5 HYDROLOGY

5.1 Introduction

This section presents a summary of baseline hydrologic information compiled from the literature and derived from available data and field measurements. The study area includes the Mackenzie Delta and the Mackenzie Valley. The hydrology of the study area covers its surface water features, including lakes, rivers, ponds, streams and the Beaufort Sea.

5.1.1 Environmental Setting

Figure 5-1 shows the drainage area of the Mackenzie River, which extends from the headwaters of the Finlay River in British Columbia to the Arctic coast. The predominant surface water features that might be affected by the project are the Mackenzie Delta and the Mackenzie River.

5.1.1.1 Mackenzie Delta

The Mackenzie Delta is the largest delta in Canada, extending about 200 km from Point Separation in the south to the Beaufort Sea in the north. It is bounded on the west by the Richardson Mountains and on the east by higher grounds of the delta. Over 25% of the delta area is covered by water. Most water in the Mackenzie Delta originates from the Mackenzie River. However, the Peel River on the west side of the delta is also a major contributor.

5.1.1.2 Mackenzie River

The Mackenzie River is the longest drainage system in Canada, flowing about 4,200 km from the headwaters of the Finlay River in British Columbia to the Arctic coast. The Mackenzie River drains about 1.8 million km^2 and its basin covers nearly 20% of Canada’s total surface area. The streams in the Mackenzie Valley have a relatively brief but dominant spring snowmelt in late May and early June, with flow decreasing slowly over the summer to late fall. The spring flood is normally the dominant event of both large and small rivers, though the smaller rivers are also likely to experience floods after intense summer rainfall. Downstream ice jamming and backwater effects from the Mackenzie River can often cause peak water levels.

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5.1.2 Baseline Study Objective

The objective of the baseline hydrology study was to establish the hydrologic conditions in the study area to support assessing the environmental effects of the project on hydrologic resources and aquatic habitats. The following baseline hydrologic information was determined:

- watercourse flow characteristics, such as ephemeral, intermittent and perennial flow
- flow and flow variations, including annual, seasonal and peak flow and winter low flow
- ice conditions
- stream morphology

5.2 Methods

Figure 5-2 shows the approach used for the baseline hydrology study.

5.2.1 Study Areas

The baseline hydrology study area was designed to encompass the local study areas (LSAs) and regional study areas (RSAs) for the hydrologic assessment of the effects of the project. The LSA is defined as an area within which the potential effects of the project, if any, are most likely to be observable. The RSAs represent larger watersheds outside which no effects from the project are expected. Details of the LSAs and RSAs for specific project components are provided in Volume 5 Section 5, Hydrology. The following figures show the project components and some of the watercourses and lakes in the Mackenzie River basin:

- Figure 5-3: Watercourses, Lakes and Project Components – North
- Figure 5-4: Watercourses, Lakes and Project Components – Central
- Figure 5-5: Watercourses, Lakes and Project Components – South

Section 5.3, Regional Baseline Conditions, describes the hydrology study areas used to determine baseline hydrologic conditions. These hydrologic regions are larger than the LSAs and RSAs because the available hydrologic data from the literature is for watersheds that might not be affected by the project.

The production area for the project includes the three anchor fields, Niglintgak, Taglu and Parsons Lake, the gathering pipelines and the Inuvik area facility. The pipeline corridor extends from Inuvik to the NOVA Gas Transmission Ltd. (NGTL) interconnect facility.

Field studies were designed to collect data in the LSAs. Data available from the literature and from project-specific field studies was then analyzed to characterize the baseline hydrologic conditions within the RSAs and the LSAs.

5.2.2 Sources of Available Hydrologic Information

Air temperature, precipitation and evaporation are the three most important climate parameters determining the hydrologic characteristics of a watershed or waterbody. Their seasonality and annual variability provide valuable indicators of stream flow variability and seasonality, especially in cases where stream flow data is not available or is only available for short periods of record. A literature review and data search was done to identify data and information related to these three climate parameters in the production area and pipeline corridor.

