northern Somerset Island may be described as an exceedingly barren, gently undulating plateau. Streams become incised into the underlying carbonate bedrock as they near the coast, then develop into extensive sand-gravel, braided river systems in long, narrow estuarine deltas. Many of the fluvial landforms, such as bedrock terraces and sharply incised meanders in bedrock suggest that these valleys on northern Somerset are older than the 8,000 to 10,000 years since the Wisconsinian Glaciation. Compared to the rivers of Melville and Bathurst islands, the streams of this region are relatively free of sediment, and a number of the lakes on southern Cornwallis support char populations. Annual mean runoff, again based on modified precipitation data, is estimated to be in the order of 150 to 160 mm. The mantle of weathered, fine material overlying bedrock appears generally to be quite permeable and is thus able to support substantial volumes of groundwater flow in the active layer. Most of the vegetation of this region is found on sheltered valley floors and in the wetland region between Fiona and Stanwell-Fletcher lakes. Patterned ground on terraces and floodplains suggests that massive ground ice is found in reaches of river valley with fine, frost-susceptible soils. The drop from the northern plateau into the Union River valley is very steep. Patterned ground and thermokarst ponds in the valley suggest the presence of ground ice. Union River below Stanwell-Fletcher Lake occasionally maintains flows through the winter. Rust & Coakley (1965) report it as flowing prior to the spring freshet. In 1975, 1976 and 1977, the stream froze solid, however. It is a relatively important char migration route between Stanwell-Fletcher Lake and Creswell Bay and its waters are exceptionally clear and free of sediment load. Sketch maps (Fig. 7 and 8) illustrate some findings of FP-1 reconnaissance on Cornwallis and Somerset islands.

### 5.1.3 Southern Somerset Island and Northern Boothia Peninsula

Although maximum relief in the region is only slightly more than 500 metres, the hydrologic characteristics are those of mountainous regions. Long, narrow mountain lakes occupy a series of east-west trending faults on Pre-Cambrian bedrock. Local relief is severe and watercourses are marked by numerous rapids and waterfalls. In valleys and low areas, till is the dominant soil material. Many of the till areas are frost-patterned and rather extensively vegetated. The presence of ground ice is inferred. For the most part, sediment concentrations are quite low, although some minor streams along the east coast south from Bellot

Strait were turbid and appeared to be carrying fairly large sediment loads. The mountain lakes prevalent in this region support char populations. Some channel substrates may be susceptible to collapse through vibration or impact (Woo & Zoltai 1976). [See Fig. 8 and 9 for research findings in this region.]

#### 5.1.4 Southern Boothia to Hermann River

Along the route of the pipeline, the southern half of Boothia Peninsula is a rather featureless till plain modified by exposures of rounded, knobby intrusions of underlying gneissic-granitic bedrock. Vegetation is much more extensive than is the case farther north. River valleys are shallow and poorly defined. From the Lord Lindsay River south, the relief is gentle and watercourses exhibit numerous knickpoints (rapids) where bedrock outcrops on the surface. Channel materials are mostly of sand-gravel-cobble on underlying till. Felsenmeer (rock fields) are common. A number of large lakes dominate the landscape just to the north of Spence Bay and these serve to regulate the flow of connecting streams and to smooth out the fluctuations in discharge from rainfall, snowmelt or cold spells so common to the simple dendritic systems of the Queen Elizabeth Islands. Some silt-clay channel substrates are susceptible to structural collapse from vibration or impact. In the undisturbed state, the natural sediment regime varies from light to moderate. This situation was noted on the stream crossing below Lake Jekyll. South from Krusenstern Lake, the pipeline route traverses a recently-emerged marine plain known as the Rasmussen Lowlands. Streams are turbid, channel banks exhibit some instabilities, and thermokarst lakes abound. The clay-silt-sand soil matrix is felt to be conducive to ground-ice formation. Northwestern exposure to the sea and eastern highlands are thought to modify precipitation patterns. On the Hayes, Murchison and Hermann rivers, orographic rainfall customarily generates a period of high discharge in late August or early September, on occasion approaching spring runoff volumes. High flows at the time of maximum groundmelt generate significant sediment discharges. At the Polar Gas crossing of the Arctic Hayes, exposures of highly dissected clay-silt strata give the valley a unique appearance. Surficial channel and floodplain material is alluvial sand and gravel overlying a clay-silt substrate. Ice-runs at break-up on the larger rivers of this region do not appear to affect channel banks since the gentle bank slopes simply allow ice blocks to ride up on them with minimal damage.

#### 5.1.5 Wager Plateau

The effects of glaciation are pronounced in this rolling upland physiographic province. Bedrock exposures are Pre-Cambrian and felsenmeer is extensive over bare rock exposures on hilltops and crests. The intervening depressions and low ground are mantled by bouldery glacial till. Low-heath tundra vegetation mantles the soil area. Wetlands and lakes are joined by watercourses in poorly defined channels and valleys. Stream erosive ability is low in the overall, although at knickpoints (rapids, falls), sufficient stream energy may be available to initiate local erosion. Channel materials are of a lag boulder deposit underlain by a stable till matrix. Waters are clear and low sediment concentrations are normal. Most lakes support fish populations with lake trout at the head of the food chain. Rivers serve as spawning areas and migration routes. Patterned ground in low-lying wetlands along the route indicate the presence of ice-wedge polygons.

#### 5.1.6 Thelon River to Thirty Mile Lake

The gneissic bedrock typical of the Canadian Shield is overlain in this region by sandstone and sandstone conglomerate known geologically as the Thelon Formation. The till mantle of the area is modified by weathering products of this native rock. Thus, the channel materials of the Thelon River above Baker Lake are composed of a considerable depth of alluvial sands and gravels. That material transport takes place is demonstrated by extensive sand flats at the estuary of the Thelon in Baker Lake. A little farther south, there is considerable erosion of sand-gravel-cobble materials along the Pitz River. Where river gradients are sufficiently steep, selective transport has left behind a lag pavement of coarser materials and on the more gentle reaches, extensive deposition of sand and gravel has occurred. Occasional hills of intrusive rocks modify the gently rolling terrain. A fairly dense vegetative mat covers uncohesive materials and thermal erosion would become a problem in low-lying areas conducive to ground-ice accumulation. Bed materials of the Thelon River, a perennial stream, are unfrozen (Neill pers. comm. 1977). Numerous large lakes are found in the drainage basins within the area. Marine submergence occurred in this region in the Wisconsinian, and relic beach lines are visible to elevations of 200 m in the region south from Baker Lake. Patterned ground in low-lying areas is indicative of ice-wedge polygons. Regular ice-runs at break-up occur on the Thelon River and sporadic ice-push ridges may be noted along the river bank, although shore-fast ice generally

protects the river banks from damage in the period of intense ice activity. Ice jams do form and cause marked rises in water level (Way & Thorne 1977). At Thirty Mile Lake on the Kazan River, we return to terrain typical of the northern shield. At the Polar Gas crossing of Kazan River above Thirty Mile Lake, channel banks are lined with boulder ice-push ridges indicating that ice-runs on this perennial stream are perhaps its most distinctive fluvial feature. The innermost set of rock ridges is bare of vegetation indicating that it is being actively reworked. The river reach appears to be conducive to ice jamming because unbroken ice on Thirty Mile Lake just below would act as an effective barrier to ice-runs in the river. In flood years, when the river flows could approach 4000 m<sup>3</sup>/s, the effect of ice-runs and ice jams could be quite severe.

#### 5.1.7 Southern Keewatin

Physiographically, the region could be described as a gently rolling till plain containing numerous lakes and intrusive rock outcrops, the latter extensively frost-shattered. Because of the terrain, most of the region's watercourses are low-energy systems and most of that energy is expended at knickpoints. Bed materials are a bouldery lag pavement, and there are no defined river valleys. Waters are clear with very light sediment loads. The arctic heath tundra gradually gives way to boreal forest in the region of the Tha-Anne and Thlewiaza rivers, two perennial streams in this region. This region marks the zone of transition from the continuous permafrost zone to the discontinuous one, and extensive, thawed zones could be expected to occur beneath the larger rivers and under many of the lakes of the area.

In its lower reaches, the Thlewiaza River displays boulder drifts along its banks, indicative of ice-runs. The ice break-up on this river has not yet been observed; however, rigorous ice-runs can be inferred from the size and extent of boulder-drift shorelines and from smoothly-paved boulder beds that are common along the river. Channel substrates are thought to consist of fairly compact bouldery till, and the boulder channel beds represent a lag pavement from which the finer particles have been washed out. In regions of smaller gradients, the till substrate is overlain by sand and gravel deposits which, in the unthawed state, are quite permeable and therefore capable of substantial sub-channel groundwater flow.

## 5.2 Results by Form and Process

### 5.2.1 River Discharge

It has been well documented by Wedel & Way (1976) and by Way & Thorne (1977) that for the region of interest, hard data for streamflow is generally lacking. This prevents the use of normal statistical procedures used to evaluate extreme-flow events. The writer feels that any statistical data derived herein must therefore be treated with caution since sample size is inadequate or the data points are poorly defined.

#### 5.2.1.1 50-Year Peak Flow Determination

The relationship between snow-water content and runoff described by Wedel *et al* (1977) provides one conceivable method of defining extreme-value hydrologic events if some relation exists between snow water available for runoff and the magnitude of peak flows resulting from the annual thaw. For the purposes of this discussion we might describe peak flow ( $F_p$ ) as a function of basin area ( $A$ ), basin slope ( $S$ ), average water content of accumulated snow ( $P_s$ ), energy accumulation rates in degree days ( $H$ ), lake storage effects ( $L$ ), vegetation ( $V$ ), and some geometric basin characteristics ( $G$ ). The last could well be expressed as circularity ratios or drainage density values.

Very generally, then, we could summarize the foregoing as follows:

$$F_p = f(A, S, P_s, H, L, V, G)$$

For a relatively homogeneous region, it could be argued that items such as slope and basin geometry should be fairly consistent.

Since the existing flow data for the region is of short duration, *ie*, many stations have only one or two years' data, and this data comes from different years, an attempt was made to standardize input flow data based on snow records. Snow depths for the last winter month from northern weather stations showing a net accumulation were used to calculate water contents using average density values listed by Billelo (1956) and used by Wedel *et al* (1977). This data was fed into a computer program to produce five common extreme-value listings. The Gumbel distribution was used to define the 2%-probability-of-recurrence level (50-year return period) of snow events. The snow-water content for the year with streamflow data was compared to the expected 2% probability level and a "multiplier" value calculated. This factor times the documented peak flow was then plotted

in Fig. 11 versus the appropriate drainage. The equation of the envelope curve drawn was found to be  $Q = 4.9A^{-0.342}$ , where Q is the peak flow of 2% probability in cubic metres per second per square kilometre, and A is the area in square kilometres.

This simple model incorporates two parameters of the seven listed earlier, and as expected, considerable scatter is noted in Fig. 11. Incorporation of additional parameters, most notably degree-day energy accumulations and basin geometry factors, should reduce the scatter. Calculation of extreme values was done with a computer program known as Program FRQAN written in Fortran by Water Planning and Management, Inland Waters Directorate, DFE, Regina. Tables 1 to 13 are the output data from the northern weather stations used. Table 14 lists the calculations of extreme-flow values. The assembled data for mean snow-water distribution is illustrated in Figure 12.

5.2.1.2 For the Keewatin, maximum yearly flows were selected from Water Survey of Canada data and subjected to conventional statistical analysis. Fifty-year-return-period (2% probability) values appear in Tables 15 to 18. No great confidence is held for this data since the sets are of insufficient length and many of the values which do appear as annual maximum discharge occurred when ice was still affecting the stage discharge relation.

On the Dubawnt River, an upstream tributary of the Thelon, the annual flow regime is quite regular, rising slowly to a peak value in late June to mid-July and then receding gradually. This is so because of considerable lake storage upstream of the measurement site. Although continuous flow data is sparse, measurements made since 1960 in the June-July period appear to provide a reasonable data set for high flows (see Table 19). This data shows that 1962 flows on the Dubawnt were approximately of 1% probability (a 100-year flood), based on a sample size of 17 annual high-flow measurements. A flow of 50% probability is of the order of 570 - 580 cu m/sec, approximately half the 1% flood.

5.2.1.3 Time of Occurrence of Peak Flows

For the entire region, the maximum flow event from snowmelt occurs when snow and ice are still present in river channels. As a consequence, accurate data is extremely difficult to obtain since conventional stage-discharge relations do not hold and it is well-nigh impossible to put trained personnel on site at this critical time, except at great cost. In the

Queen Elizabeth Islands, and in the region from Cornwallis Island south into the Keewatin District, August rainstorms many times generate river flows which approach the volumes prevalent in the spring freshet. Documentation of late August rainfall run-off exists for the Meham and Allen rivers on Cornwallis Island and for the Hayes River east from Chantrey Inlet in northern Keewatin. In a short paper, Thomas & Thompson (1962) describe the record rainfall of August 1960 in the Queen Elizabeth Islands. Resolute Bay, Cornwallis Island, recorded a one-day rainfall of 25 mm on 12 August 1960. The effect on local drainages was quite dramatic. The authors describe it as follows, "Nearly one inch of rain fell on the area on August 12th, and almost immediately numerous cataracts plunged down the hills to the east, ditches overflowed along the roadway, and the creek became a swollen torrent." If a runoff ratio of 0.75 is assumed for this event, the runoff for this single day's rainfall would be 19 mm, approximately 12% of an average year's runoff. It appears certain that flow rates from a rainstorm of this magnitude would exceed flow rates in the spring freshet.

## 5.2.2 Sediment Transport

### 5.2.2.1 Suspended Sediment Transport

Those researchers who have investigated sediment transport in the North (McLaren 1975, Wedel *et al* 1977) have found that the greatest rates of sediment transport precede the arrival of peak flows at spring freshet. Fine materials already present in the channel is one source of supply. Another factor thought to be conducive to this process is the extremely uncohesive fabric of newly-thawed, saturated soils. As the soil regains a more cohesive structure with the loss of excess pore water, contributions of fine sediments from sheet and rill flow decrease sharply.

### 5.2.2.2 Bedload Transport

On Bathurst Island, bedload transport of materials from within the channel is impeded by the presence of snowbeds and bottom ice which effectively "lock in" supplies of erodible materials which might otherwise be moved. Day (pers. comm. 1978) indicates that on Banks Island rivers, this process is not effective and that snow and ice are normally gone from the river channels at the time of peak flows. The writer's observations on Snowbird Creek processes on Bathurst Island might thus be applicable only to a small geographic zone or be peculiar only to the year of study (1976). It is conceivable, however, that an extreme-

rainfall event such as the one of August 1960, with its attendant high river flows would move much more material in a few days than several spring freshets of similar magnitude. It is also possible, although this has not been observed, that river ice frozen solidly to the bottom would carry with it bed material when it floats free at spring runoff. Way & Thorne (1977) report the transport of boulders on running ice at the Kazan River crossing in 1976. It is felt that these ice floes were rammed into the shoreline boulder drift, picked up the rocks and were then subsequently refloated with a further rise in water level. This process is thought to be relatively rare and of minor importance.

### 5.2.2.3 Scour

Mercer & Cooper (1977), in a paper at the Quebec Hydro-technical Conference, discuss riverbed scour initiated by ice jams. Their mathematical model indicates that uncohesive materials could be scoured by ice jams which significantly constrict the "live" channel cross-sectional area, thus causing a velocity increase. This process is thought to be applicable to the Thelon River in the vicinity of the pipeline crossing since the necessary criteria of unconsolidated channel materials and ice-jam formation both are present. Cogley (1975) also speculates that this may be the case.

In the islands, many small river valleys and steep-walled gullies become completely snow-choked during the winter. At the commencement of melt, water collects behind snow dams forming temporary reservoirs of meltwater. Where release is by overflow and gradual downcutting of the snow dam, no pronounced erosional effects occur. On occasion, however, the snow dam becomes sufficiently saturated, particularly if the snowbed is one formed over a number of years, so that the entire upper slush mass gives way catastrophically. Slushflows such as this have considerable erosive power and are capable of transporting coarse boulder material, albeit over short distances only (Washburn 1973, Wedel *et al* 1977).

## 5.2.3 Groundwater

### 5.2.3.1 Boothia Peninsula and North

In permeable soils, interflow in the active layer may be substantial. Marsh (pers. comm. 1977) indicates that in the Resolute area, downslope movement of groundwater sustains low flows in principal stream channels in late summer,

and that it appears to have a definite volume response to varying intensities of insolation. Wedel *et al* (1977) in the Snowbird study felt that groundwater was an important contributor to post-recession flows, because surface-water conductivities increased as discharge dropped—interflow became a larger portion of downstream runoff. Wilson (1977) at Nanasivik recorded a 50% increase in surface-water flow volume over a short distance on the drainage canal from East Twin Lake. In the trenching operation in July 1977 at Resolute Bay village, the ditching operators had great difficulty in their task—the excavation kept filling with groundwater. Rill flow was noted at the down-slope end of one excavation. Holinshead (1975), in a report on hydrometric activity on Little Cornwallis Island, states that sub-surface water was seen to move in a soil pit excavated to ascertain the frost table.

#### 5.2.3.2 Keewatin District

To the south, in the Keewatin, open taliks are known to exist under large lakes and rivers probably as far north as Back's River. Thus an interchange of sub-permafrost water with the surface is likely in this region. It is felt that many of the midwinter river flows in the Keewatin are maintained by groundwater contributions.

#### 5.2.4 River Percolation and Icings

##### 5.2.4.1 Percolations in Channel Substrates

With one or two exceptions, it would be reasonable to state that sub-surface flow in channel substrates is of minor importance in the river reaches along the Polar Gas route. In the islands, streams are quite shallow and are of insufficient size or flow duration to maintain any sizeable taliks. It was found in the 1975 and 1976 field research that depths to frozen ground in stream channels was essentially the same as on dry ground nearby. Except in occasional deep pools, no unthawed channel materials persist into the winter when channel percolations might become important. In the Keewatin where river size and warmer temperatures maintain unfrozen river channels throughout the winter, the substrate materials are generally of fairly compact till, sufficiently impermeable to make groundwater movement in river-channel materials insignificant. If there are exceptions to these findings, they could likely be in rivers draining the Thelon Formation sandstone and sandstone conglomerate region south and west from Baker Lake. Of these the Thelon River, with unconsolidated,

unthawed, alluvial materials to considerable depth beneath the river channel, would likely be the best example.