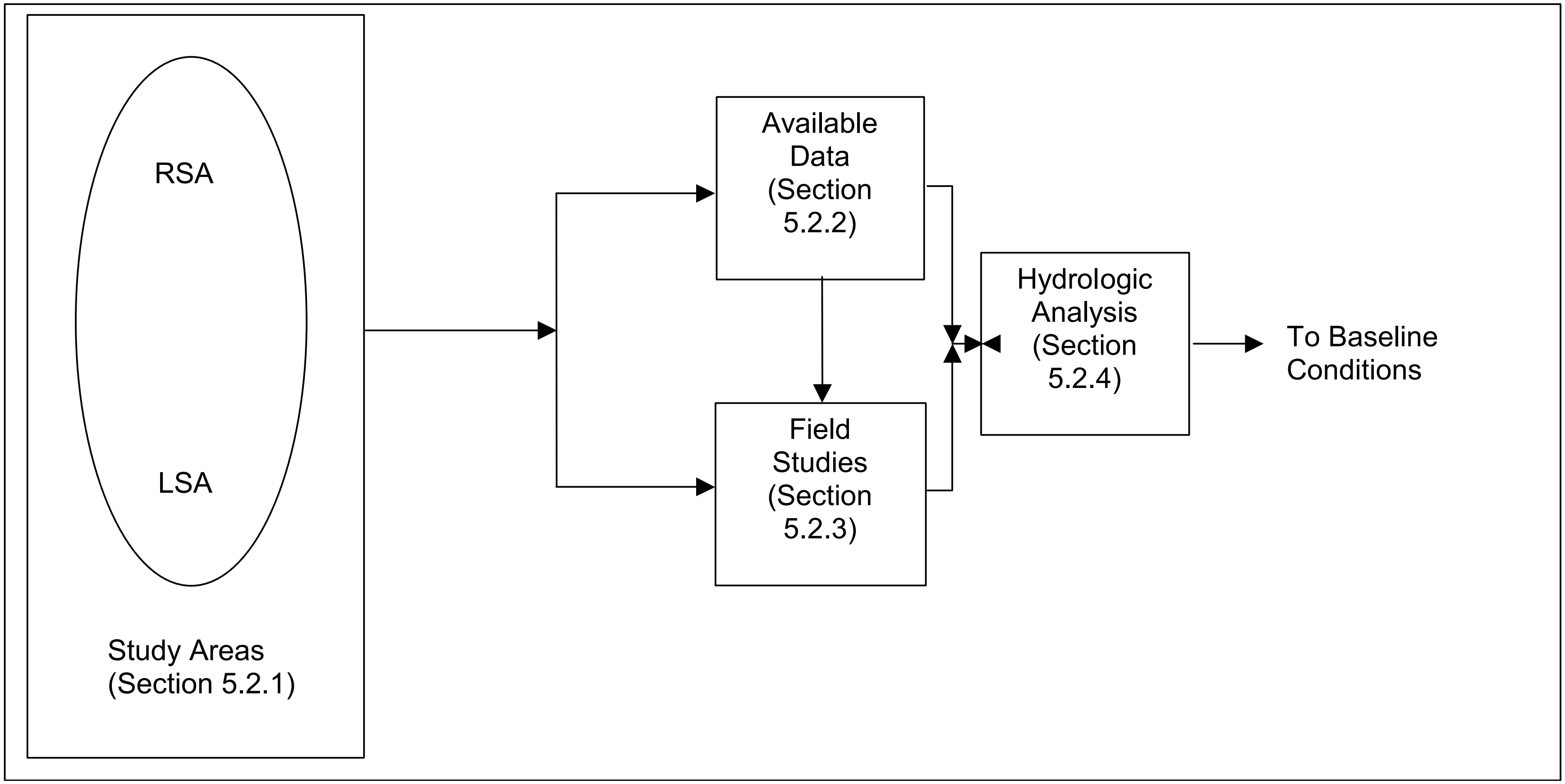

Figure 5-2: Method for Hydrology Baseline Study

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Figure 5.5 has been removed for the purposes of reducing file size and can be viewed as a graphic separately. This document can be accessed through the link in the Table of Contents reference web page.

5.2.2.1 Climate

Climate information was gathered from climate stations operated by the Meteorological Service Division of Environment Canada (Environment Canada 2000, 2002a, 2002b, 2002c) and from two additional upper air stations at Inuvik and Norman Wells. Table 5-1 identifies the Environment Canada climate stations in the production area and along the pipeline corridor, locations of these stations and available climate information. Climate normals are shown for seven stations in the area.

Table 5-1: Climate Station Attributes and Type of Available Data

Climate Station Name	Climate Station Number	Location		Elevation (m)	Climate Normals	Monthly Temperature	Monthly Precipitation	Monthly Evaporation 1971–2000
		Latitude (N)	Longitude (W)					
Tuktoyaktuk	2203910	69° 7'	133° 0'	18	●	●	●	–
Inuvik A	2202570	68° 18'	133° 28'	68	●	●	●	●[1]
Aklavik A	2200100	68° 13'	135° 00'	6	–	●	●	–
Little Chicago	220B6Q3	67° 11'	130° 14'	63	–	●[2]	–	–
Fort Good Hope A	2201400	66° 16´	128° 37´	52	●	●	●	–
Norman Wells A	2202800	65° 17'	126° 48'	74	●	●	●	●[3]
Tulita A	2201700	64° 55'	125° 34'	101	–	●	●	–
Wrigley A	2204000	63° 13'	123° 26'	150	●	●	●	–
Fort Simpson A	2202101	61° 46'	121° 14'	169	●	●	●	–
Trout Lake	220CQHR	60° 26'	121° 14'	498	–	●[4]	–	–
High Level A	3073146	58° 37'	117° 09'	338	●	●	●	–
Upper Air Stations								
Inuvik UA	2202582	68° 19'	133° 31'	103	–	–	–	●[1]
Norman Wells UA	2202816	65° 17'	126° 45'	94	–	–	–	●[3]

NOTES:
A =airport climate station
UA = upper air climate station
● = available data
– = data unavailable
1 Evaporation amounts derived from available air temperature, dew point temperature and solar radiation data from stations 2202570 and 2202582 using the Morton Lake evaporation method (Morton et al. 1985).
2 Partial record from 1996 to 2002
3 Evaporation pan was moved from Station 2202800 to 2202816 in 1985. As statistical tests showed no significant difference, evaporation data from the two stations was combined.
4 Partial record from 1998 to 2002

SOURCE: Environment Canada (2002a)

5.2.2.2 Stream Flow

Environment Canada maintains a network of hydrometric stations in the Mackenzie River basin. These stations provide a database of relatively long-term water level and flow records that can be used to characterize hydrologic conditions. Stream flow and water level data to the end of 2000 is published on the Hydat CD (Environment Canada 2002d) and was updated to the end of 2001 for stations currently operating.