#### 5.2.4.2 Icings

Icings, or augeis formations, occur in nature where the movement of water downslope, either underground or beneath an ice cover, is restricted and flow is forced to the surface. Two varieties are common. In the mountains, groundwater movement downslope is many times forced to the surface by impermeable materials and springs occur which create large ice bodies in winter. Spring-fed ice formations such as this are not found along the entire Polar Gas route. The other type of icing is formed in river channels, most often in perennial streams whose midwinter flows drop to very low values. In winter, the river channel essentially becomes a closed conduit with surface ice completing the enclosure. At shoals, or other restrictions, the cross-sectional area may become restricted or completely sealed by ice growth. Water is then forced to the surface, where it refreezes, many times completely filling a natural stream channel with ice. This type of icing is quite common on small prairie streams in southern Canada. The only site on the route where this occurs naturally, but not every year, is on the lower Meadowbank River. In the mid-60s, large icings were observed here on a number of occasions by the writer although this has not been the case in 1975, 1976 or 1977. It is not known precisely what alterations to the natural flow regime may have occurred, although southern experience suggests that volumes of flow are critical for the initiation of the process, *ie*, river discharge has to drop below a certain critical value.

#### 5.2.5 Valley Walls

The valley walls along the pipeline route on Melville and Bathurst islands are not very steep but they are thought to contain high ice-content soils. The presence of mud slides and solifluction lobes supports this premise. This is also true in the Rasmussen Lowlands south from Spence Bay, especially on the Murchison River. On Somerset Island below 250 m (Grey 1976), bedrock-entrenched channels in the Aston Bay, Cape Ann region are steep, varying from vertical drops at the outside of meander bends to approximately 35° on colluvial slopes.

It is not known what the sub-surface materials on the Thelon River valley walls are at the selected crossing site. South from the Thelon River, the typical shield rivers cannot be said to have any valley walls.

## 5.2.6 Valley Floor

The heading used here is intended to include low-level terraces and other relatively flat landforms not normally flooded, as well as the floodplain which is periodically inundated. In the islands along the route and on Boothia Peninsula, river valleys provide a unique ecological zone. What vegetation there is, is concentrated here. Valleys thus sustain the wildlife endemic to the region. Valley bottoms also characteristically contain considerable deposits of unconsolidated soil materials of alluvial, colluvial or marine origin. Many of these soils are ice rich. It is felt that, in many instances, the combination of rather extensive vegetation and underlying ice-rich soils are in a fragile state of equilibrium. Specific examples of this type of environment are at the upper crossing of King Point River on Melville Island, the Goodsir River crossing, the Union River on Somerset Island, the northern route approach to Lang River crossing and a number of unnamed crossings in northern Boothia Peninsula.

### 5.2.6.1 Current Floodplain Activity

Examination of river valleys in the islands has raised some doubts in researchers' minds about the relationships that exist between observed landforms and the time frame in which they were formed. This is particularly true of northern Somerset Island. It is difficult to accept the view that incised meanders such as occur in the tributary reaches of Cunningham River are of post-Wisconsin age. Bedrock (of limestone, dolomite) terraces within the valley further suggest a greater age for riverine features than is commonly supposed. Netterville *et al* (1976) suggests that other geologic features such as nunataks in northern Somerset argue against extensive dynamic glaciation in the Wisconsinian for many places in the islands including Somerset. Terrain scientists show that the weathered mantle is the product of *in situ* weathering. All of these points taken together make a case against extensive Wisconsinian glaciation, and some writers go on to suggest that ice of that era consisted of relatively quiescent island ice caps. If this view is accepted, it would appear that the braided river channels common to the islands would have experienced their dominant channel-forming discharges during the post-Wisconsin proglacial regimes and the deeply incised reaches of river channel date to earlier periods. This hypothesis would satisfactorily explain the uniform elevations noted by Grey (1976) at which incised channels begin. Above the 250 m isoline on Somerset, the plateau would have been ice covered for many thousand years.

To return to the braided lower reaches, a fairly good example of the geologic time distribution of post-Wisconsin sediment transport may be obtained from the delta formation on the north shore of Somerset Island where the proposed pipeline route exits from Barrow Strait. Stereo examination of airphotos A 31161-102 and 103 shows clearly that various sections of delta formation are linked to four most recent beach ridges. These findings are illustrated in Fig. 13 and separate the delta into four distinct age divisions. Of the four, only section A is thought to be currently active. The results of stereoscopic heighting along the line  $P_1 P_2$  in Fig. 13 are shown in Fig. 14. These figures are necessarily of preliminary nature since we lack precise stereoscopic equipment, but they illustrate clearly that only a small portion of the extensive deltaic deposit is being reworked by present fluvial activity. According to Day (pers. comm. 1978), the braided watercourses on Banks Island are stable to degrading in response to changes in water and sediment supply since Wisconsinian times.

#### 5.2.7 Channel Banks

For the Keewatin District and for most of Boothia Peninsula where the predominant surface material is bouldery till, channel banks are not a distinct feature and are simply a continuum of approach slopes to the river. This is also the case for the valley-contained rivers where the floor is substantially wider than the stream. Exceptions to this general rule occur where the stream impinges on an alluvial terrace or in braided systems common in the northern islands. Old braid scars visible on aerial photographs suggest that the entire multi-channel floodplains have been active at one time or another, although the time frame of this activity is somewhat in doubt. Evidence such as that from the small stream delta in northern Somerset Island, dealt with in the previous section, suggests that many of the braid scars thought to be of recent origin are in fact relic and outside the time frame of 20 - 50 years for a pipeline project. Some reworking of materials, particularly on Melville and Bathurst islands, is quite in evidence. The process of thermal niching, where warmer water undercuts frozen silt-sand banks, sometimes occurs. Subsequent collapse of the overhang generates slugs of sediment. On Melville Island, new bank exposures such as this occasionally reveal massive ground-ice accumulation.

## 6.0 DISCUSSION OF RESULTS

To give the reader a clearer conception of some of the fluvio-morphologic features discussed, a selection of photographs appears in the listing of figures. Collectively, they are labelled Fig. 15.

### 6.1 Runoff

#### 6.1.1. Flood Magnitude

Although base data to determine flood magnitude is inadequate, the computation has nevertheless been attempted. The results must be considered to be quite subjective. Comparison with other envelope curves of flood magnitudes (Fig. 16) such as the one from Gray (1970), Northwest Hydraulic Consultants (1976) and from Godwin (1975), suggests that the values obtained are not entirely unreasonable; therefore these data were left in the summary report.

Examination of Water Survey of Canada records reveals that for the most part, maximum flows occur in the spring freshet when the conventional stage-discharge relation is affected by backwater effects from ice. As a result, much of the maximum flow data which does exist is of questionable accuracy, being based on hydrograph extrapolation. Subjective material of this nature does not take the place of hard data. This situation cannot be rectified within the present constraints of manpower and money imposed on that agency.

#### 6.1.2 Daily and Annual Runoff Regime in the Islands

Comparison of runoff data from the Snowbird Creek study in 1976 with that produced by other hydrologic research in the High Arctic reveals good agreement. In all cases of runoff documentation, the spring freshet flows were of greatest magnitude and these early flows were subject to strong diurnal fluctuation, *ie*, daily high-flow values lagged some hours (dependent on basin size) behind daily high temperatures. In the recession period, diurnal flow variations gradually disappeared. Invariably, all attempts to correlate annual runoff totals with available precipitation data were unsuccessful. Runoff was found to be consistently much greater than annual precipitation. Both in the Snowbird basin and in the small catchment north of Resolute airport, good agreement was found to exist between data from basin snow surveys and runoff.

## 6.2 Sedimentation

### 6.2.1 General

For the region under study, sediment data is most notable by its absence. Miscellaneous sampling at various sites does not provide any indication of what maximum values might be since all these samples were made in periods of flow recession when sediment concentrations are low. No clear understanding of maximum sediment loadings in streams on the route is thus possible. In respect to pipeline activity on river crossings, a rational conclusion is that increased sediment production will have the most deleterious effects on streams which are presently clear or very nearly so. V. Steiberger (pers. comm. 1977), a freshwater biologist in the Pacific region, states that concentrations of sediment greater than 2500 ppm are harmful to migrating salmon. It is not known what the sediment generation as a result of construction will be on clear-water rivers such as the Kazan or Thlewiaza, but it is felt that the natural sediment regimes of perennial clear-water systems will be altered significantly during the construction period.

### 6.2.2 Thermal Erosion

Thermal erosion is a sediment-generating process felt to be a significant factor in construction activity in permafrost regions, particularly in ice-rich soils. It was noted in the Snowbird report that newly-melted soils with excess pore water did not regain a cohesive structure for several days subsequent to melt. Where such ice-rich soils are found on slopes and the insulating cover is removed, mud flows or soil slip could occur and the process would become self-perpetuating. Similar situations might well be triggered on the walls of a pipeline trench dug through ice-rich soils in the melt season. Increased sediment loadings to watercourses could result.

## 6.3 Groundwater

Marsh (pers. comm. 1977) indicates that downslope groundwater movement in the active layer occurs in the soil materials in their study basin just to the north of Resolute Bay airport. There is no reason to believe that those materials are substantially different from the ones along the long valley slope which the proposed route traverses to bypass the Trafalgar Lakes systems on the southern tip of Cornwallis. It appeared to the writer that several adverse effects might occur because of pipeline activity. Since the route traverses a valley wall upslope from the lakes,

the construction phase could generate silt movement into the lakes in rill and surface flow. The lake chain is used for recreational sport fishing by local people and this could be disrupted. The long-term effect of pipe burial could well result in ponding upslope of the pipe with redirection of surface flow along the pipeline or in new rill and gully development downslope. If the thermal regime of the pipe is generally colder than that of the surrounding permafrost, the frost-bulb around the pipe will intrude into the active layer, thus restricting the inter-flow zone.

Casagrande (1932) indicates also that a freezing front, *ie*, the edge of advancing frost in soils, becomes susceptible to ice accumulation when soil-pore spaces are of a certain critical size. From data in School of Military Engineering lecture notes (1960), it appears that particle sizes of 0.02 mm are essential to ice accumulation.

The entire problem of interflow in the active layer appears to be fairly widespread in the Arctic Islands and not applicable only to the specific site dealt with here. Thus, Holinshead (1975) describes visible soil-water movement in a soil pit on Little Cornwallis Island; and Wilson (1977) reports increases in flow in the drainage below East Twin Lake at Nanasivik Mines on Borden Peninsula on Baffin Island. His report lists some data to make the case for substantial, active-layer interflow. Thus, the outflow of Twin Lakes is listed at 4.81 m<sup>3</sup>/s on 1 July 1977, yet the measured surface flow 90 m above Strathcona Sound, some 4 km downstream, was only 2.59 m<sup>3</sup>/s, a loss of 46% of out-flow water to sub-surface flow. In the newly-constructed diversion channel below East Twin Lake, an increase in flow from groundwater discharge was measured on 26 August 1977. On that day, the following data was assembled: (1) 12 m below lake - 0.113 m<sup>3</sup>/s; (2) At gauge (200 m downstream) - 0.176 m<sup>3</sup>/s; and (3) 450 m downstream - 0.195 m<sup>3</sup>/s.

In an indirect way, *ie*, from the assessment of dissolved solids in streamflow at Snowbird Creek on Bathurst Island (Wedel *et al* 1977) Guilbault & Chacko 1977), the case is also made that interflow occurs during the late summer in the Queen Elizabeth Islands.



## 7.0 CONCLUSIONS

### 7.1 Runoff

#### 7.1.1 Mean Annual Runoff

Based on the data from Snowbird Creek in 1976 and from Consett Head in 1975, the total annual runoff for the High Arctic "desert" region is approximately 150 mm. Southward runoff values increase with increasing precipitation and isopleths defining equivalent runoff values would trend northwest to southeast. At Seal River in northern Manitoba, mean annual runoff is 225 mm.

#### 7.1.2 Flood Flows

For the region, maximum annual flow normally occurs as a result of snowmelt. In-channel snow and ice in the islands inhibit channel scour and degradation. For the large rivers of the Keewatin District, ice jams associated with the spring freshet may initiate scour on unconsolidated bed material such as is found on the lower Thelon River. Very rarely, peak flows from rainfall may generate flows greater than those of the snowmelt period. It is conceivable that this was the case in the Queen Elizabeth Islands in August 1960.

Orographically enhanced precipitation of late summer in the region south from Spence Bay frequently generates late summer flow peaks. High autumn discharges have been documented on the Arctic Hayes and the Murchison rivers. Flood discharge values in this report have been interpolated from snow precipitation data or peak-flow data sets of insufficient length and should be used with caution.

### 7.2 Sediment Regimes

High natural production rates of sediment were found on Melville and Bathurst islands and in the Rasmussen Lowland region south from Spence Bay. Addition of new sediments from construction into rivers of these regions would not be as harmful as it would be to clear-water systems along the route, particularly those with exploitable aquatic resources.

### 7.3 River Valleys

In the High Arctic "polar desert", river valleys sustain most of the plant communities of the region. Aside from its ecological significance, the vegetation serves to

insulate ice-rich soils of alluvial or colluvial origin. Disturbance of the surface could lead to thermal erosion and increased sedimentation.

#### 7.4 River Channel Activity

The presence of near-surface permafrost, and snow or ice within High Arctic river channels serves to protect natural stream channels from erosion. Compact till, armoured with lag deposit boulders, commonly found in the Keewatin District, are not susceptible to erosion in the low-energy regimes common to most crossings. Some exceptions to these generalizations will be discussed in the following subsections.

##### 7.4.1 Braided Channels

Lateral migration of principal channels within a braided floodplain, frequently by thermal niching, is known to occur on Melville, Bathurst and Cornwallis islands. Such braided floodplains should be trenched to sufficient depth to allow the deepest channel to assume any position within the floodplain cross-section.

##### 7.4.2 Thelon River Channel

The channel materials are unfrozen, alluvial gravels and sands to considerable depth (Neill pers. comm. 1977). Scour and fill processes may occur during floods and in proximity to ice jams formed in the spring freshet.

##### 7.4.3 Marine Soils

Some channel substrates in southern Boothia are of unconsolidated marine silts and clays which suffer structural collapse from impact or vibration when in their thawed state. These materials were noted at the cross-section investigated below Lake Jekyll on the Krusenstern River system. Copious siltation accompanies their disturbance in summer.

#### 7.5 Icings

Icings are felt to be a potential problem on Keewatin rivers whose discharges in winter fall to critically low values. In the writer's experience, natural icings have been noted in the vicinity of the lower Meadowbank River crossing. If the gas pipeline temperatures are significantly lower than the surrounding frozen ground, the lower

temperatures may serve to form bottom ice and thus constrict the "live channel" of certain other "low-flow" perennial streams in Keewatin and northern Manitoba, such as the Hermann, Caribou and Nejanilini rivers. These last three rivers are mentioned on the basis of Northwest Hydraulic Consultants' data of winter flow conditions (1976). Although icings *per se* would not affect buried pipelines, the in-filling of a channel with ice would cause the high flows of spring to be directed against river banks at levels above those normally protected. Increased erosion of high-level river banks could occur. Similar high-level river bank erosion could also take place in the islands where accumulations of snow and ice block the channel and direct the flow against one bank or the other.

#### 7.6 Ice-runs and Ice Jams

Ice-runs of undegraded, heavy ice occur on the major rivers crossed by the Polar Gas route in the Keewatin District. On the Thelon and Kazan rivers, the spring freshet ice activity has been documented. Ice jams create temporary restrictions to flow and their release causes some reworking of riverbed and bank materials as is evidenced by the creation of longitudinal boulder drifts along the shores of the Kazan and Thlewiaza rivers. The Kazan river crossing is thought to be susceptible to ice jamming because of its location immediately above Thirty Mile Lake. In view of the quantities and nature of the active ice, damage to river shorelines is not as severe as it might be because river banks are generally of gentle slope, thus allowing the ice to override the shoreline.



## 8.0 SUMMARY

The sensitivity of hydrologic regimes to disturbance is terrain-dependent along the Polar Gas route and this lends itself to regionalization. North from Stanwell-Fletcher Lake, surface materials are predominantly the products of *in situ* weathering of underlying bedrock with glacial till occurring only sporadically. It is further separated into two sub-regions.

On Melville and Bathurst islands, surface exposures of shales, siltstone and sandstone have weathered into fine, easily-eroded soils, many of which are ice rich, particularly in river valleys and in the coastal zones. Rivers on these two islands carry substantial sediments (up to 5000 ppm) and rill or gully development is prevalent. In ice-rich soils, thermal erosion triggered by surface disturbance is a possibility. Near the coasts, stream channels are braided. Streams are seasonal and peak flows occur as a result of snowmelt. Near-surface permafrost, snow and ice present in-channel at spring freshet inhibit channel degradation, and much of the available stream energy is expended on lateral erosion, especially in braided reaches. Average annual runoff approximates 150 mm.

Cornwallis and Somerset islands constitute the other half of the region and the division is principally because of different surface bedrock—carbonates, gneisses, meta-sediments and sandstones dominate. Soils weathered from these materials are less susceptible to erosion, and streams on the two islands have much smaller sediment concentrations. Below elevation 250 m, entrenchment of rivers draining the northern Somerset plateau is frequent (Grey 1975). Steep valley walls varying from vertical cliff faces to 35° colluvial slopes are found below this elevation. Airphoto analysis of a small delta in northern Somerset Island indicates a lower current level of fluvial activity than might be inferred from total amounts of alluvial materials found in the lower reaches of these river channels. No streams in this region flowed through the winter during the three-year study, although the Union River is said to maintain midwinter flows on occasion. River valleys harbour most of the vegetation of the region; in many cases sub-surface soils beneath the plant communities appear to be ice rich. Removal of the cover will likely give rise to thermal erosion and thermokarst. The permeability of soil materials in the active layer is conducive to groundwater movement as interflow in the active layer during the summer.

South from Stanwell-Fletcher Lake, glacial till becomes the dominant soil material. The terrain is that of the Canadian Shield. Knobby hills of Pre-Cambrian bedrock (much of it frost-shattered) separate low-lying areas, swales and valleys infilled with glacial debris. Lakes abound and much bog terrain is in evidence. In a regional sense, the rivers of this area have gentle longitudinal slopes and therefore low geomorphic energy. Gradients may become steep at knickpoints and develop sufficient energy for local erosion. Generally, valley walls and river banks are of sufficiently low slope to make them almost indistinguishable from the surrounding terrain. Variations to this theme occur where rivers abut old terraces or eskers. In the Keewatin District, the proposed pipeline crosses four major streams: the Thelon, Kazan, Thlewiaza and Tha-Anne rivers. The channel beds appear to be thawed but only the Thelon bed (and perhaps that of the Tha-Anne) contains materials susceptible to erosion (sand, gravel, cobble). Ice runoff at spring freshet has produced ice-push ridges along their banks. On the Kazan and Thlewiaza, these could best be described as longitudinal boulder drifts. They are not continuous and the Thlewiaza crossing has none, although the extremely low river banks of bouldery material have a distinct planed appearance thought to be caused by ice floe action. The many clear-water streams of this region support substantial fish populations as do the intervening lakes. Sediment pollution from construction activity would have the greatest adverse impact on such rivers.

Two terrain units within the southern region exhibit distinct hydrologic characteristics different from those just generalized upon.

1. The Bellot Strait region could be more correctly termed a mountainous zone rather than typical Shield terrain. Local relief is severe; long, narrow mountain lakes are frequent and streams are marked by waterfalls and rapids with characteristic tumbling flow. At flood, most of the observed streams would appear to be capable of transporting coarse bed material.
2. The Rasmussen Lowland south from Spence Bay is a low-relief, recently-emerged marine plain. Materials are ice rich and the plain is pocked with thermokarst ponds. Fine soils are susceptible to erosion and the rivers are quite turbid. Fish resources are found in the lakes of the region, *eg*, Murchison Lake. It could well be that additional siltation from human activity could raise sediment levels sufficiently to be harmful to aquatic

resources. Orographic rainfall events generate large late-summer flows. Some channel substrates have been found to be susceptible to collapse from vibration or impact.

Finally, several points will be made dealing with the entire region.

1. Mean annual runoff varies from 150 mm in the northern "polar desert" around Resolute to 225 mm at Seal River in northern Manitoba.
2. In southern Keewatin and northern Manitoba, the shift from the zone of continuous permafrost to the discontinuous zone occurs. Taliks become widespread underneath water bodies and permafrost temperature regimes lie near 0°C. Because of these factors, permafrost regions are thought to become increasingly sensitive to disturbance from north to south.
3. Because no generalized analysis such as this report presents can begin to account for local variations, it is recommended that river-crossing design be based on site-specific information and not on regionalized information.



## 9.0 IMPLICATIONS AND RECOMMENDATIONS

Although the writer feels that the knowledge and skills exist to build an acceptable "design-with-nature" gas pipeline from the High Arctic, some concerns are still felt to be valid.

### 9.1 Pipeline Oriented Concerns and Recommendations

#### 9.1.1 Induced Icing

As described earlier, induced icing could be caused in low-flow regimes if gas pipeline temperatures were considerably lower than that in the natural state. It is possible that this may be the case if a low-flow system lies some distance away from a compressor station since the gradual loss of pressure down-pipe implies a corresponding temperature drop for adiabatic reasons. The problem could be prevented by locating a compressor site just above a critical stream crossing and so to control the temperature or, if it is decided to live with potential icing, to protect the river channel approaches against erosion to a much higher level than would appear to be necessary from examination of the river in its natural state.

#### 9.1.2 Groundwater Routing

In areas where the pipeline traverses slopes with permeable materials in the active layer, movements of near-surface groundwater will be restricted by higher-than-normal permafrost horizons underneath berms or roadways or by the upper levels of the frost-bulb around a buried pipe. Surface expression of such groundwater movements are thought likely to occur. Rechannelization of flow and gully development are distinct possibilities, the latter of particular consequence in ice-rich soils where it might initiate thermal erosion. Removal of gravel work surfaces after construction and deeper burial of the pipe are two procedures which would prevent extensive permafrost aggradation and help to maintain groundwater movement in its original state. Adequate surface drains and culverts should be provided for slopes where restoration of the original surface is not feasible.

#### 9.1.3 Thermal Erosion

Exposure of ice-rich soils in the melt period induces structural collapse of soil fabric. Where this occurs on a slope, removal of thawed soil by running water or slippage

makes the process an ongoing one. Experience at Snowbird Creek suggests that these materials regain a substantial, cohesive structure after the excess pore water is drained. Physical restraint of such soils for a short period during their melt (by shoring, for example) would reduce the harmful effects of this process on slopes or on the walls of a pipeline trench dug in summer. Ideally, no construction should take place in regions of ice-rich soils during the melt period.

#### 9.1.4 Increased Siltation

The foregoing concerns may have two conceivable effects in the hydrologic-morphologic sense. First, the process at a river crossing or along the pipeline right-of-way may affect the integrity of the pipeline. Secondly, all the processes have the potential of increasing sediment loads in drainage systems. Increased siltation is not thought of as a serious concern where high sediment transport rates already prevail, but great care should be taken to prevent increased sediment transport on those streams with low natural levels of sediment pollution. On rivers such as the Kazan and the Thlewiaza, spoil materials should not be left in the near-shore environment where they would be susceptible to entrainment by flood flows. In clear-water basins, man-made drainages on slopes should be armoured by rubble rock to minimize erosion and subsequent high sediment levels in downstream watercourses.

#### 9.1.5 Ice Jams

Because water levels for an extreme flood in periods with ice-jam potential are unknown for rivers such as the Kazan, conservative design concepts should be adopted for the placement of any surface structures associated with the crossing and for the elevations above river level at which to begin deep trenching.

### 9.2 Scientific Findings

- 9.2.1 Annual runoff totals for the central Arctic Islands are considerably greater than isopleths on national runoff maps indicate. An average value of annual runoff for the region around Resolute Bay is thought to be 150 mm. The peak discharges occur as a result of snowmelt, although rare rainstorms may generate flow of similar magnitude in late summer.

- 9.2.2 Sediment transport rates are greatest in the period preceding peak flow and considerably higher than previously thought. On Melville and Bathurst islands values for suspended sediment could approach 5000 ppm at spring freshet.
- 9.2.3 Assessment of snow-water contents on the basis of snow precipitation measurements at weather stations in the barren lands is inadequate in a hydrologic sense. Good agreement between snow-water equivalents and the resulting runoff is obtainable from snow-course measurements made just before the melt period. Average snow density values are surprisingly consistent and in good agreement with data originally presented by Billelo (1957).

### 9.3 Personal Views

It is thought that the construction and operation of a chilled gas pipeline is environmentally compatible with the hydrology and river-generated landforms of the region. The "wide brush" techniques used to regionalize hydrologic characteristics in this report will have to be applied with caution to site-specific problems, however. It appears that many generalizations made here will require modification to fit the needs encountered at particular crossings and decisions will have to be made while construction is in progress.



## 10.0 NEED FOR FURTHER STUDY

### 10.1 Hydrometric Data

Central to the researchers' problems in this study was the lack of sufficient streamflow data to make acceptable predictions of extreme flood events for the region. Such predictions as were made were based, not on actual flood data, but on a relationship thought to exist between precipitation and streamflow. Extrapolations such as these are a very poor substitute for real-data evaluations.

Aside from the problems of short data sets and lack of flood-flow documentation, attempts to regionalize hydrologic characteristics of specific zones such as the tree-line area, the mid-arctic low-heath tundra and polar desert regimes require the study and data assembly for basins entirely within a given zone. Large, intra-regional river systems which constitute the bulk of the hydrometric network should be expanded to include such smaller basins.

It seems reasonable to suppose that increased industrial activity in the North, such as mining, will follow the pipeline phase. This will mean new townsites with requirements for fresh water, both for industrial use and human consumption. Waste disposal in the Arctic, given the low levels of biological activity, becomes a very large problem. It is clear that a larger hydrometric network, especially in the northern islands, is essential to the intelligent development of northern industrial capability.

### 10.2 Sediment Data

No systematic collection of sediment data is presently being made in the eastern or High Arctic. Since knowledge of sediment is considered to be of prime importance to this study, the establishment of at least index sediment stations in this region is highly recommended, particularly on streams which will be affected by foreseeable construction activity.

### 10.3 Snowfall

There is a need to devise a method of snowfall measurement suited to the arctic environment so that this data could become an accurate component in northern water budget calculations.

#### 10.4 Monitoring

This will not be the first gas pipeline to traverse arctic territory, and much data applicable to our interests will become available from the construction and operation of the Alcan project. Both government and private industry should monitor the design procedures and construction techniques as they develop. Similarly, once construction starts, studies should be maintained at selected sites along the Polar Gas route in order to document those techniques which worked and to record the modifications of those procedures found unsatisfactory.

Table 1: YBK BAKER LAKE - SNOW WATER EQUIVALENTS (SWE)

YEAR	ANNUAL SWE (mm)	DESCENDING ORDER	RANK	CUMULATIVE PROBABILITY
1950	155	356	1	.036
1951	100	320	2	.071
1952	0	283	3	.107
1953	219	228	4	.143
1954	164	219	5	.179
1955	155	210	6	.214
1956	210	210	7	.250
1957	137	201	8	.286
1958	91	173	9	.321
1959	118	164	10	.357
1960	228	155	11	.393
1961	210	155	12	.429
1962	356	155	13	.464
1963	45	146	14	.500
1964	82	137	15	.536
1965	320	137	16	.571
1966	210	137	17	.607
1967	118	118	18	.643
1968	173	118	19	.679
1969	137	118	20	.714
1970	146	100	21	.750
1971	91	100	22	.786
1972	137	91	23	.821
1973	118	91	24	.867
1974	100	82	25	.893
1975	155	45	26	.929
1976	283	0	27	.964

SERIES	MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	COEFFICIENT OF SKEW
X	157.85	79.02	.501	.689
LOG X	2.09099	.46762	.22363	-3.84211
LOG (X-A)	2.43360	.12370	.05083	-.36482

CALCULATED MEDIAN (X SERIES) = 146.30

PARAMETER A = -124.05

#### EXTREME VALUE DISTRIBUTIONS (mm)

T	P	GUMBEL	PEARSON	LOG PEARSON	LOG NORMAL	3 PARAMETER LOG NORMAL
1.01	99	17	14	1	10	15 139
1.05	95	46	45	17	20	45 169
1.11	90	64	64	44	31	64 188
1.25	80	89	90	96	49	89 213
2.00	50	146	148	192	123	147 271
2.33	42.92	160	163	203	150	161 285
5.00	20	223	220	215	305	220 344
10.00	10	274	262	217	490	266 390
20.00	5	323	301	228	724	309 433
50.00	2	386	347	267	1125	363 487
100.00	1	434	380	324	1508	402 526
1000.00	.1	591	482	969	3435	530 654
10000.00	.01	747	577	5439	6769	658 782

MEAN (CHECK) = 158.57

Table 2: YCB CAMBRIDGE BAY - SNOW WATER EQUIVALENTS (SWE)

YEAR	ANNUAL SWE (mm)	DESCENDING ORDER	RANK	CUMULATIVE PROBABILITY
1948	45	210	1	.033
1949	146	210	2	.067
1950	155	173	3	.100
1951	155	164	4	.133
1952	164	155	5	.167
1953	210	155	6	.200
1954	137	155	7	.233
1955	137	155	8	.267
1956	155	146	9	.300
1957	155	137	10	.333
1958	210	137	11	.367
1959	173	128	12	.400
1960	91	109	13	.433
1961	64	109	14	.467
1962	82	100	15	.500
1963	109	91	16	.533
1964	109	91	17	.567
1965	91	91	18	.600
1966	73	91	19	.633
1967	73	91	20	.667
1968	128	91	21	.700
1969	100	82	22	.733
1970	64	73	23	.767
1971	73	73	24	.800
1972	91	73	25	.833
1073	91	64	26	.867
1974	91	64	27	.900
1975	36	45	28	.933
1976	91	36	29	.967

SERIES	MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	COEFFICIENT OF SKEW
X	114.14	45.83	.401	.443
LOG X	2.02101	.18704	.09255	-.45254
LOG (X-A)	1.89409	.26319	.13895	-.97666

CALCULATED MEDIAN (X SERIES) = 100.58  
PARAMETER A = 23.14

## EXTREME VALUE DISTRIBUTIONS (mm)

T	P	GUMBEL	PEARSON	LOG PEARSON	LOG NORMAL	3 PARAMETER LOG NORMAL	
1.01	99	34	22	33	38	42	19
1.05	95	50	44	49	51	52	28
1.11	90	60	58	59	60	59	36
1.25	80	74	74	73	73	70	47
2.00	50	106	110	108	104	101	78
2.33	42.92	114	119	117	113	110	87
5.00	20	149	151	151	150	153	130
10.00	10	178	174	177	182	193	170
20.00	5	205	194	200	213	235	212
50.00	2	241	218	228	254	295	272
100.00	1	267	235	247	285	343	320
1000.00	.1	355	285	304	397	532	509
10000.00	.01	443	330	352	520	769	746

MEAN (CHECK) = 117.29

Table 3: YCS CHESTERFIELD INLET - SNOW WATER EQUIVALENTS (SWE)

YEAR	ANNUAL SWE (mm)	DESCENDING ORDER	RANK	CUMULATIVE PROBABILITY
1947	155	411	1	.032
1948	118	411	2	.065
1949	0	365	3	.097
1950	91	292	4	.129
1951	411	265	5	.161
1952	201	265	6	.194
1953	146	201	7	.226
1954	146	201	8	.258
1955	155	192	9	.290
1956	265	182	10	.323
1957	192	182	11	.355
1958	164	173	12	.387
1959	137	173	13	.419
1960	128	164	14	.452
1961	109	155	15	.484
1962	411	155	16	.516
1963	91	146	17	.548
1964	182	146	18	.581
1965	128	137	19	.613
1966	182	128	20	.645
1967	109	128	21	.677
1968	201	128	22	.710
1969	292	118	23	.742
1970	265	109	24	.774
1971	109	109	25	.806
1972	91	109	26	.839
1973	128	91	27	.871
1974	173	91	28	.903
1975	365	91	29	.935
1976	173	0	30	.968

SERIES	MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	COEFFICIENT OF SKEW
X	177.73	94.26	.530	1.145
LOG X	2.14765	.45149	.21023	-4.05948
LOG (X-A)	2.33770	.17672	.07560	-.61837

CALCULATED MEDIAN (X SERIES) = 156.97  
 PARAMETER A = -57.04

## EXTREME VALUE DISTRIBUTIONS (mm)

T	P	GUMBEL	PEARSON	LOG PEARSON	LOG NORMAL	3 PARAMETER LOG NORMAL	
1.01	99	24	36	1	12	27	84
1.05	95	56	58	22	25	54	111
1.11	90	75	74	55	37	72	129
1.25	80	101	98	115	58	97	154
2.00	50	163	160	216	140	160	217
2.33	42.92	178	176	225	169	177	234
5.00	20	246	247	234	337	249	306
10.00	10	301	303	238	532	309	366
20.00	5	353	356	257	776	367	425
50.00	2	422	423	320	1188	444	501
100.00	1	473	472	411	1576	503	560
1000.00	.1	641	630	1569	3489	708	765
10000.00	.01	810	784	12099	6717	931	988

MEAN (CHECK) = 179.36

Table 4: YYQ CHURCHILL - SNOW WATER EQUIVALENTS (SWE)

YEAR	ANNUAL SWE (mm)	DESCENDING ORDER	RANK	CUMULATIVE PROBABILITY
1947	325	365	1	.032
1948	227	333	2	.065
1949	65	325	3	.097
1950	186	325	4	.129
1951	333	276	5	.161
1952	203	227	6	.194
1953	365	227	7	.226
1954	138	211	8	.258
1955	325	211	9	.290
1956	89	203	10	.323
1957	105	203	11	.355
1958	138	186	12	.387
1959	146	170	13	.419
1960	154	170	14	.452
1961	146	154	15	.484
1962	203	146	16	.516
1963	65	146	17	.548
1964	81	138	18	.581
1965	65	138	19	.613
1966	276	130	20	.645
1967	211	105	21	.677
1968	227	97	22	.710
1969	97	89	23	.742
1970	89	89	24	.774
1971	130	81	25	.806
1972	65	65	26	.839
1973	48	65	27	.871
1974	211	65	28	.903
1975	170	65	29	.935
1976	170	48	30	.968

SERIES	MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	COEFFICIENT OF SKEW
X	168.79	89.23	.529	.676
LOG X	2.16494	.24385	.11264	-.21212
LOG (X-A)	2.44587	.12983	.05308	.18813

CALCULATED MEDIAN (X SERIES) = 154.43  
PARAMETER A = -122.83

## EXTREME VALUE DISTRIBUTIONS (mm)

T	P	GUMBEL	PEARSON	LOG PEARSON	LOG NORMAL	3 PARAMETER LOG NORMAL	
1.01	99	22	5	36	39	16	139
1.05	95	52	40	56	58	47	170
1.11	90	70	62	70	71	67	190
1.25	80	95	92	91	91	94	217
2.00	50	153	158	149	146	156	279
2.33	42.92	167	175	165	161	171	294
5.00	20	231	239	235	234	236	359
10.00	10	282	287	296	300	286	409
20.00	5	332	330	355	368	333	456
50.00	2	396	382	434	463	393	515
100.00	1	444	419	494	539	436	559
1000.00	.1	603	533	701	828	580	703
10000.00	.01	762	639	921	1180	726	848

MEAN (CHECK) = 169.09

Table 5: YWO CONTWOYTO LAKE - SNOW WATER EQUIVALENTS (SWE)

YEAR	ANNUAL SWE (mm)	DESCENDING ORDER	RANK	CUMULATIVE PROBABILITY
1959	284	284	1	.053
1960	241	267	2	.105
1961	250	250	3	.158
1962	198	241	4	.211
1963	155	233	5	.263
1964	172	233	6	.316
1965	164	207	7	.368
1966	172	207	8	.421
1967	129	198	9	.474
1968	267	172	10	.526
1969	120	172	11	.579
1970	138	164	12	.632
1971	233	155	13	.684
1972	233	155	14	.737
1973	207	138	15	.789
1974	112	129	16	.842
1975	207	120	17	.895
1976	155	112	18	.947