Recent analyses of stream flow data by Indian and Northern Affairs Canada (INAC) for the Gwich'in and Sahtu Settlement Areas (Kokelj 2001) and Deh Cho Region (Faria 2002) were restricted to analysis of at-station data and did not address regional conditions. Hydrologic data related to pipeline projects between Norman Wells and the Mackenzie Delta was reviewed for INAC (HBT AGRA Limited 1992).

5.2.3 Field Studies

Hydrology field studies in 2001, 2002 and 2003 included:

- aquatics reconnaissance survey
- winter low flow and ice survey
- spring breakup and flood survey
- channel slope and transect survey
- hydrometric monitoring program

5.2.3.1 Aquatics Reconnaissance Survey

Visual observations were made at each watercourse crossing along the pipeline route during the aquatic resources reconnaissance surveys in 2001, 2002 and 2003. About 80 watercourses in the production area and 500 watercourses along the pipeline corridor were surveyed. The purpose of the survey was to identify stream features that are considered important for fish habitat and hydrologic assessment. Digital photographs were taken of the upstream and downstream views at each crossing. Additional photographs were taken to document banks, substrate and other features that could affect fish habitat or drainage.

5.2.3.2 Winter Low Flow and Ice Surveys

The purpose of the winter low flow and ice surveys was to document stream flow conditions under river ice. The surveys were done in April 2002 and 2003, as part of the fisheries overwintering studies.

Site selection for the surveys was based on stream size, i.e., width, depth, and topography as documented during the reconnaissance surveys. Within a given hydrologic region, the sample streams were assumed to be representative of streams from various basin sizes, slopes and drainage characteristics in that region. Nine sites were visited in the Gwich'in Settlement Area, 17 in the Sahtu Settlement Area, 19 in the Deh Cho Region and 11 in northwestern Alberta.

The surveys included ground reconnaissance and measurement of flow characteristics. Flow, ice conditions, channel widths and surface icing were noted. For stream widths of less than about 15 m, a single hole was bored in the stream channel using an auger. On larger streams, as many as four holes were bored. The plan forms of channels, bank erosion locations, and typical cross-section shapes were assessed visually to locate the deepest areas of the flow paths. The information collected was used to estimate flow during winter.

5.2.3.3 Spring Breakup and Flood Surveys

In early June 2002, aerial observations of floods on streams along the entire length of the proposed pipeline route were carried out. The streams surveyed were among the watercourses identified during the reconnaissance and winter field studies as having discernible banks and substrate.

In addition to the flood survey, a reconnaissance-level survey of spring breakup in the Niglintgak and Taglu areas was done during June 2002. A more extensive survey was also done during late May and early June 2003. The surveys involved aerial observations and documenting:

- ice conditions
- the progression of breakup
- evidence of thermal and dynamic breakup processes

Sediment Deposition

To gain a better understanding of sedimentation rates along the channels, sediment plates were installed during the spring breakup survey in 2003 to measure the amount of sediment deposited along channel banks. Three sets of three sediment plates were installed in the Niglintgak and Taglu areas. Deposited sediment was collected for analysis at the end of the spring program. Temporary and short-term benchmarks were used to measure the changes in elevation of the sediment plates.

Spring Discharge Measurements

To characterize the flood flow distribution among the various channels at near-peak and post-peak water levels, ground surveys at Niglintgak and Taglu in June 2003 included monitoring water levels and measuring discharge at near-peak and post-peak flow conditions.

5.2.3.4 Channel Slope and Transect Survey

In August and September 2002 and 2003, channel slope and transect data was collected at three transects on most watercourses where detailed aquatics surveys had been done because of the presence of fish habitat. The purpose of the surveys was to determine the geometric and morphologic characteristics of the reach to assist in the hydrologic and fish habitat assessment. The transects were:

- at the proposed crossing location
- upstream from the crossing
- downstream from the crossing

The transects were at least 50 m apart and were surveyed from bankfull to bankfull elevations on small and medium-sized streams. Discharge was also measured at one of the transects.

5.2.3.5 Hydrometric Monitoring Program

Limited historical flow data is available for small to medium-sized basins, i.e., basins smaller than 500 km^2, along the proposed pipeline route. Most hydrometric stations maintained by the Meteorological Service Division are for larger drainage areas. The purpose of the hydrometric monitoring program was to provide information on the hydrologic characteristics of small watersheds.

Table 5-2 lists the small basins where hydrometric monitoring was done from June to September 2002 to record seasonal flow conditions. The monitoring program was limited to the open-water season, i.e., June to September, because drainage basins in the Mackenzie Valley region are frozen ice in the winter.

Table 5-2: Short-Term Hydrometric Station Network

Corresponding Crossing ID	Watercourse Name	Location	Drainage Area[1] (km^2)
Not available	Holmes Creek	Inuvialuit Settlement Region	400
RPR-075	Unnamed stream	Gwich'in Settlement Area	71
RPR-097	Travaillant River	Gwich'in Settlement Area	274
RPR-261	South Snafu Creek	Sahtu Settlement Area	148
RPR-301	Bosworth Creek	Sahtu Settlement Area	116
RPR-371	Steep Creek	Sahtu Settlement Area	148
RPR-477	Jean-Marie Creek	Deh Cho Region	105
RPR-487	Unnamed stream	Deh Cho Region	60

NOTE:
1 Station locations are close to but not necessarily coincident with crossing locations so drainage areas above the stations are not equal to drainage areas above the crossing locations.

A sequence of flow for the 2002 recording period was derived for each stream using data recorded at each site. The hydrograph covers mid-June to mid-September, when the hydrometric stations were active.

During the 2003 spring breakup survey, two water level monitoring stations were installed, one on Kuluarpak Channel near the existing D-43 gravel pad at Taglu and the other on the Beaufort Coast at the outlet of Kumak Channel, about 10 km downstream from Niglintgak. Both stations were removed in the fall of 2003. The purpose of these stations was to gather data to understand water level fluctuations in the channels in the production area and to assess the effects of the project.

5.2.4 Hydrologic Analysis

5.2.4.1 Regional Hydrology

Regional hydrology analysis distinguishes regions within which hydrologic conditions tend to be similar, but different from region to region. Regional hydrologic characteristics, combined with results from field studies, were used to estimate hydrologic conditions at streams for which there are no site-specific data. The regional hydrologic analysis included five main elements:

- climate and stream flow analysis
- sediment analysis
- stream classification
- geomorphic assessment
- hydrologic and storm surge analysis for the delta

The hydrologic regions were established following a review and analysis of factors that govern hydrologic response factors such as:

- climate
- physiography
- soils
- vegetation
- aspect
- elevation
- slopes
- wetland areas
- lake areas
- stream order

Annual and seasonal climate data was used to delineate distinct hydrologic regions in the production area and along the pipeline corridor. Recorded annual and monthly stream flow and extreme peak and low flow were evaluated for each region. The available data could support only a coarse hydrologic regionalization.

Four hydrologic regions were established (see Figure 5-6) from the production area at the Beaufort Sea to northwestern Alberta:

- delta region – Mackenzie Delta to Inuvik
- northern region – Inuvik to the north end of the Franklin Mountains
- central region – Franklin Mountains to Ebbutt Hills
- southern region – Ebbutt Hills to northwestern Alberta

5.2.4.2 Stream Flow

Hydrometric information, available for the stations shown in Figure 5-6, was used to characterize the hydrologic regimes of gauged streams. Annual, seasonal, peak and low flow of ungauged streams was estimated based on basin characteristics, such as size, slope and amount of upland storage. Mean discharges were based on the annual record, where available, or on the seasonal record where the annual record was not available. Peak and low flow frequency analyses were done for each hydrologic region to characterize regional flow conditions. Following review and analysis of the available information, the appropriate stations for defining hydrologic regions were determined.

5.2.4.3 Sediment

The amount of sediment reaching the Mackenzie Delta is influenced by the amount of sediment generated in tributary sub-basins and carried along the Mackenzie River. Bank erosion, landslides and general alluvial processes contribute to the amount of sediment transported into the delta. Most of the sediment information for the Mackenzie Delta was acquired, analyzed and synthesized during an Environment Canada and Northern Oil and Gas Action program carried out from 1991 to 1994 (see Section 5.3.5, Sediment Conditions).

5.2.4.4 Stream Classification

A stream classification system was developed to describe the drainage and flow characteristics of the many watercourses that would be crossed by the proposed pipeline. The classification involved the following steps:

1. Determining the drainage area, basin slope and channel slope for each watercourse crossed by the proposed pipeline.

2. Assigning a stream type based on watercourse characteristics observed during the reconnaissance survey and from available photographs.

3. Determining the relationships between drainage area, slope and stream type.

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The stream classes were derived on a regional basis and are considered transferable within a given hydrologic region. Further details on the method are discussed in the results section.

5.2.4.5 Lakes

The proposed pipeline does not cross any lakes so lake effects on hydrology were not considered quantitatively in the characterization of the regional hydrology. Detailed information on surveyed lakes pertaining to perimeter, surface area and range of depths can be found in Section 7, Fish and Fish Habitat. Supplemental limnological information including secchi depth, dissolved oxygen (DO), turbidity, conductance, pH and acid sensitivity can be found in Section 6, Water Quality.

5.2.4.6 Geomorphic Assessment

Stream morphology is directly related to the sediment regime of a stream. The availability of sediment and the stream’s ability to carry it downstream determine the dominant substrate and the substrate distribution in the channel.

When undisturbed, alluvial streams reach equilibrium conditions that can be described by local relationships among flow, channel size, sinuosity and substrate. These relationships have often been used to estimate stream characteristics, such as average width and depth, and type of substrate. The relationships between stream slope, dominant substrate and channel features were assessed based on data collected during the detailed fish habitat surveys. See Section 5.3.7, Geomorphic Assessment, for details on the method.

5.2.4.7 Hydrology of the Delta

A limited study of the effects of storm surges on water levels near Niglintgak and Taglu was done using a one-dimensional storm surge model developed for Tuktoyaktuk. The model was calibrated based on several historical storm surges of various magnitudes and theoretical equations for storm surge setup and wave setup. See Section 5.3.8, Hydrologic Conditions in the Mackenzie Delta, for details on the method.