SERIES	MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	COEFFICIENT OF SKEW
X	191.43	52.34	.273	.179
LOG X	2.26609	.12246	.05404	-.20147
LOG (X-A)	2.58085	.05926	.02296	-.00401

CALCULATED MEDIAN (X SERIES) = 187.83  
PARAMETER A = -192.86

## EXTREME VALUE DISTRIBUTIONS (mm)

T	P	GUMBEL	PEARSON	LOG PEARSON	LOG NORMAL	3 PARAMETER LOG NORMAL	
1.01	99	98	76	91	95	84	277
1.05	95	117	108	114	116	111	304
1.11	90	129	125	127	128	126	319
1.25	80	145	146	146	145	146	339
2.00	50	182	189	186	184	188	380
2.33	42.92	192	199	196	194	197	390
5.00	20	232	234	234	233	234	427
10.00	10	266	259	263	264	260	453
20.00	5	298	280	288	293	283	476
50.00	2	339	303	319	329	311	504
100.00	1	370	320	340	355	330	523
1000.00	.1	472	366	407	441	387	580
10000.00	.01	574	406	467	526	439	632

MEAN (CHECK) = 191.63

Table 6: YEI ENNADAI LAKE - SNOW WATER EQUIVALENTS (SWE)

YEAR	ANNUAL SWE (mm)	DESCENDING ORDER	RANK	CUMULATIVE PROBABILITY
1950	105	325	1	.036
1951	195	276	2	.071
1952	211	276	3	.107
1953	138	243	4	.143
1954	113	219	5	.179
1955	219	211	6	.214
1956	121	203	7	.250
1957	276	195	8	.286
1958	243	195	9	.321
1959	113	186	10	.357
1960	121	154	11	.393
1961	130	154	12	.429
1962	325	146	13	.464
1963	146	146	14	.500
1964	65	138	15	.536
1965	154	130	16	.571
1966	276	130	17	.607
1967	195	130	18	.643
1968	154	121	19	.679
1969	130	121	20	.714
1970	203	121	21	.750
1971	105	113	22	.786
1972	121	113	23	.821
1973	186	105	24	.857
1974	56	105	25	.893
1975	146	65	26	.929
1976	130	56	27	.964

SERIES	MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	COEFFICIENT OF SKEW
X	162.56	65.10	.400	.782
LOG X	2.17724	.17781	.08167	-.29641
LOG (X-A)	2.04709	.25055	.12239	-.88291

CALCULATED MEDIAN (X SERIES) = 143.05  
PARAMETER A = 34.42

## EXTREME VALUE DISTRIBUTIONS (mm)

T	P	GUMBEL	PEARSON	LOG PEARSON	LOG NORMAL	3 PARAMETER LOG NORMAL	
1.01	99	54	48	53	58	63	29
1.05	95	76	71	74	76	77	43
1.11	90	90	86	87	88	87	53
1.25	80	108	106	107	106	102	68
2.00	50	151	154	153	150	145	111
2.33	42.92	162	165	165	162	158	123
5.00	20	210	213	213	212	215	181
10.00	10	248	249	250	254	267	233
20.00	5	285	281	284	294	322	287
50.00	2	333	321	326	348	398	364
100.00	1	369	350	356	389	460	426
1000.00	.1	488	439	450	532	698	662
10000.00	.01	607	522	537	689	987	953

MEAN (CHECK) = 166.05

Table 7: YUX HALL BEACH - SNOW WATER EQUIVALENTS (SWE)

YEAR	ANNUAL SWE (mm)	DESCENDING ORDER	RANK	CUMULATIVE PROBABILITY
1957	246	283	1	.048
1958	155	246	2	.095
1959	82	246	3	.143
1960	128	228	4	.190
1961	118	201	5	.238
1962	246	192	6	.286
1963	182	182	7	.333
1964	192	182	8	.381
1965	118	173	9	.429
1966	137	164	10	.476
1967	137	155	11	.524
1968	283	146	12	.571
1969	228	137	13	.619
1970	137	137	14	.667
1971	164	137	15	.714
1972	201	128	16	.762
1973	182	128	17	.810
1974	146	118	18	.857
1975	128	118	19	.905
1976	173	82	20	.952

SERIES	MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	COEFFICIENT OF SKEW
X	169.62	51.51	.304	.625
LOG X	2.21064	.13193	.05968	-.08359
LOG (X-A)	2.14431	.15418	.07190	-.23550

CALCULATED MEDIAN (X SERIES) = 160.02  
PARAMETER A = 21.84

## EXTREME VALUE DISTRIBUTIONS (mm)

T	P	GUMBEL	PEARSON	LOG PEARSON	LOG NORMAL	3 PARAMETER LOG NORMAL	
1.01	99	82	73	78	80	82	61
1.05	95	100	94	97	98	99	77
1.11	90	111	108	109	110	110	88
1.25	80	126	125	125	125	125	103
2.00	50	161	164	163	162	161	139
2.33	42.92	170	173	172	171	170	148
5.00	20	208	210	209	209	209	187
10.00	10	239	238	239	239	241	219
20.00	5	269	262	265	267	271	249
50.00	2	308	291	298	303	310	289
100.00	1	337	312	323	329	340	318
1000.00	.1	433	376	400	415	439	417
1000.00	.01	529	434	476	502	544	522

MEAN (CHECK) = 170.32

Table 8: YIC ISACHEN - SNOW WATER EQUIVALENTS (SWE)

YEAR	ANNUAL SWE (mm)	DESCENDING ORDER	RANK	CUMULATIVE PROBABILITY
1948	91	228	1	.033
1949	0	210	2	.067
1950	45	182	3	.100
1951	91	137	4	.133
1952	82	128	5	.167
1953	54	100	6	.200
1954	73	100	7	.233
1955	182	91	8	.267
1956	228	91	9	.300
1957	82	91	10	.333
1958	64	91	11	.367
1959	91	82	12	.400
1960	91	82	13	.433
1961	64	73	14	.467
1962	45	73	15	.500
1963	210	73	16	.533
1964	128	64	17	.567
1965	64	64	18	.600
1966	100	64	19	.633
1967	36	64	20	.667
1968	73	54	21	.700
1969	100	54	22	.733
1970	73	45	23	.767
1971	137	45	24	.800
1972	54	45	25	.833
1973	36	36	26	.867
1974	36	36	27	.900
1975	64	36	28	.933
1976	45	0	29	.967

SERIES	MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	COEFFICIENT OF SKEW
X	84.53	51.36	.608	1.412
LOG X	1.82056	.41560	.22828	-3.22984
LOG (X-A)	2.07439	.16378	.07895	.08036

CALCULATED MEDIAN (X SERIES) = 73.15  
PARAMETER A = -42.73

## EXTREME VALUE DISTRIBUTIONS (mm)

T	P	GUMBEL	PEARSON	LOG PEARSON	LOG NORMAL	3 PARAMETER LOG NORMAL	
1.01	99	6	16	1	7	6	49
1.05	95	22	24	10	13	21	63
1.11	90	32	31	23	19	30	73
1.25	80	45	42	47	29	43	86
2.00	50	76	73	96	66	75	118
2.33	42.92	84	81	104	78	84	127
5.00	20	117	120	118	148	120	163
10.00	10	145	152	119	225	149	192
20.00	5	171	183	120	319	177	220
50.00	2	206	223	124	472	214	257
100.00	1	231	253	131	612	242	285
1000.00	.1	316	351	199	1272	337	380
10000.00	.01	401	450	429	2325	439	482

MEAN (CHECK) = 84.69

Table 9: YMD MOULD BAY - SNOW WATER EQUIVALENTS (SWE)

YEAR	ANNUAL SWE (mm)	DESCENDING ORDER	RANK	CUMULATIVE PROBABILITY
1948	109	146	1	.033
1949	73	137	2	.067
1950	27	118	3	.100
1951	73	109	4	.133
1952	146	109	5	.167
1953	100	109	6	.200
1954	64	109	7	.233
1955	109	109	8	.267
1956	109	100	9	.300
1957	54	100	10	.333
1958	91	91	11	.367
1959	73	91	12	.400
1960	82	82	13	.433
1961	73	82	14	.467
1962	54	82	15	.500
1963	82	82	16	.533
1964	109	73	17	.567
1965	137	73	18	.600
1966	109	73	19	.633
1967	73	73	20	.667
1968	100	73	21	.700
1969	64	73	22	.733
1970	64	64	23	.767
1971	118	64	24	.800
1972	82	64	25	.833
1973	73	64	26	.867
1974	64	54	27	.900
1975	91	54	28	.933
1976	82	27	29	.967

SERIES	MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	COEFFICIENT OF SKEW
X	86.08	26.04	.302	.306
LOG X	1.91362	.14485	.07570	-1.01708
LOG (X-A)	1.77563	.22873	.12882	-2.18838

CALCULATED MEDIAN (X SERIES) = 80.47  
PARAMETER A = 20.07

## EXTREME VALUE DISTRIBUTIONS (mm)

T	P	GUMBEL	PEARSON	LOG PEARSON	LOG NORMAL	3 PARAMETER LOG NORMAL	
1.01	99	36	31	29	37	37	17
1.05	95	47	45	43	47	45	25
1.11	90	53	53	52	53	50	30
1.25	80	62	63	63	61	58	38
2.00	50	82	84	86	81	79	59
2.33	42.92	87	89	91	87	85	65
5.00	20	109	107	108	108	113	92
10.00	10	128	120	119	125	137	117
20.00	5	145	131	127	141	161	141
50.00	2	167	143	134	162	196	175
100.00	1	184	152	139	178	223	203
1000.00	.1	240	178	148	229	323	303
10000.00	.01	296	200	153	283	443	423

MEAN (CHECK) = 88.60

Table 10: YRB RESOLUTE BAY - SNOW WATER EQUIVALENTS (SWE)

YEAR	ANNUAL SWE (mm)	DESCENDING ORDER	RANK	CUMULATIVE PROBABILITY
1948	192	246	1	.033
1949	118	192	2	.067
1950	91	182	3	.100
1951	82	182	4	.133
1952	82	173	5	.167
1953	91	164	6	.200
1954	155	164	7	.233
1955	128	155	8	.267
1956	182	137	9	.300
1957	91	137	10	.333
1958	73	128	11	.367
1959	36	128	12	.400
1960	82	128	13	.433
1961	164	118	14	.467
1962	137	118	15	.500
1963	128	118	16	.533
1964	164	109	17	.567
1965	82	100	18	.600
1966	109	100	19	.633
1967	100	91	20	.667
1968	182	91	21	.700
1969	118	91	22	.733
1970	100	82	23	.767
1971	173	82	24	.800
1972	118	82	25	.833
1973	82	82	26	.867
1974	246	82	27	.900
1975	137	73	28	.933
1976	128	36	29	.967

SERIES	MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	COEFFICIENT OF SKEW
X	123.60	45.24	.366	.682
LOG X	2.06273	.16754	.08122	-.59982
LOG (X-A)	2.33596	.08733	.03739	.09502

CALCULATED MEDIAN (X SERIES) = 118.27  
 PARAMETER A = -97.45

## EXTREME VALUE DISTRIBUTIONS (mm)

T	P	GUMBEL	PEARSON	LOG PEARSON	LOG NORMAL	3 PARAMETER LOG NORMAL	
1.01	99	45	41	39	47	38	135
1.05	95	61	58	57	61	58	155
1.11	90	71	69	69	70	70	167
1.25	80	84	84	84	83	85	182
2.00	50	116	118	120	115	119	216
2.33	42.92	124	126	128	123	127	224
5.00	20	159	159	160	159	159	256
10.00	10	187	183	183	189	183	280
20.00	5	214	205	202	217	204	301
50.00	2	250	232	224	255	230	327
100.00	1	276	250	239	283	248	346
1000.00	.1	363	308	278	380	306	403
10000.00	.01	450	362	308	485	360	457

MEAN (CHECK) = 123.73

Table 11: YUS SHEPHERD BAY - SNOW WATER EQUIVALENTS (SWE)

YEAR	ANNUAL SWE (mm)	DESCENDING ORDER	RANK	CUMULATIVE PROBABILITY
1960	100	210	1	.063
1961	164	173	2	.125
1962	118	164	3	.188
1963	155	164	4	.250
1964	91	155	5	.313
1965	164	155	6	.375
1966	173	146	7	.438
1967	64	118	8	.500
1968	64	100	9	.563
1969	91	91	10	.625
1970	155	91	11	.688
1971	91	91	12	.750
1972	210	91	13	.813
1973	146	64	14	.875
1974	91	64	15	.938

SERIES	MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	COEFFICIENT OF SKEW
X	125.58	44.46	.354	.243
LOG X	2.07191	.16155	.07797	-.24343
LOG (X-A)	2.43216	.07054	.02900	.02805

CALCULATED MEDIAN (X SERIES) = 121.92  
 PARAMETER A = -148.26

## EXTREME VALUE DISTRIBUTIONS (mm)

T	P	GUMBEL	PEARSON	LOG PEARSON	LOG NORMAL	3 PARAMETER LOG NORMAL
1.01	99	48	30	46	49	37 185
1.05	95	64	55	62	63	58 207
1.11	90	74	69	72	73	71 219
1.25	80	87	87	86	86	87 235
2.00	50	118	123	119	118	122 270
2.33	42.92	125	131	128	126	130 278
5.00	20	159	162	161	161	161 310
10.00	10	187	183	188	190	184 333
20.00	5	213	201	211	217	205 353
50.00	2	248	222	241	253	229 377
100.00	1	273	236	262	280	246 394
1000.00	.1	358	278	328	372	298 446
10000.00	.01	443	314	390	470	346 494

MEAN (CHECK) = 125.82

Table 12: YYH SPENCE BAY - SNOW WATER EQUIVALENTS (SWE)

YEAR	ANNUAL SWE (mm)	DESCENDING ORDER	RANK	CUMULATIVE PROBABILITY
1952	109	173	1	.056
1953	128	164	2	.111
1954	109	128	3	.167
1955	64	128	4	.222
1956	118	128	5	.278
1957	82	118	6	.333
1958	82	118	7	.389
1959	91	109	8	.444
1960	91	109	9	.500
1961	118	109	10	.556
1962	128	91	11	.611
1963	164	91	12	.667
1964	128	91	13	.722
1965	109	82	14	.778
1966	64	82	15	.833
1967	91	64	16	.889
1968	173	64	17	.944

SERIES	MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	COEFFICIENT OF SKEW
X	109.19	30.58	.280	.547
LOG X	2.02211	.12265	.06065	-.13051
LOG (X-A)	2.63174	.03056	.01161	.37316

CALCULATED MEDIAN (X SERIES) = 109.73

ADJUSTED MEDIAN = 108.10

PARAMETER A = -320.10

## EXTREME VALUE DISTRIBUTIONS (mm)

T	P	GUMBEL	PEARSON	LOG PEARSON	LOG NORMAL	3 PARAMETER LOG NORMAL
1.01	99	56	50	53	54	43 363
1.05	95	67	64	65	66	61 381
1.11	90	73	72	72	73	71 391
1.25	80	83	83	83	82	83 403
2.00	50	104	106	105	105	108 428
2.33	42.92	109	111	111	110	113 433
5.00	20	132	133	133	133	134 454
10.00	10	151	149	150	151	148 468
20.00	5	170	163	165	167	160 480
50.00	2	193	180	184	187	174 494
100.00	1	211	192	197	202	184 504
1000.00	.1	269	228	239	251	212 532
10000.00	.01	327	260	278	300	236 556

MEAN (CHECK) = 109.24

Table 13: YTH THOMPSON - SNOW WATER EQUIVALENTS (SWE)

YEAR	ANNUAL SWE (mm)	DESCENDING ORDER	RANK	CUMULATIVE PROBABILITY
1967	151	198	1	.091
1968	198	191	2	.182
1969	158	158	3	.273
1970	92	151	4	.364
1971	145	145	5	.455
1972	191	145	6	.545
1973	138	138	7	.636
1974	138	138	8	.727
1975	105	105	9	.818
1976	145	92	10	.909

SERIES	MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	COEFFICIENT OF SKEW
X	146.61	32.62	.223	.002
LOG X	2.15591	.10133	.04700	-.56566
LOG (X-A)	2.55998	.03916	.01530	-.22025

CALCULATED MEDIAN (X SERIES) = 145.29  
 ADJUSTED MEDIAN = 145.14  
 PARAMETER A = -217.78

## EXTREME VALUE DISTRIBUTIONS (mm)

T	P	GUMBEL	PEARSON	LOG PEARSON	LOG NORMAL	3 PARAMETER LOG NORMAL	
1.01	99	86	70	75	83	76	294
1.05	95	98	92	94	97	95	313
1.11	90	106	104	105	106	105	323
1.25	80	117	119	118	117	118	336
2.00	50	141	146	146	143	145	363
2.33	42.92	143	152	152	149	151	369
5.00	20	175	174	174	174	173	391
10.00	10	197	188	189	193	189	407
20.00	5	218	200	201	210	203	421
50.00	2	245	213	215	231	219	436
100.00	1	266	222	223	246	230	447
1000.00	.1	334	247	246	294	261	479
10000.00	.01	402	268	263	341	289	507