5.3 Regional Baseline Conditions

5.3.1 Hydrologic Regions

5.3.1.1 Delta Hydrologic Region

The delta hydrologic region stretches from the Beaufort Sea coast south to Inuvik (see Figure 5-6, shown previously). Most of the runoff in the delta region occurs in the spring from snowmelt. Because of low precipitation, water yield is low and tributary streams are relatively small. Smaller catchments do not typically generate enough runoff or stream flow to maintain a channel with discernible banks and substrate. The runoff period is also short, allowing vegetation to grow in ephemeral flow paths. Larger catchments generate sufficient flow volume over a long enough period to maintain a channel with discernible banks and substrate.

The hydrology of the Mackenzie Delta channels is different from local streams. The delta is a complex network of distributary channels with hydrologic characteristics dominated by the proportion and temporal variation of flow that they convey. The network is highly dynamic, and aggradation and degradation in the channels affect flow distribution. At the outer delta, where the anchor fields are located, coastal processes, such as tides and storm surges, also affect the hydrologic regime of delta channels.

5.3.1.2 Northern Hydrologic Region

The northern hydrologic region extends from Inuvik south to the Franklin Mountains and includes the southern Gwich'in and northern Sahtu settlement areas. The area is homogeneous with flat terrain. Drainage basins are typically small, and discharge periods tend to be short in duration (Polar Gas 1984). Because of impermeable ground resulting from extensive permafrost, most of the spring snowmelt and rainfall results in flooding and fast response in channels. Most of the small tributary streams in this area freeze to the bottom in winter.

5.3.1.3 Central Hydrologic Region

The central hydrologic region is dominated by the Franklin Mountains and Ebbutt Hills drainage basins. The region lies in the zones of continuous and discontinuous permafrost and includes streams in both the Sahtu Settlement Area and northern Deh Cho Region. Flow varies considerably because of the steep topography and high groundwater contribution in the area. Streams typically have higher peak flow per unit area than in other regions, and many flow through the winter. Peak flow tends to occur in late May and early June from snowmelt, but can also occur in late summer or fall after intense rainfall. Watercourse crossings for the proposed pipeline are in low-lying areas adjacent to the Mackenzie River. The topography becomes much steeper eastward to the mountains.

The Great Bear and Blackwater rivers are the largest drainage basins in the central hydrologic region, and large lakes in their headwaters moderate their flow. Both rivers have stable flow throughout the year.

5.3.1.4 Southern Hydrologic Region

The southern hydrologic region extends from south of Ebbutt Hills into northwestern Alberta. This area is underlain by discontinuous permafrost and characterized by low-lying topography. The hydrologic response of streams is highly influenced by muskeg, wetlands and lakes in terms of flow attenuation and annual yield. The area is also poorly drained with relatively flat gradients and with streams that are continually affected by beaver activity. Thaw proceeds slowly in the spring and summer, as vegetation and muskeg provide good insulation. Considerable volumes of water are held in the organic material at or near the surface, and are released slowly throughout the summer (Church 1971). Because this is in the southernmost hydrologic region, temperatures are usually milder, and the spring and fall seasons are more pronounced. The southern hydrologic region includes streams in the Deh Cho Region and in northwestern Alberta.

5.3.2 Climate Conditions

The following discussion of climate is limited to the main variables that affect stream hydrology:

- temperature
- precipitation
- evaporation
- river and lake ice
- permafrost

These variables determine the runoff rates and volumes from watersheds and the quantity and seasonal variability of flow.

5.3.2.1 Temperature

Air temperature is the variable most commonly used to characterize the climate of northern regions (Krauss 1996; Prowse 1990). Air temperature is a key factor in determining snowmelt rate and timing of floods during the break-up of spring ice cover. The production area and pipeline corridor lie in the subarctic region, which has the following characteristics:

- mean temperature for the coldest month is below freezing
- mean temperature for the warmest month is above 10°C
- no more than four months have a mean temperature above 10°C

Mean annual temperatures in the region range from -2.3°C in the south at Trout Lake to -10.5°C in the north at Tuktoyaktuk. January is the coldest month, with monthly mean temperatures ranging from -21°C to –31.3°C. July is the warmest month, with monthly mean temperatures ranging from 10.9°C to 16.9°C. The difference in mean monthly temperature from winter to summer months can be as much as 40°C. Table 5-3 summarizes mean monthly and mean annual temperatures at climate stations in the region. Figure 5-7 illustrates the seasonal variation based on 1961 to 1990 temperature normals.

Figure 5-8 shows an empirical relationship between mean annual temperature and latitude. There is about a 0.8°C decrease in mean annual temperature with every degree increase in latitude. One degree of latitude equals 60 nautical miles or 111.2 km.

Data on average maximum and minimum daily temperatures is also available for each of the climate stations. The data for five of the stations is summarized in Table 5-4. The difference between the maximum and minimum daily temperatures averages about 10°C, which indicates that temperatures do not vary much daily. The difference between extremes is greater in the south and less in the north.

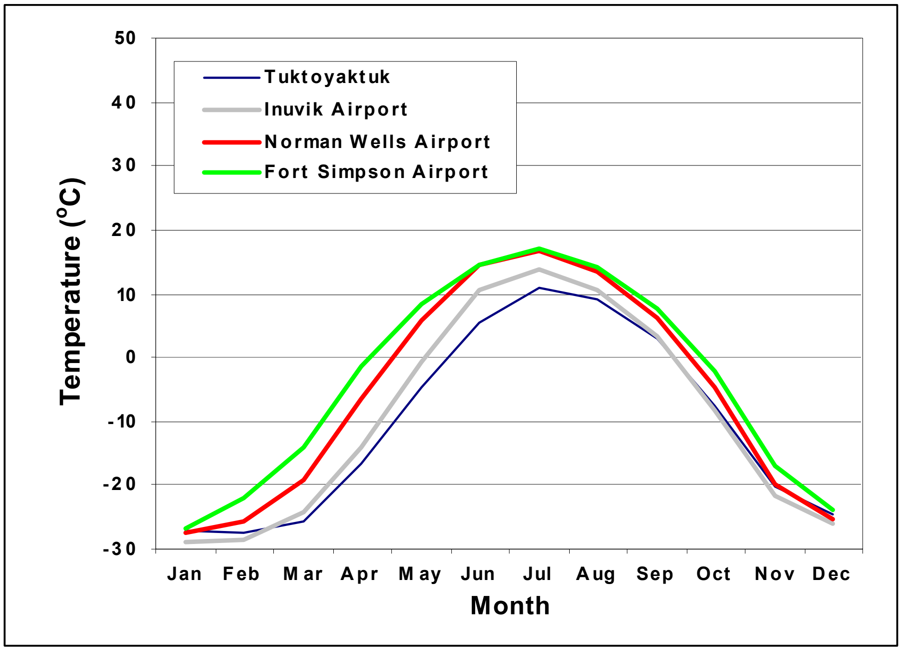


Figure 5-7: Mean Monthly Temperature

Table 5-3: Mean Monthly and Mean Annual Temperatures of Climate Stations

Station	Temperature (ºC)												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean Annual**
Tuktoyaktuk[1]	-27.2	-27.6	-25.7	-16.7	-4.7	5.5	10.9	9.1	2.8	-7.6	-20.2	-24.7	-10.5
Inuvik Airport[1]	-28.8	-28.5	-24.1	-14.1	-0.7	10.6	13.8	10.5	3.3	-8.2	-21.5	-26.1	-9.5
Aklavik Airport[2]	-29.4	-28.0	-22.8	-12.3	-0.5	9.8	14.0	11.2	3.7	-7.4	-20.2	-27.1	-9.1
Little Chicago[3]	-28.6	-24.6	-20.7	-7.3	4.1	14.7	16.1	13.2	5.7	-7.2	-18.5	-26.1	-6.6
Fort Good Hope Airport[2]	-31.3	-28.2	-21.5	-9.3	4.0	13.5	16.3	12.8	5.3	-6.1	-20.9	-27.7	-7.8
Norman Wells Airport[1]	-27.4	-25.8	-19.0	-6.5	5.8	14.6	16.7	13.5	6.3	-4.8	-19.7	-25.2	-6.0
Tulita Airport[2]	-28.6	-25.9	-19.4	-7.0	5.3	13.3	16.0	13.3	6.3	-4.4	-18.2	-26.0	-6.3
Wrigley Airport[1]	-28.4	-23.9	-16.4	-2.8	7.5	14.5	16.3	–	6.6	-3.5	-19.1	–	–
Fort Simpson Airport[1]	-26.7	-22.0	-14.2	-1.3	8.5	14.7	16.9	14.3	7.5	-2.0	-16.8	-23.8	-3.7
Trout Lake[3]	-21.0	-16.0	-10.2	-1.5	5.6	12.7	15.0	12.6	7.2	-0.4	-11.5	-20.4	-2.3
High Level Airport[1]	-21.4	-18.0	-10.4	1.9	9.7	14.2	16.2	14.0	8.2	–	-12.8	-20.2	–

NOTES:
– = not available
1 Based on climate normals for 1961 to 1990 from Environment Canada
2 Based on climate normals for 1951 to 1980 from Environment Canada
3 Mean monthly and mean annual temperatures are based on all available station data

Table 5-4: Maximum and Minimum Daily Temperature for each Climate Station

Values	Station	Temperature (ºC)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum	Tuktoyaktuk	-23.9	-24.2	-22.0	-12.4	-1.0	10.1	15.4	12.6	5.4	-5.2	-16.8	-21.3
	Inuvik Airport	-24.1	-23.4	-18.2	-8.0	4.2	16.6	19.5	15.7	7.5	-4.8	-17.1	-21.4
	Norman Wells Airport	-23.6	-21.4	-13.1	-0.4	11.6	20.4	22.4	19.0	10.9	-1.7	-16.1	-21.5
	Fort Simpson Airport	-22.2	-16.4	-7.2	5.0	15.0	21.3	23.4	20.8	13.2	2.0	-12.6	-19.5
	High Level Airport	-15.8	-11.4	-3.1	8.6	16.9	21.1	22.9	20.9	14.8	–	-8.1	-14.8
Minimum	Tuktoyaktuk	-31.2	-31.8	-29.6	-21.1	-8.5	0.8	6.4	5.4	0.2	-10.3	-23.7	-28.4
	Inuvik Airport	-33.5	-33.7	-30.3	-20.2	-5.7	4.5	8.0	5.3	-0.9	-11.8	-26.0	-31.0
	Norman Wells Airport	-31.4	-30.4	-25.1	-12.7	-0.1	8.7	11.0	8.0	1.7	-8.1	-23.4	-29.2
	Fort Simpson Airport	-31.3	-27.8	-21.2	-7.7	1.9	8.0	10.3	7.7	1.8	-6.1	-21.1	-28.3
	High Level Airport	-27.2	-24.9	-17.7	-5.0	2.4	7.3	9.3	7.1	1.6	–	-17.5	-25.7