MEDIAN (CHECK) = 146.76

TABLE 14: MAXIMIZATION TO 50-YEAR RECURRENCE VALUES OF KNOWN PEAK FLOWS BASED ON SNOW-WATER DATA

STATION NO.	NAME	YEAR	RUNOFF m <sup>3</sup> /s/km <sup>2</sup>	STATION USED	MULTIPLIERS	50-YEAR VALUES GUMBEL m <sup>3</sup> /s/km <sup>2</sup>	DRAINAGE AREA km <sup>2</sup>
10TC018	SNOWBIRD CREEK	1976	.23	YRB*	1.950	.449	61.1
10TC019	WHITEBEAR CREEK	1976	.19	YRB	1.950	.371	8.5
	HUNTING RIVER	1975	.11	YRB	1.820	.201	42.0
	THOMSON RIVER	1976	.081	YMD	2.040	.165	5,280
	THOMSON RIVER	1976	.090	YMD	2.040	.184	3,610
	CHEBYSHEV RIVER	1976	.060	YMD	2.040	.122	1,670
	EUCLID RIVER	1976	.112	YMD	2.040	.228	1,060
	GALLOIS RIVER	1976	.313	YMD	2.040	.639	221
10TC001	ALLEN RIVER	1971	.366	YRB	1.445	.529	448
10TC002	MECHAM RIVER	1970	.286	YRB	2.500	.715	97.7
		1971	.522		1.445	.754	
		1972	.491		2.119	1.040	
		1973	.327		3.049	.997	
		1974	.594		1.016	.604	
	GULLY RIVER	1972	.273	YRB	2.119	.578	22.4
		1973	.314		3.049	.957	
	(UNNAMED CREEK NORTH OF RESOLUTE AIRPORT)	1976	.34	YRB	1.953	.664	10
		1976	.25		1.953	.488	35
10TD002	UNION RIVER	1975	.024	YRB	1.825	.044	1970
		1976	.023		1.953	.045	1970
	AIRPLANE LAKE BASIN	1976	.117	YBK	1.364	.160	21.0
06JC002	THELON RIVER (BEVERLY LAKE)	1973	.0194	YWO	1.638	.032	59,100
		1976	.0266		2.187	.058	
10SB001	HAYES RIVER	1973	.054	YUS	1.700	.092	17,700
		1974	.034		2.725	.093	
		1976	.134		1.200	.161	
06LC001	KAZAN RIVER (KAZAN FALLS)	1962	.043	YBK	1.084	.047	72,300
		1966	.025		1.920	.048	
		1967	.020		3.271	.065	
		1968	.029		2.231	.065	
		1969	.022		2.817	.062	
		1970	.018		2.644	.048	
		1973	.026		3.271	.085	
		1975	.027		2.490	.067	
		1976	.021		1.364	.029	
06LA001	ENNADAI RIVER (ENNADAI LAKE)	1966	.011	YEI	1.207	.013	23,900
		1967	.009		1.708	.015	
		1968	.018		2.162	.039	
		1969	.009		2.562	.023	
		1970	.006		1.640	.010	
		1971	.005		3.171	.016	
		1972	.009		2.752	.025	
		1973	.009		1.790	.016	
		1974	.005		5.946	.030	
		1975	.007		2.281	.016	
		1976	.015		2.562	.038	
06MA002	KINGYOUK CREEK	1970	.069	YBK	2.644	.182	432
		1971	.092		4.242	.390	
		1972	.128		2.818	.361	
		1973	.118		3.271	.386	
		1974	.066		3.860	.255	
		1975	.209		2.490	.521	
		1976	.193		1.364	.260	
06MB001	QUDICH RIVER	1973	.021	YCS	3.297	.069	28,700
		1974	.039		2.439	.095	
		1975	.041		1.156	.047	
		1976	.052		2.439	.127	
06MA003	THELON RIVER (BAKER LAKE)	1973	.020	YBK	3.271	.065	153,600
		1974	.021		3.860	.081	
		1975	.017		2.490	.042	
		1976	.021		1.364	.029	

\*CODES: YRB - RESOLUTE  
YMD - MOULD BAY  
YBK - BAKER LAKE

YWO - CONTWOYT LAKE  
YUS - SHEPHERD BAY

YEI - ENNADAI LAKE  
YCS - CHESTERFIELD

Table 15: 10RC001 - BACK RIVER BELOW DEEP ROSE LAKE

DRAINAGE AREA 98,200 km<sup>2</sup> NATURAL FLOW

YEAR	ANNUAL FLOOD m <sup>3</sup> /s	DESCENDING ORDER	RANK	CUMULATIVE PROBABILITY
1965	4046	5150	1	.100
1966	3820	4244	2	.200
1967	3990	4046	3	.300
1969	5150	3990	4	.400
1970	3056	3820	5	.500
1972	2306	3056	6	.600
1973	2824	2914	7	.700
1974	2914	2824	8	.800
1975	4244	2306	9	.900

SERIES	MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	COEFFICIENT OF SKEW
X	3595.04	884.63	.246	.264
LOG X	3.54374	.10903	.03077	-.19339
LOG (X-A)	4.03696	.03506	.00869	.11066

CALCULATED MEDIAN (X SERIES) = 3820.50

ADJUSTED MEDIAN = 3559.09

PARAMETER A = -7325.03

FLOOD ESTIMATES m<sup>3</sup>/s

T	P	GUMBEL	PEARSON	LOG PEARSON	LOG NORMAL	3 PARAMETER LOG NORMAL	
1.01	99	2071	1709	1882	1950	1699	9024
1.05	95	2385	2209	2283	2314	2209	9534
1.11	90	2578	2489	2522	2534	2492	9817
1.25	80	2839	2841	2838	2830	2847	10172
2.00	50	3455	3556	3525	3497	3563	10888
2.33	42.92	3610	3717	3689	3660	3724	11049
5.00	20	4284	4326	4329	4320	4329	11654
10.00	10	4832	4750	4797	4825	4750	12075
20.00	5	5358	5113	5210	5285	5109	12434
50.00	2	6039	5534	5704	5857	5527	12852
100.00	1	6550	5823	6050	6271	5812	13137
1000.00	.1	8236	6666	7096	7597	6648	13973
10000.00	.01	9919	7400	8042	8898	7377	14702

MEAN (CHECK) = 3598.71

Table 16: 06KC003 - DUBAWNT RIVER BELOW MARJORIE LAKE

DRAINAGE AREA 67,800 km<sup>2</sup> NATURAL FLOW

YEAR	ANNUAL FLOOD m <sup>3</sup> /s	DESCENDING ORDER	RANK	CUMULATIVE PROBABILITY
1960	710	1103	1	.056
1961	741	741	2	.111
1962	1103	713	3	.167
1963	582	710	4	.222
1964	432	642	5	.278
1965	461	625	6	.333
1966	495	582	7	.389
1967	430	565	8	.444
1968	642	515	9	.500
1969	713	509	10	.556
1970	387	495	11	.611
1971	515	492	12	.667
1972	565	461	13	.722
1973	418	432	14	.778
1974	509	430	15	.838
1975	625	418	16	.889
1976	492	387	17	.944

SERIES	MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	COEFFICIENT OF SKEW
X	578.15	174.34	.302	1.792
LOG X	2.74652	.11527	.04197	.97270
LOG (X-A)	2.52345	.18201	.07213	.58760

CALCULATED MEDIAN (X SERIES) = 530.15  
 PARAMETER A = 213.54

FLOOD ESTIMATES m<sup>3</sup>/s

T	P	GUMBEL	PEARSON	LOG PEARSON	LOG NORMAL	3 PARAMETER LOG NORMAL
1.01	99	337	385	362	300	339 125
1.05	95	385	397	391	360	381 167
1.11	90	414	412	413	396	408 195
1.25	80	454	439	445	446	448 234
2.00	50	548	530	534	557	547 333
2.33	42.92	571	558	560	585	573 360
5.00	20	674	689	682	697	688 475
10.00	10	757	804	795	783	784 571
20.00	5	838	919	915	863	878 685
50.00	2	941	1072	1092	962	1002 789
100.00	1	1019	1188	1240	1034	1098 884
1000.00	.1	1276	1583	1860	1266	1432 1218
1000.00	.01	1532	1991	2745	1497	1800 1586

MEAN (CHECK) = 577.95

Table 17: 06LC001 - KAZAN RIVER AT KAZAN FALLS

DRAINAGE AREA 72,300 km<sup>2</sup> NATURAL FLOW

YEAR	ANNUAL FLOOD m <sup>3</sup> /s	DESCENDING ORDER	RANK	CUMULATIVE PROBABILITY
1962	2914	2914	1	.100
1966	1811	2085	2	.200
1967	1468	1927	3	.300
1968	2085	1893	4	.400
1969	1624	1811	5	.500
1970	1287	1624	6	.600
1973	1893	1491	7	.700
1975	1927	1468	8	.800
1976	1491	1287	9	.900

SERIES	MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	COEFFICIENT OF SKEW
X	1833.84	479.27	.261	1.488
LOG X	3.25167	.10416	.03203	.85491
LOG (X-A)	3.70558	.03905	.01054	1.25580

CALCULATED MEDIAN (X SERIES) = 1811.20  
 PARAMETER A -3261.71

FLOOD ESTIMATES m<sup>3</sup>/s

T	P	GUMBEL	PEARSON	LOG PEARSON	LOG NORMAL	3 PARAMETER LOG NORMAL	
1.01	99	1149	1220	1186	1021	856	4118
1.05	95	1286	1285	1284	1203	1116	4378
1.11	90	1370	1343	1353	1312	1262	4523
1.25	80	1485	1439	1454	1458	1444	4706
2.00	50	1754	1722	1726	1785	1815	5076
2.33	42.92	1822	1802	1802	1864	1898	5160
5.00	20	2116	2162	2148	2184	2214	5476
10.00	10	2356	2467	2458	2427	2435	5697
20.00	5	2586	2762	2780	2648	2624	5886
50.00	2	2884	3145	3235	2921	2844	6106
100.00	1	3107	3431	3607	3118	2996	6257
1000.00	.1	3844	4381	5077	3745	3441	6702
10000.00	.01	4580	5342	7023	4356	3831	7093

MEAN (CHECK) = 1835.49

Table 18: 06LA001 - KAZAN RIVER AT OUTLET, ENNADAI LAKE

DRAINAGE AREA 23,900 km<sup>2</sup> NATURAL FLOW

YEAR	ANNUAL FLOOD m <sup>3</sup> /s	DESCENDING ORDER	RANK	CUMULATIVE PROBABILITY
1966	260	365	1	.083
1967	207	365	2	.167
1968	365	260	3	.250
1969	211	224	4	.333
1970	130	218	5	.417
1971	127	211	6	.500
1972	224	207	7	.583
1973	218	169	8	.667
1974	108	130	9	.750
1975	169	127	10	.833
1976	365	108	11	.917

SERIES	MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	COEFFICIENT OF SKEW
X	217.04	86.97	.401	.704
LOG X	2.30502	.17444	.07568	.00683
LOG (X-A)	2.91556	.04466	.01532	.52825

CALCULATED MEDIAN (X SERIES) = 212.44

PARAMETER A = -610.28

FLOOD ESTIMATES m<sup>3</sup>/s

T	P	GUMBEL	PEARSON	LOG PEARSON	LOG NORMAL	3 PARAMETER LOG NORMAL	
1.01	99	77	59	79	79	37	648
1.05	95	106	93	104	104	84	695
1.11	90	123	114	120	120	111	721
1.25	80	147	142	143	143	144	755
2.00	50	202	206	201	201	213	823
2.33	42.92	216	222	217	217	228	838
5.00	20	276	285	283	283	287	897
10.00	10	326	332	337	337	329	939
20.00	5	373	375	391	390	364	975
50.00	2	434	426	461	460	406	1016
100.00	1	480	463	514	513	435	1045
1000.00	.1	632	576	701	698	520	1131
10000.00	.01	783	681	904	899	596	1206

MEAN (CHECK) = 217.36

Table 19: 06MA002 - KINGYOUK CREEK NEAR BAKER LAKE

DRAINAGE AREA 432 km<sup>2</sup> NATURAL FLOW

YEAR	ANNUAL FLOOD m <sup>3</sup> /s	DESCENDING ORDER	RANK	CUMULATIVE PROBABILITY
1970	29	90	1	.125
1971	39	83	2	.250
1972	55	55	3	.375
1973	50	50	4	.500
1974	28	39	5	.625
1975	90	29	6	.750
1976	83	28	7	.875

SERIES	MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	COEFFICIENT OF SKEW
X	53.97	24.55	.455	.620
LOG X	1.69350	.19849	.11720	.14056
LOG (X-A)	1.99986	.10164	.05082	.38412

CALCULATED MEDIAN (X SERIES) = 50.94  
 PARAMETER A = -48.41

FLOOD ESTIMATES m<sup>3</sup>/s

T	P	GUMBEL	PEARSON	LOG PEARSON	LOG NORMAL	3 PARAMETER LOG NORMAL
1.01	99	16	8	17	17	9 58
1.05	95	23	18	23	23	19 68
1.11	90	28	24	27	27	25 74
1.25	80	34	32	33	33	33 82
2.00	50	49	51	48	49	51 99
2.33	42.92	53	55	53	53	55 104
5.00	20	69	73	72	72	73 121
10.00	10	83	86	89	88	86 134
20.00	5	95	98	106	104	98 146
50.00	2	112	112	130	126	113 161
100.00	1	124	122	149	142	123 172
1000.00	.1	165	152	222	202	157 206
10000.00	.01	205	180	310	270	190 238