NOTE:
– = not available
Based on climate normals for 1961 to 1990 from Environment Canada

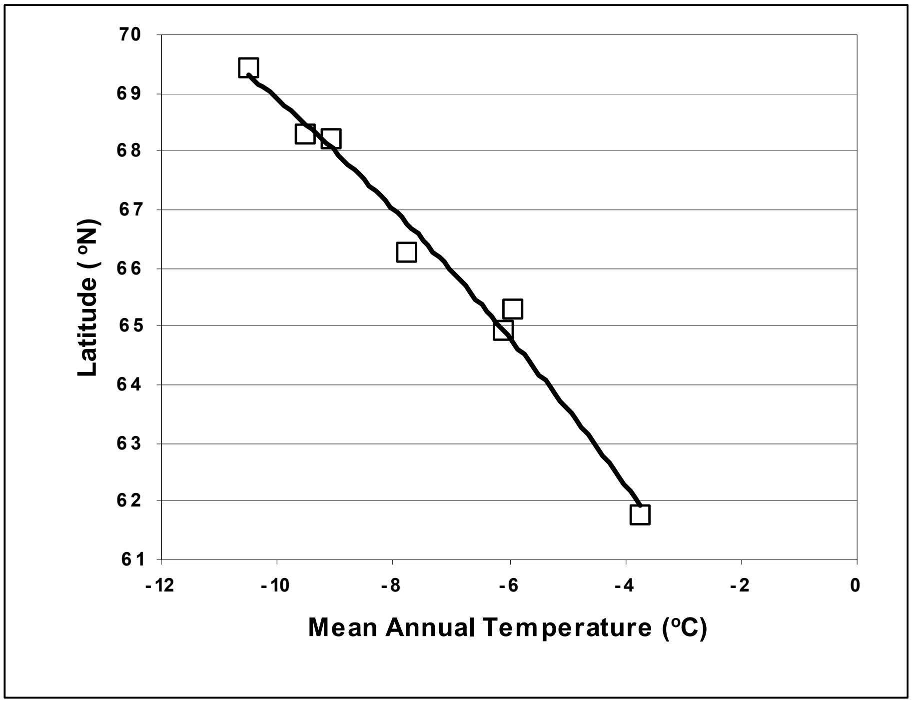


Figure 5-8: Mean Annual Temperature versus Latitude

5.3.2.2 Precipitation

The amount of precipitation in an area determines the potential amount of runoff from that area. Table 5-5 summarizes mean monthly and annual precipitation for the climate stations in the production area and along the pipeline corridor. Total annual precipitation increases from north to south along the Mackenzie Valley, from 142 mm/a at Tuktoyaktuk, to 257 mm/a at Inuvik, and 361 mm/a at Fort Simpson. Figure 5-9 shows the variation of total precipitation with latitude. The data does not show correction for snowfall undercatch.

Figure 5-10 shows the seasonal variation in precipitation for four stations. The data is based on published total precipitation values (Environment Canada 2002d) and does not take into account snowfall undercatch. Studies indicate that snowfall undercatch can be substantial at gauges where windy conditions hinder the collection of snow and where trace amounts are not recorded (Louie et al. 1999; Marsh 1990). Recommended correction factors range from about 1.15 to 1.30.

The wettest months in the production area and along the pipeline corridor are July and August. The driest months are March and April.

Table 5-5: Mean Monthly Precipitation at Climate Stations

	Precipitation[4] (mm)												
Station	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean Annual**
Tuktoyaktuk[1]	5.9	5.8	4.4	6.4	6.2	11.6	20.5	29	16.3	18.2	9.2	8.6	142
Inuvik Airport[1]	15.6	11.1	10.8	12.6	19.1	22.2	34.1	43.9	24.2	29.6	17.5	16.8	257
Aklavik Airport[2]	11.5	6.9	9.2	9.6	8.3	19.7	36.0	36.1	21.2	28.6	11.7	9.0	208
Fort Good Hope Airport[2]	14.8	12.2	11.6	13.6	16.7	31.4	41.7	43.3	27.4	29.0	20.7	19.5	282
Norman Wells Airport[1]	18.7	14.7	11.6	14.4	19.7	43.2	50.4	49	30.6	29.5	17	17.7	316
Tulita Airport[3]	13.5	11.1	10.8	12.3	20.3	38.2	48.6	51.3	37.1	26.7	20.9	12.7	304
Wrigley Airport[1]	17.2	11.9	13.0	–	26.8	53.9	56.1	48.6	30.1	36.5	21.5	–	–
Fort Simpson Airport[1]	19.6	17.8	17.6	16.4	29.8	44.3	53.3	50.7	30.2	36.1	25.7	18.9	360
High Level Airport[1]	22.9	17	19.2	17.1	41.5	65	61	–	34.1	–	29.2	22.2	–

NOTES:

– = not available
1 Based on climate normals for 1961 to 1990 from Environment Canada
2 Based on climate normals for 1951 to 1980 from Environment Canada
3 Based on all available data
4 Precipitation values do not include a correction for snowfall undercatch