MEAN (CHECK) = 54.33



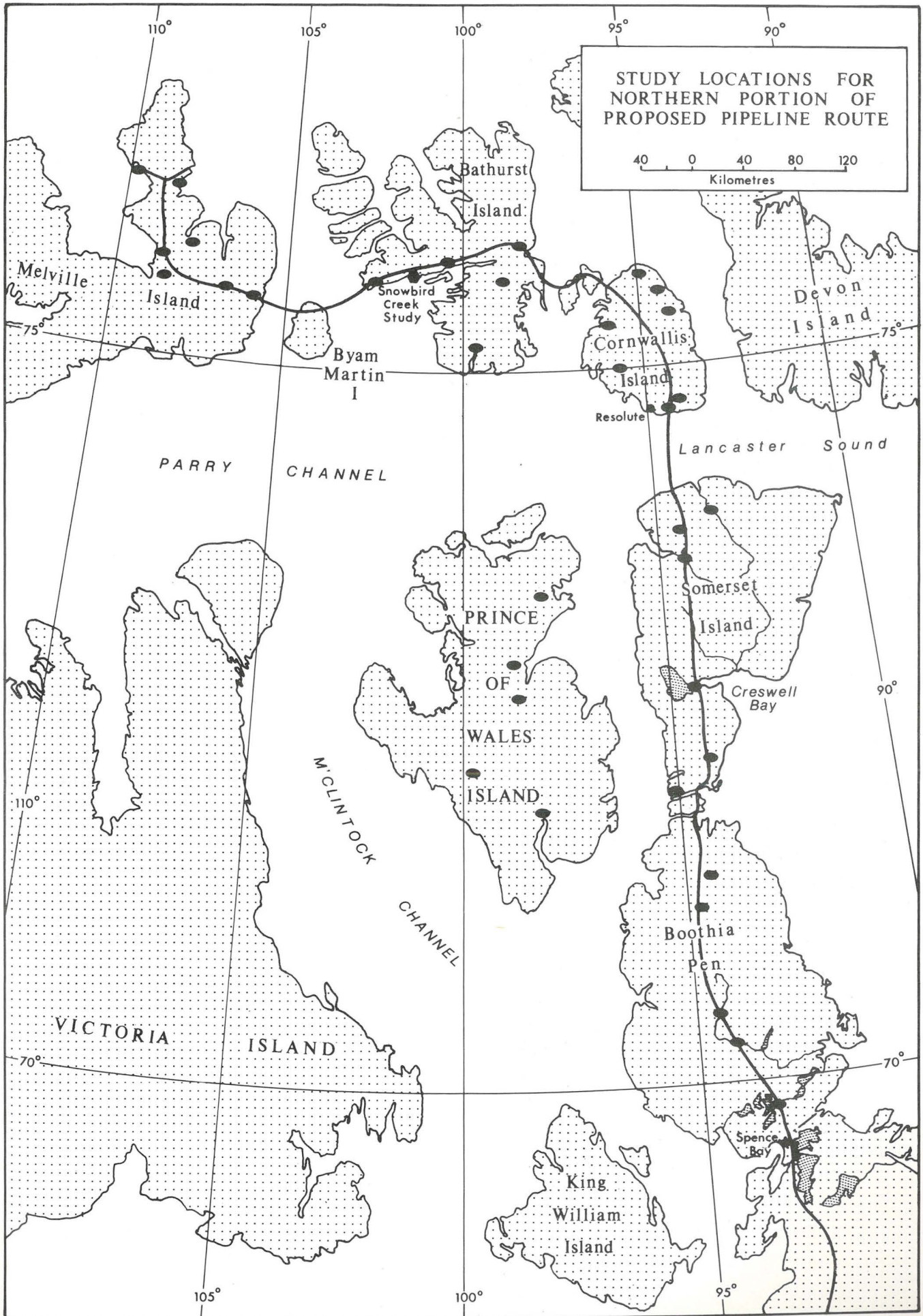


Fig. 1



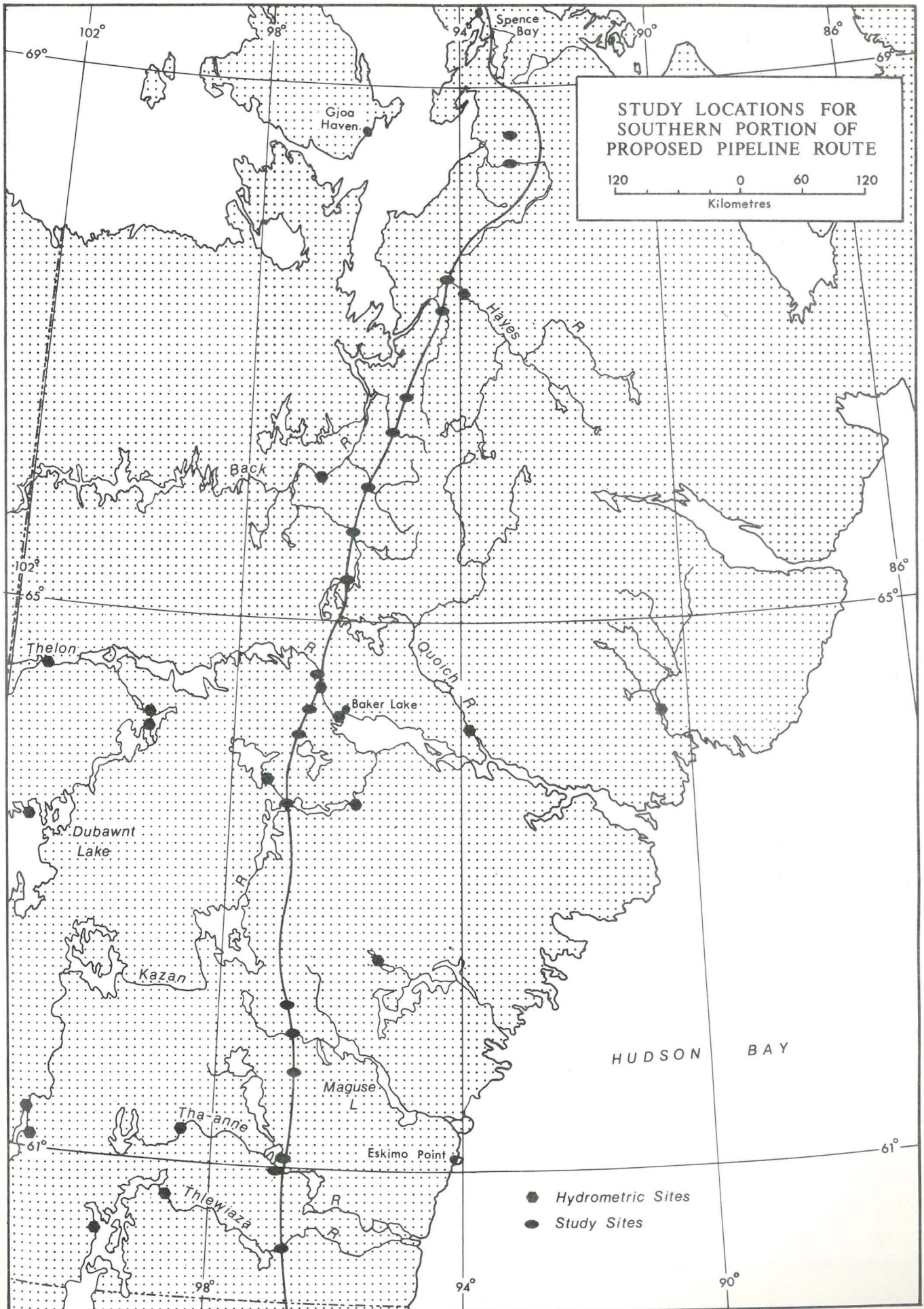


Fig. 2



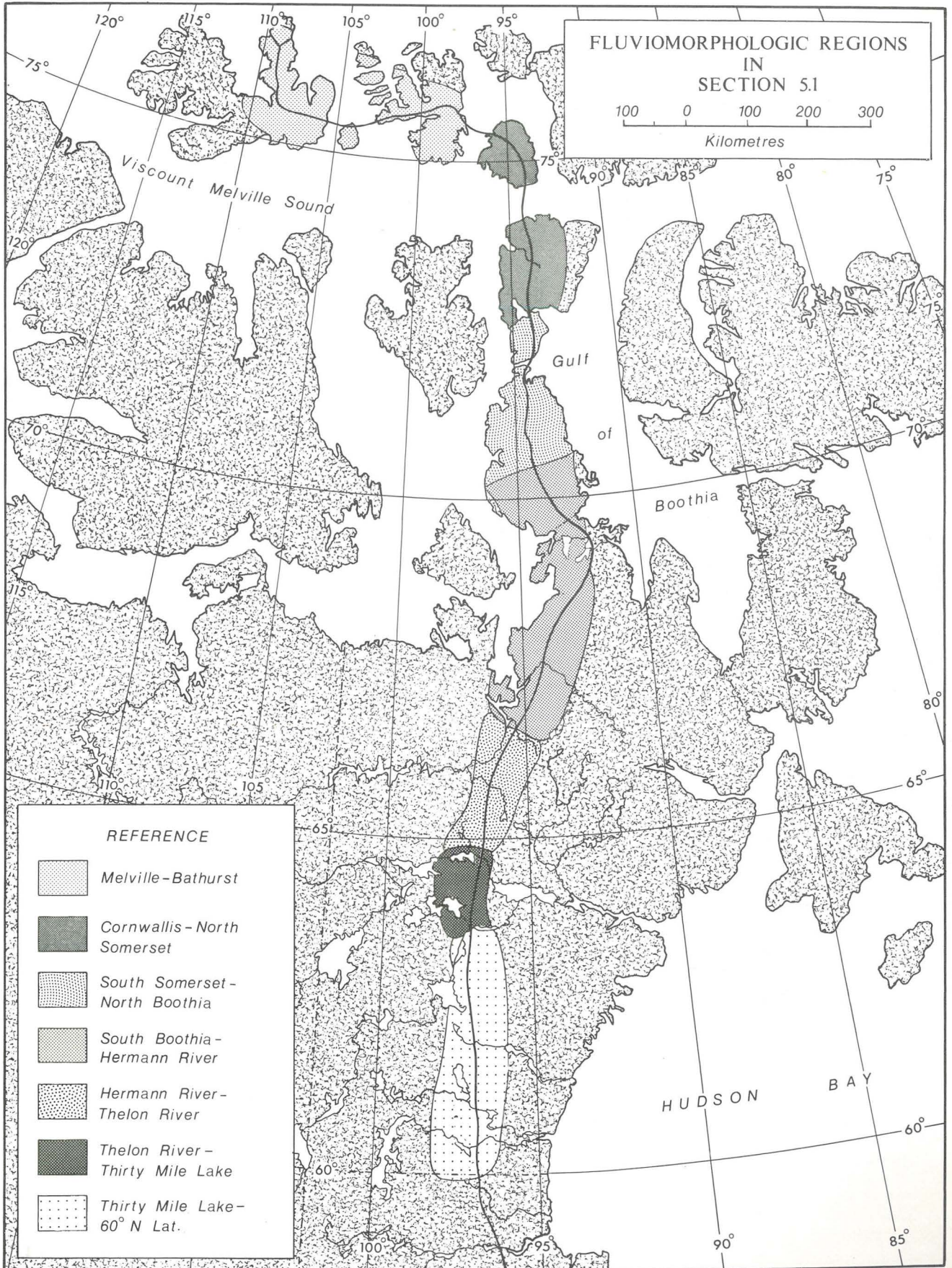


Fig. 3



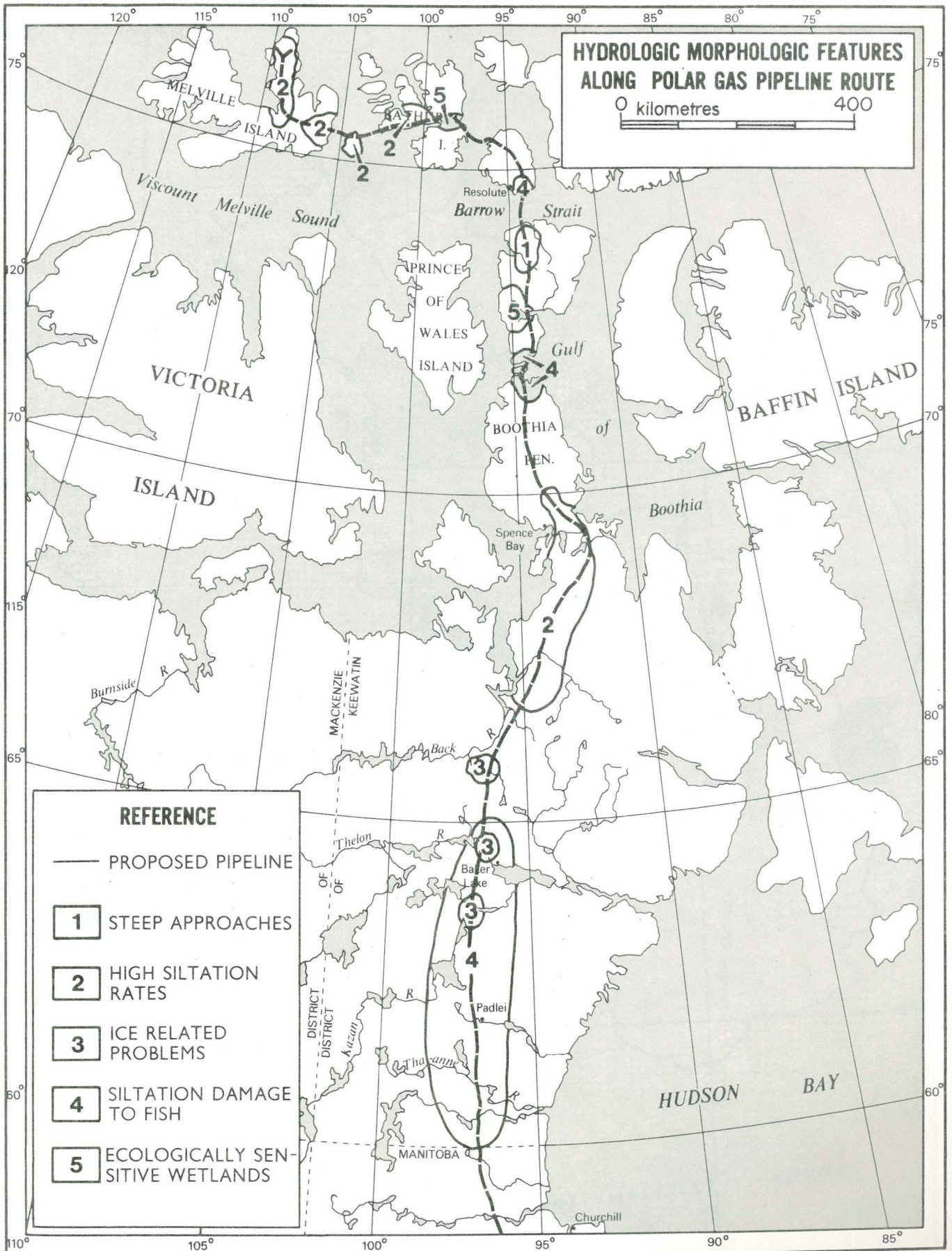


Fig. 4



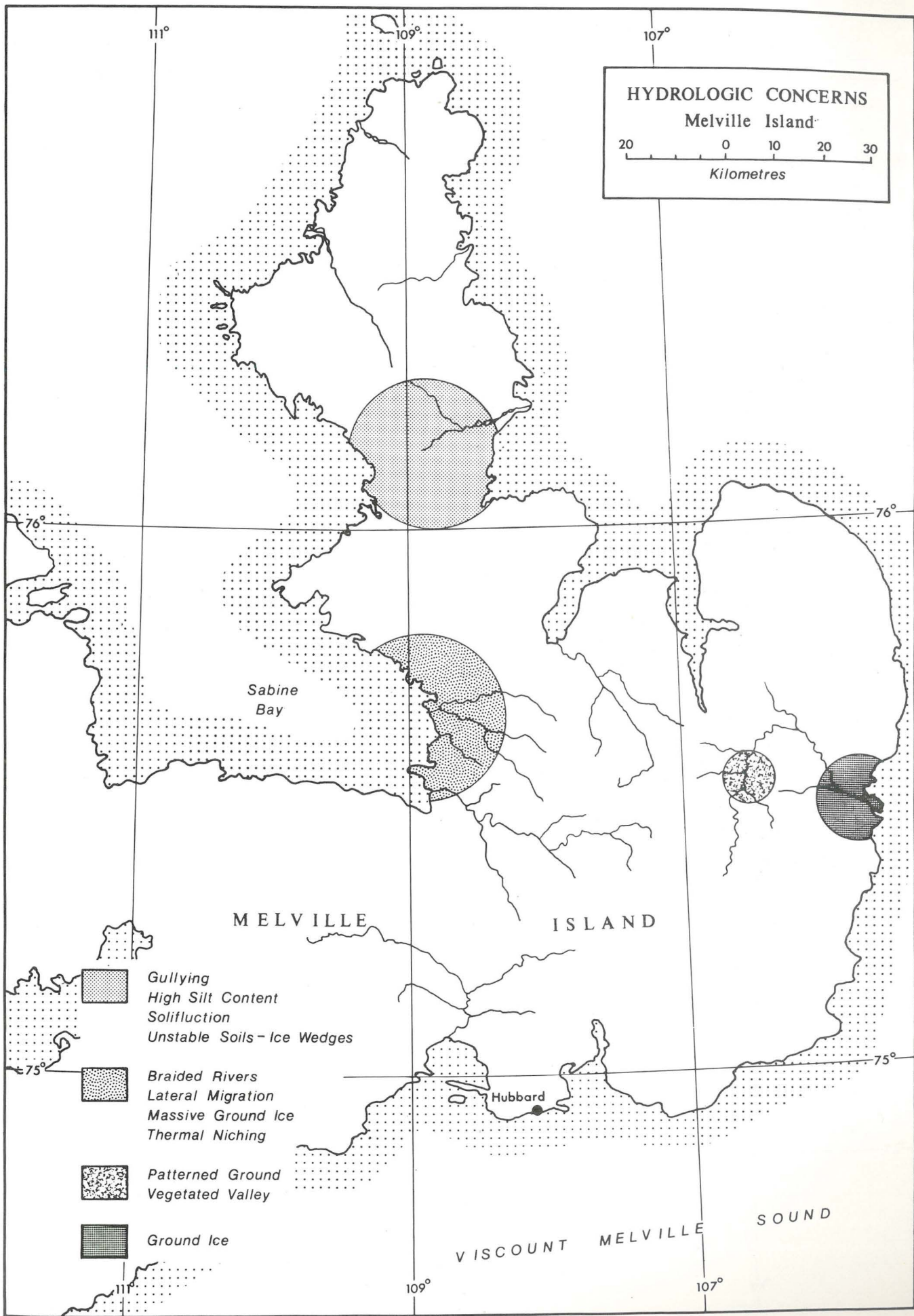


Fig. 5







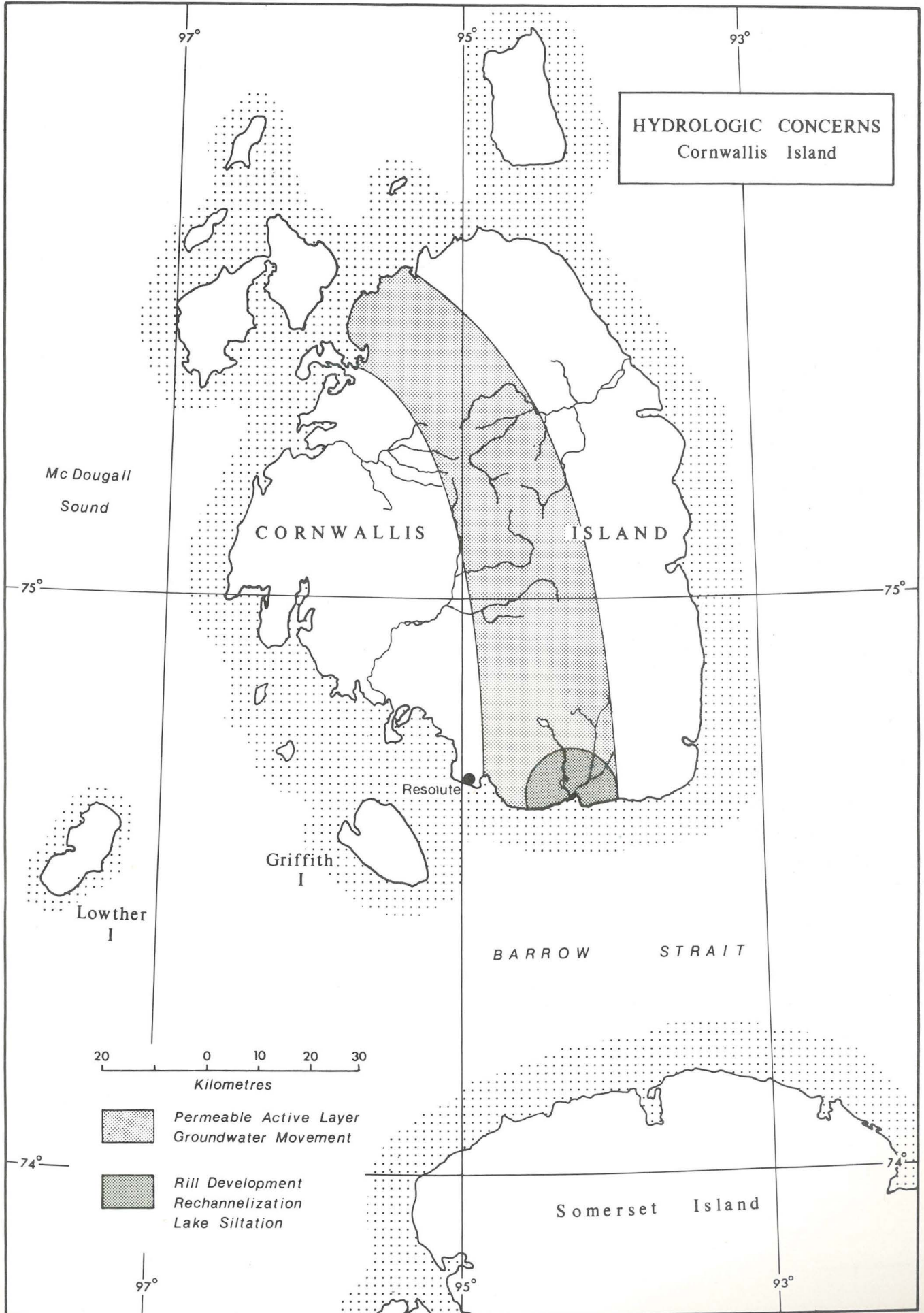


Fig. 7



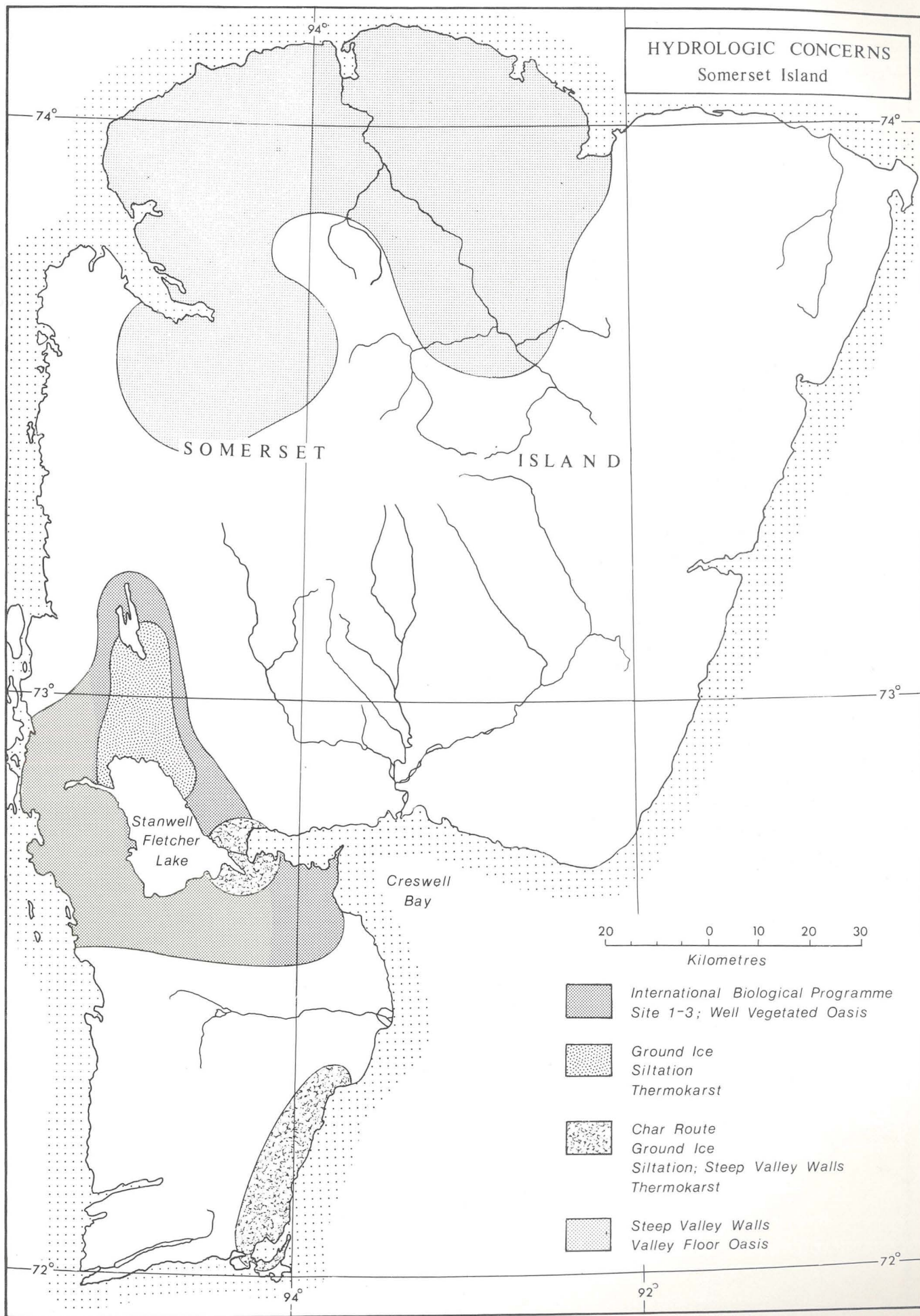


Fig. 8



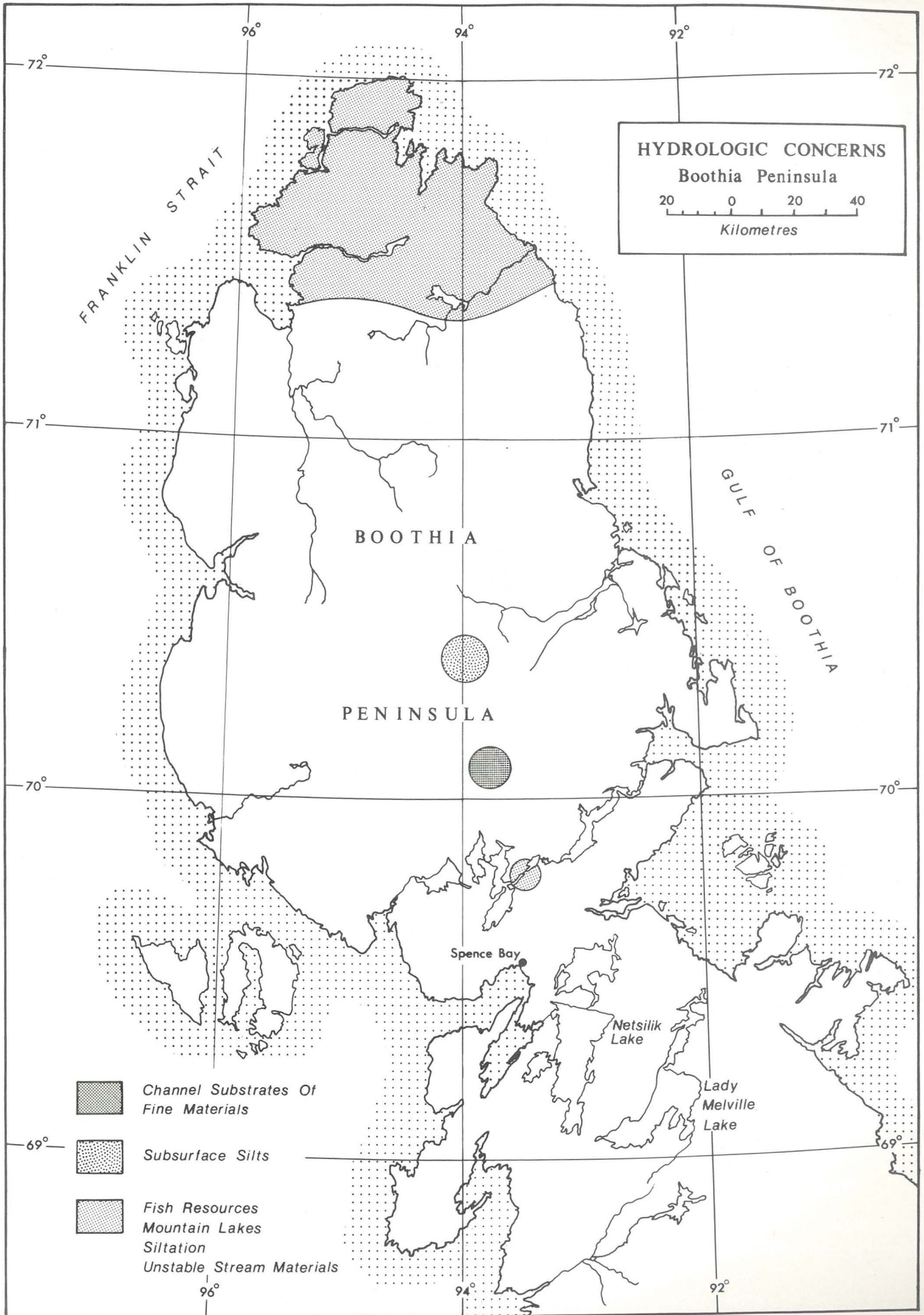


Fig. 9



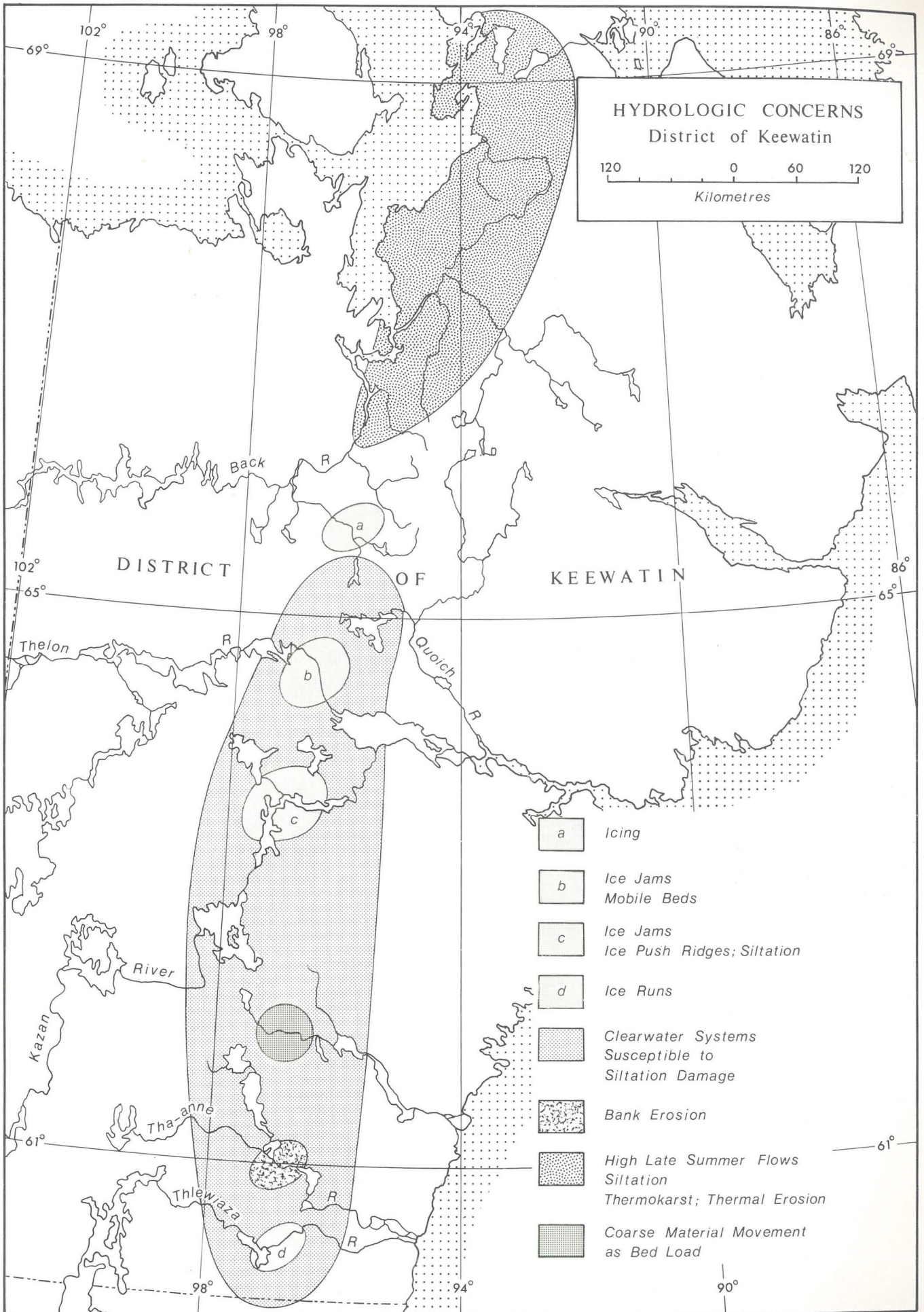


Fig. 10



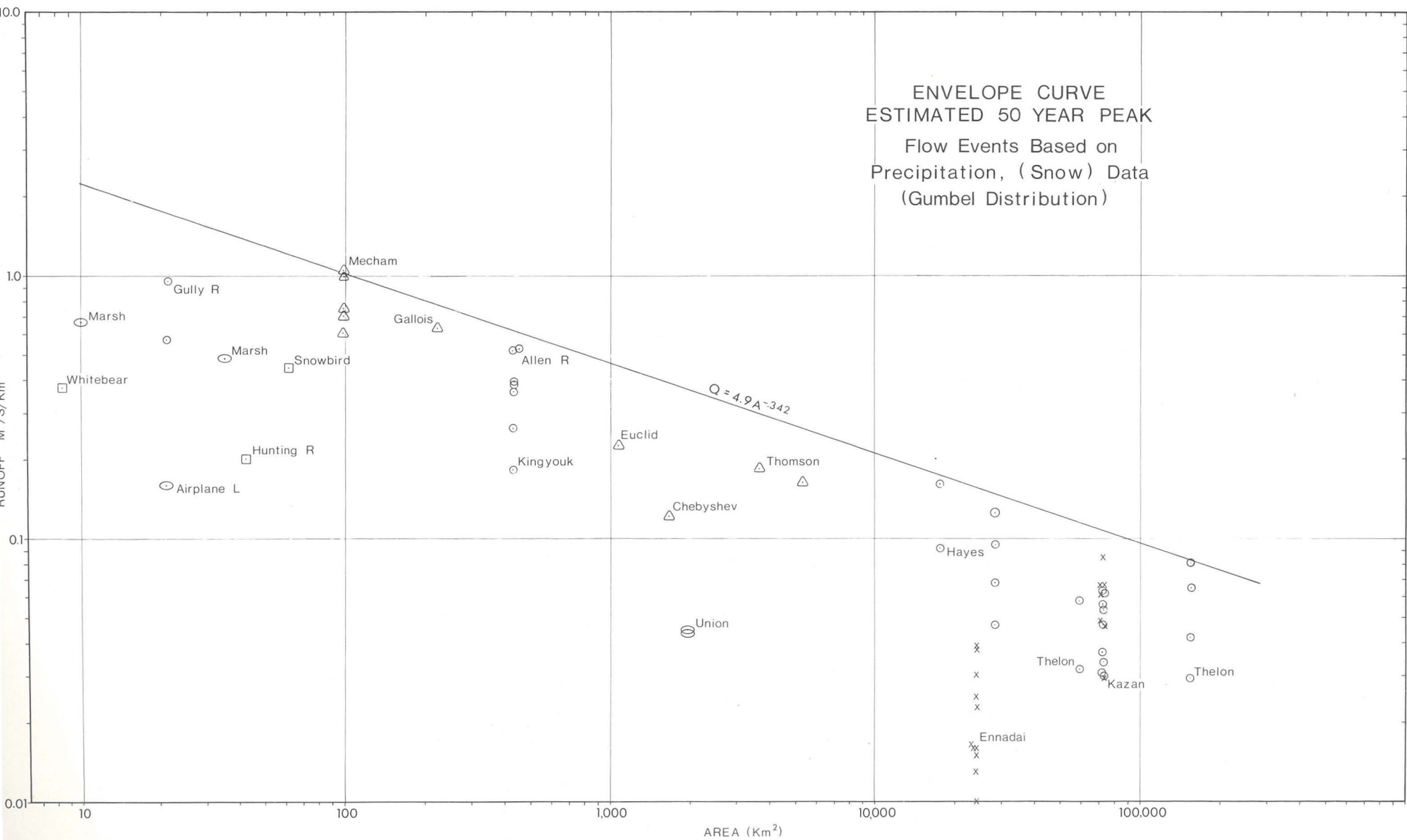


Fig. 11



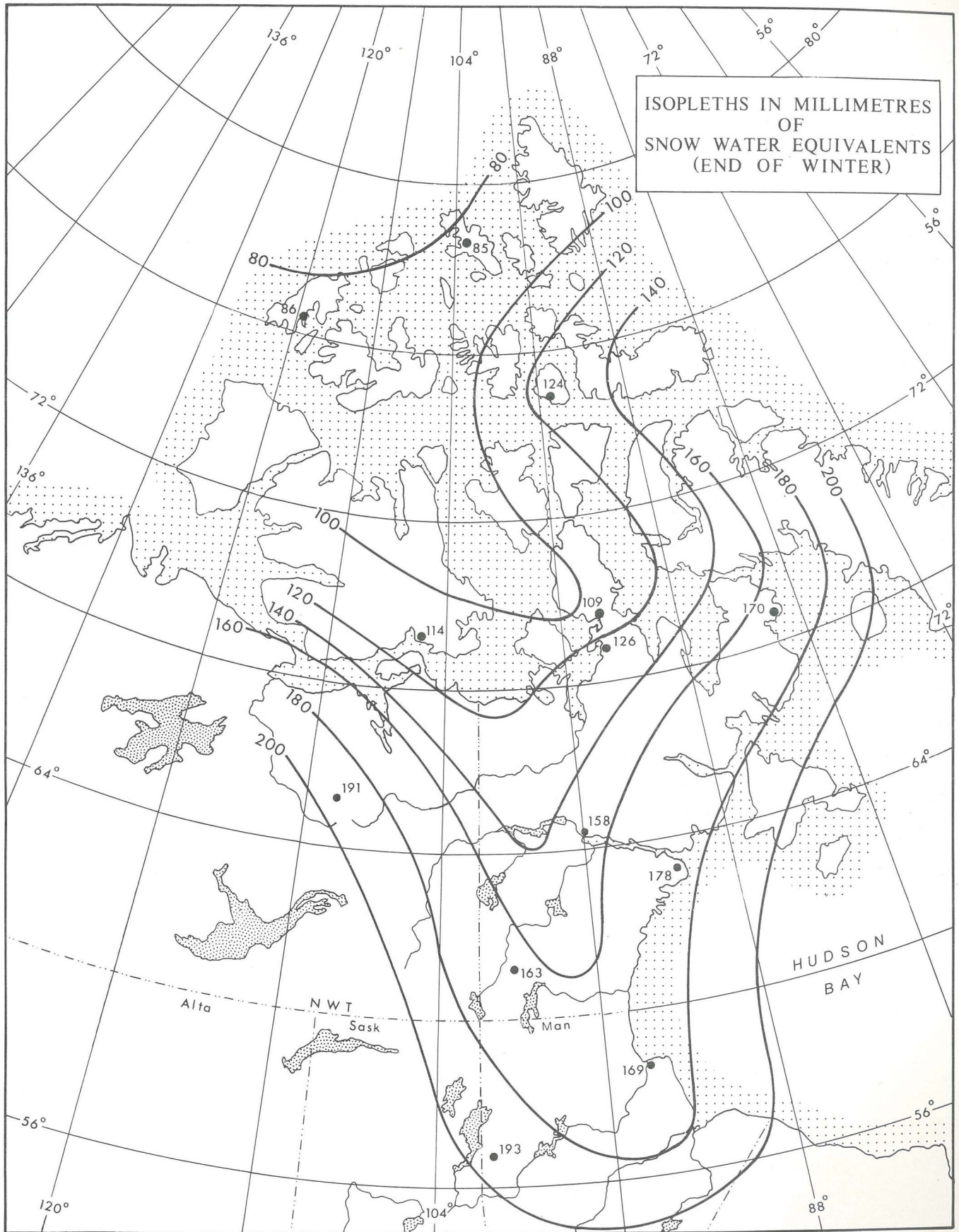
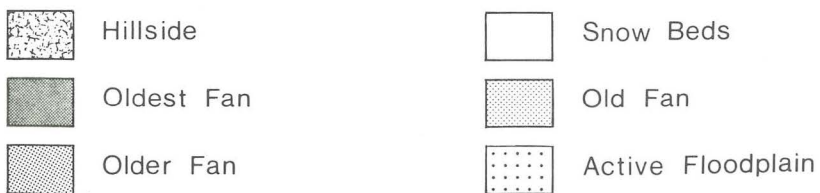


Fig. 12





*Fig. 13*



STEREOSCOPIC HEIGHTING  
Along Line P<sub>1</sub>P<sub>2</sub>  
In  
Figure 13

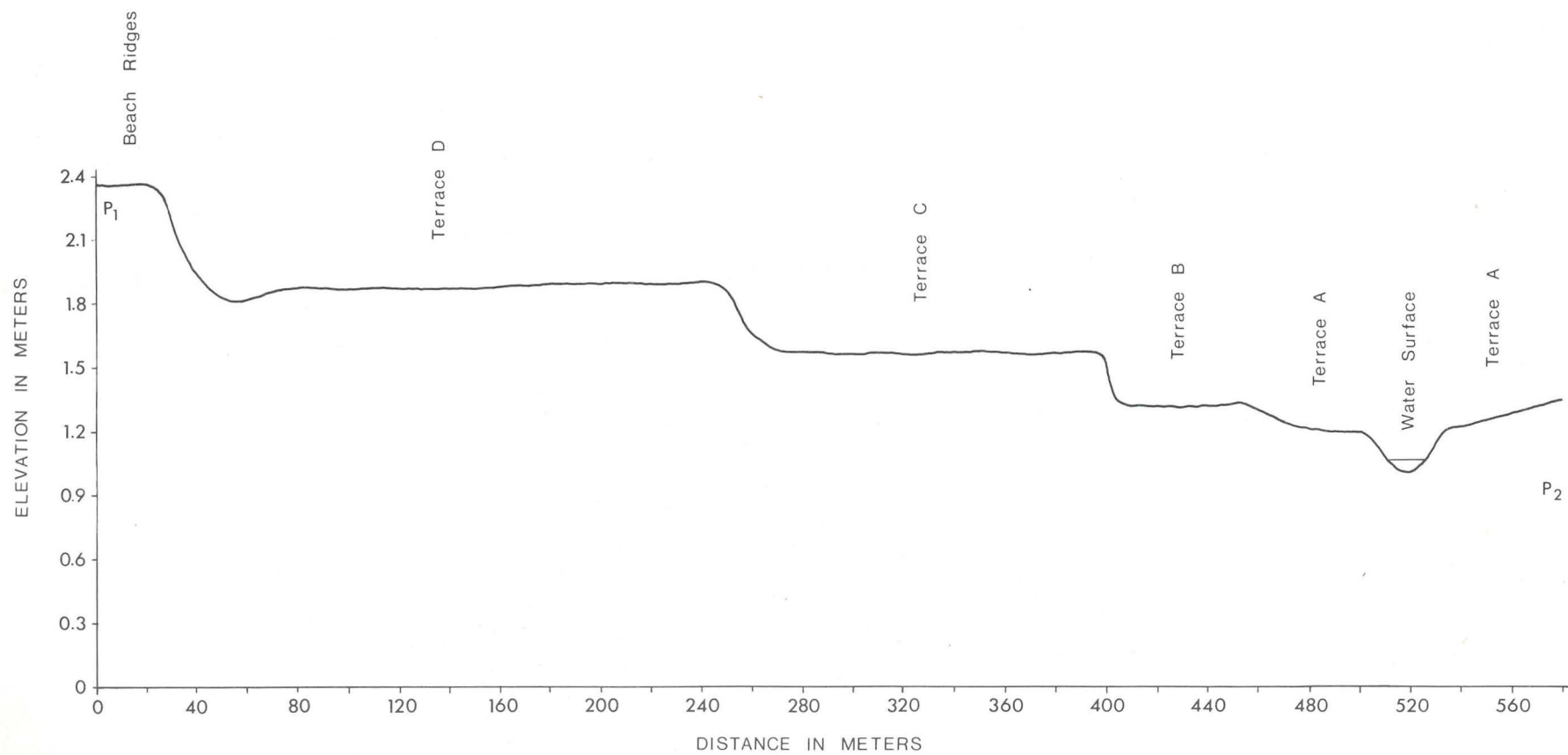


Fig. 14

Active channel bank on Pitz River, south from Baker Lake.

(Note difference in particle sizes from top of bank to bottom, also exposed sandstone bedrock in left centre.)

Lag pavement boulder bed in small watercourse in southern Keewatin.

Incised channel in carbonate bedrock on Cornwallis Island. (Allen River well below pipeline crossing.)

Thermal niching on stream in Sabine Bay region, Melville Island.

Mid-central Boothia Peninsula. (Note high gravel terrace in upper left and small ice-push ridge in lower left.)

Thermal niching on river bank within estuarine delta on Melville Island.

Gullying in silty soils on Sabine Peninsula. Veneer of gravel over uncohesive mud in river channel.

Northern Somerset: vegetated terraces within valley.

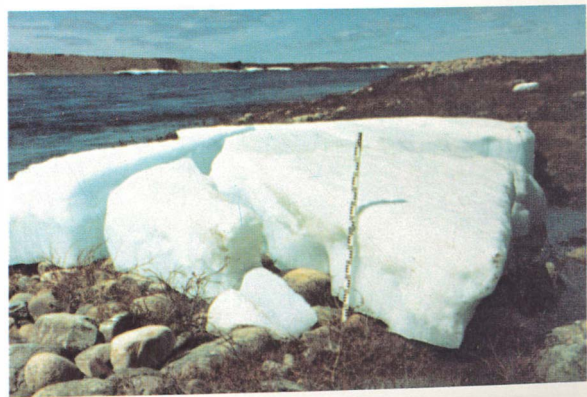
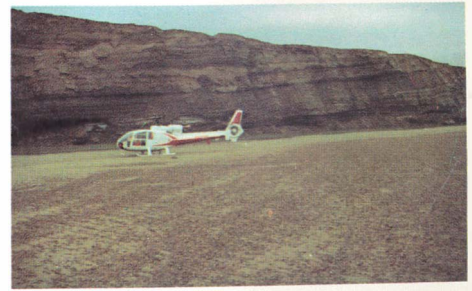
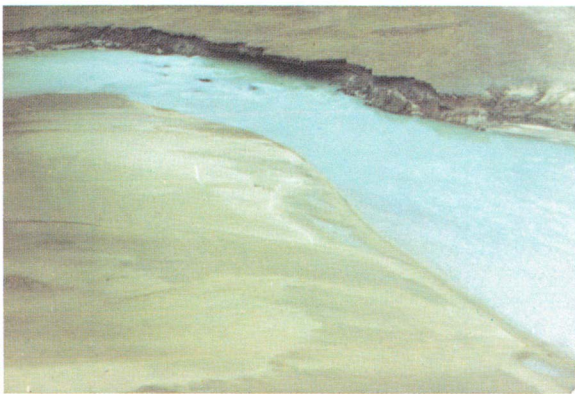
Incised channel in horizontal carbonate strata south from Stanwell-Fletcher Lake, Somerset Island. (Note headward erosion in left centre.)

Exposure of massive ground ice (just behind helicopter) in Weatherall Bay region, Melville Island.

Massive ground ice exposure from thermal niching on Melville Island. Ice exposure approximately 1m thick.

Stranded ice floe on Tha-Anne River crossing. Ice thickness approximately 0.7m.

(Note active bank on terrace in upper left.)





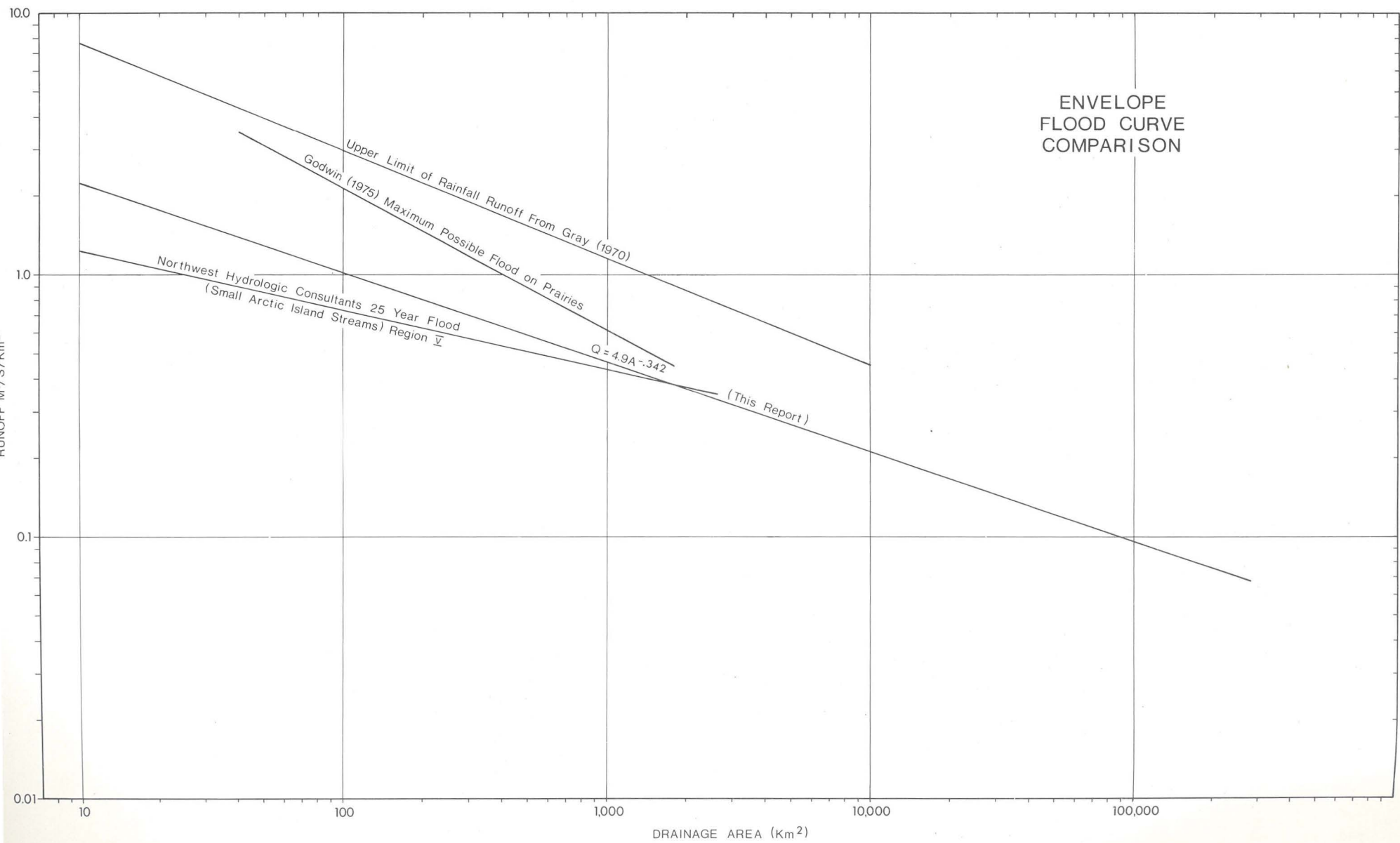


Fig. 16



## REFERENCES

- Atmospheric Environment Service 1977. *Northern climatological data for 13 selected weather stations in the central and arctic region for the period of record*. Atmospheric Environment Service, Department of Fisheries and Environment, Toronto.
- Billelo, M. 1957. "A survey of arctic snow cover properties as related to climatic conditions." *Inter. Assoc. of Sci. Hydrology, General Assembly of Toronto, 1957*, IV, pp. 63-77.
- Bird, J.B. 1972. *The natural landscapes of Canada*. Wiley, Toronto, 1972.
- Casagrande, A. 1932. "Discussion on frost heaving." *HRB Proc.*, Vol. 11, Part 1, pp. 168-172.
- Churylia, J.P. 1976. *Snowmelt runoff: Airplane Lake Basin, June 1976*. Report FP-1-76-4A to AIPP Study Board, EMS, DFE, Edmonton. Glaciology Div., IWD, DFE Ottawa.
- Cogley, J.G. 1976. *River crossings along a projected Polar Gas pipeline route, Churchill to Baker Lake*. Report No. KL 398-5-0770 to Glaciology Division, Inland Waters Directorate, DOE.
- Cogley, J.G., & McCann, S.B. 1975. "Surface runoff characteristics of an arctic nival catchment: Mecham River, Cornwallis Island." *Proceedings, Canadian Hydrology Symposium '75, Winnipeg*. National Research Council, Ottawa.
- Day, T.J. 1978. Pers. comm. from critique of this report.
- Day, T.J., & Anderson, J.C. 1976. "Observations on river ice, Thomsen River, Banks Island, District of Franklin." In *Report of Activities, Part B*. Geological Survey of Canada, EMR, Ottawa, pp. 187-196.
- Godwin, R.B. 1975. "Regionalized estimates of probable maximum floods." *Proceedings, Canadian Hydrology Symposium '75*, pp. 212-217. National Research Council, Ottawa.
- Gray, D.M., Editor-in-Chief, 1970. *Handbook on the principles of hydrology*. National Research Council, Ottawa 1970.
- Grey, B.J. 1976. *Hydrologic reconnaissance: Somerset Island, District of Franklin*. Report to AIPP Study Board, EMS, DFE, Edmonton. Glaciology Division, IWD, Environment Canada.

- Guilbault, R.A., & Chacko, V.T. 1977. *Water quality survey of Snowbird Creek basin, Bathurst Island, NWT, 1976*. Report FP-1-76-5 to AIPP Study Board, EMS, DFE, Edmonton.
- Holinshead, P. 1976. *Runoff on Little Cornwallis Island, 1974*. Unpublished report, Calgary Office, Water Survey of Canada.
- Kerr, J.W. 1974. *Geology of Bathurst Island group and Byam Martin Island, Arctic Canada*. (Operation Bathurst Island) Memoir 378, Geological Survey of Canada, EMR, Ottawa.
- Marsh, P. 1976. *A preliminary report on hydrometeorology and water balance of a small arctic basin, Cornwallis Island, NWT*. Dept. of Geography, McMaster University, Hamilton.
- Marsh, P. 1977. Pers. comm. on interflow data from Resolute study in 1977.
- McLaren, P. 1975. *Hydrology and sediment movement into Byam Channel*. Preliminary report to Geological Survey of Canada, EMR, Ottawa.
- Mercer, R.G., & Cooper, R.H. 1977. "River bed scour related to the growth of a major ice jam." *Proceedings, Third National Hydrotechnical Conference, Quebec 1977*, pp. 291-308.
- Neill, C.A. 1977. Pers. comm. on bed materials of Thelon and Kazan rivers.
- Netterville, J.A., Dyke, A.S., Thomas R.D., & Drabinsky, K.A. 1976. "Terrain inventory and quaternary geology, Somerset, Prince of Wales and adjacent islands." In *Report of activities, Part A*, pp. 145-158. Geological Survey of Canada, EMR, Ottawa, 1976.
- Nettleship, D.N., & Smith, P.A. 1975. *Ecological sites in northern Canada*. CWS, DFE, Ottawa.
- Northwest Hydraulic Consultants 1976. *River ice and flow conditions, April 1976. West Hudson Bay route*. Produced for Polar Gas, Toronto.
- Northwest Hydraulic Consultants 1976. *Surface hydrology and stream crossings, Melville Island to Longlac, Ontario*. Produced for Polar Gas, Toronto.

- Rust, B.R., & Coakley, J.P. 1970. "Physico-chemical characteristics and post-glacial desalinization of Stanwell-Fletcher Lake, Arctic Canada." *Can. Jr. of Earth Sciences*, Vol. 7, No. 3, pp. 900-911. Nat. Res. Council, Ottawa.
- School of Military Engineering lecture notes 1970. Source data from *Royal Can. Eng. Construction Handbook*.
- Sherstone, D.A. 1976. *1976 aerial photography*. Report FP-1-76-4C to AIPP Study Board, EMS, DFE, Edmonton. Glaciology Division, IWD, DFE, Ottawa.
- Steiberger, V. 1977. Pers. comm. of siltation limits and their effect on salmon migration on the Pacific and Arctic coastal rivers.
- Stockwell, C.H., McGlynn, J.C., Emslie, R.F., Sanford, B.V., Norris, A.W., Donaldson J.A., Fahrig, W.F., & Currie, K.L. 1972. "Geology of the Canadian Shield." Chapter IV in *Geology and economic minerals of Canada*. pp. 43-150. Geological Survey of Canada, EMR, Ottawa.
- Thomas, M.K., & Thompson, H.A. 1962. "Heavy rainfall in the Canadian Arctic during August, 1960." *Weatherwise*, Vol. 15, No. 4, August 1962, pp. 153-158.
- Thorsteinsson, R., & Tozer, E.T. 1972. "Geology of the arctic archipelago." Chapter X in *Geology and economic minerals of Canada*. pp. 547-590. Geological Survey of Canada, EMR, Ottawa.
- Washburn, A.L. 1973. *Periglacial processes and environments*. Edward Arnold (Publishers) Ltd.
- Water Survey of Canada, 1961-1976. *Surface water data, Yukon and Northwest Territories*. IWD, DFE, Ottawa. (Separate, annual reports for the years indicated.)
- Water Survey of Canada \_\_\_\_\_. Internal documents (R-56) listing miscellaneous discharge measurements in the Keewatin District and the District of Franklin from 1960 to 1977.
- Way, J.G., & Thorne, G.A. 1977. *Reconnaissance of Polar Gas route river crossings in Keewatin District, NWT, 1976*. Interim report to AIPP Study Group, EMS, DFE, Edmonton. Water Survey of Canada, DFE, Winnipeg

- Wedel, J.H., Thorne, G.A., & Baracos, P.C. 1977. *Site-intensive hydrologic study of a small catchment on Bathurst Island, 1976*. Water Survey of Canada, Winnipeg. Report FP-1-76-1 to AIPP Study Board, EMS, DFE, Edmonton.
- Wedel, J.H., & Way, J.G. 1976. *Interim report (1975): Hydrologic regimes, Freshwater project no. 1 - Eastern Arctic Islands pipeline project: Spence Bay to Sabine Peninsula*. Report to AIPP Study Board, EMS, DFE. Edmonton.
- Wilson, A.R. 1977. *Nanasivik report: Hydrology - Twin Lakes, 1977*. Unpublished report, Calgary District, Water Survey of Canada.
- Woo & Marsh 1977. "Determination of snow storage for small eastern High Arctic basins." *Proceedings of 34th Eastern Snow Conference, February 1977, Belleville, Ontario*.
- Woo, V. & Zoltai, S.C. 1976. *Soils and vegetation of Somerset and Prince of Wales islands, NWT*. Interim report to AIPP Study Group, EMS, DFE, Edmonton.