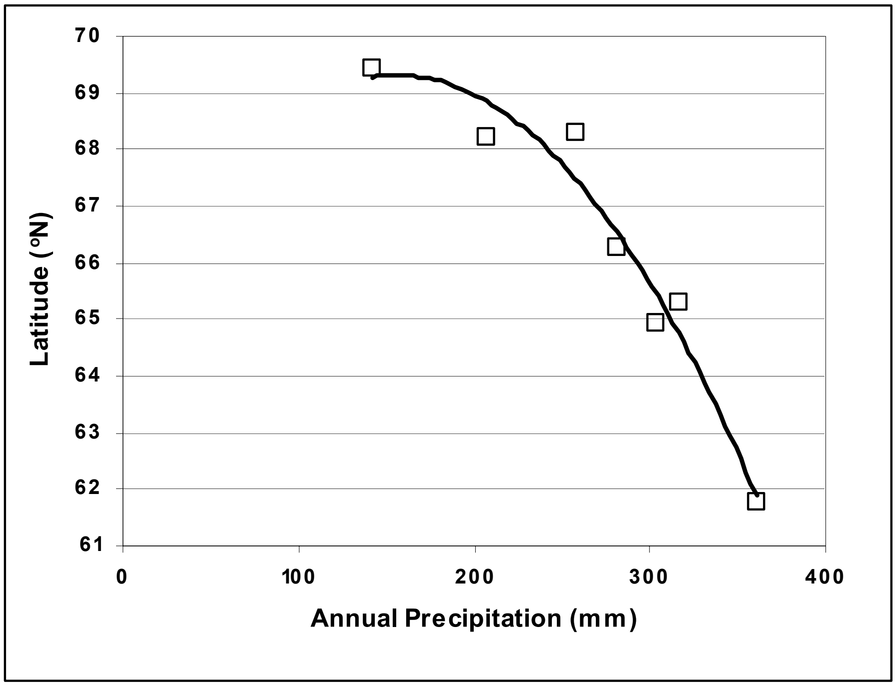


Figure 5-9: Total Annual Precipitation versus Latitude

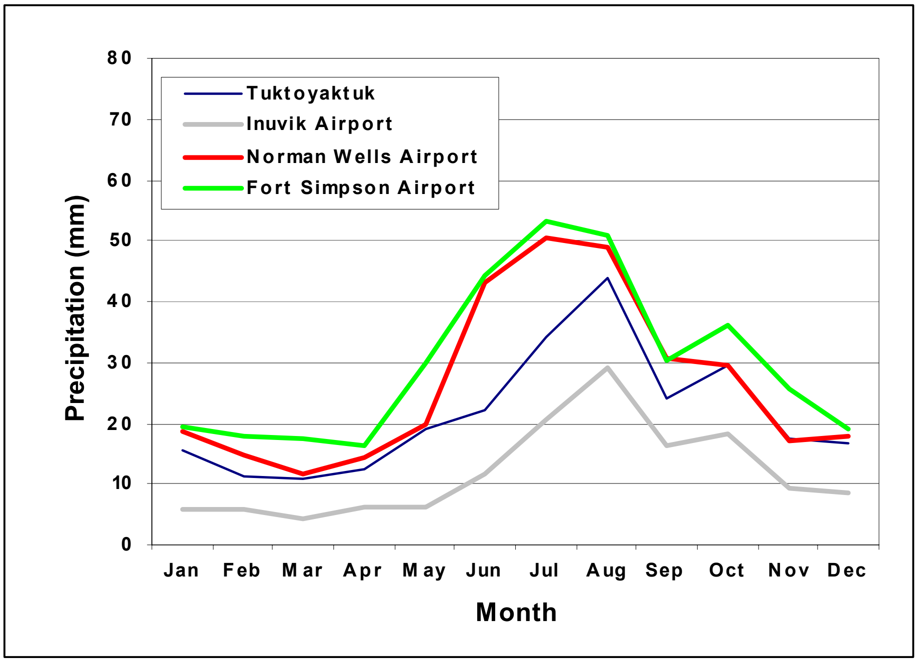


Figure 5-10: Mean Monthly Precipitation

5.3.2.3 Evaporation

Evaporation is a key factor in determining the amount of precipitation that appears as runoff from a watershed.

Evaporation is the least understood of the major hydrologic region components, especially in northern areas (Prowse 1990). In general, evaporation is greatest in the summer when days are long and solar radiation is greatest. Daily energy input controls the evaporation rate for shallow-water systems, whereas heat storage is an important factor in the evaporation potential of deeper waterbodies, particularly in fall. The relative importance of evaporation in the water balance of watersheds tends to increase in the north because of the decrease in precipitation at higher latitudes (Prowse 1990).

For northern basins, snow storage is an important part of the water cycle. Snow contributes a large part of the annual precipitation for eight months of the year (Krauss 1996). Snowfall accounts for about 45% to 70% of total annual precipitation. Snowfall occurs between October and April, although it is possible for snowfall to occur in any month. Figure 5-11 shows the rainfall and snowfall amounts for Inuvik Airport climate station.

The data represents recorded snowfall only, and does not account for reduced catch efficiency caused by wind, or trace amounts of snowfall that might not be recorded by station instruments.

Table 5-6 summarizes rainfall intensity-duration-frequency (IDF) values for the production area and proposed pipeline route. Only three stations have published IDF information. Consistent with total precipitation trends, IDF values decrease from south to north along the pipeline corridor.

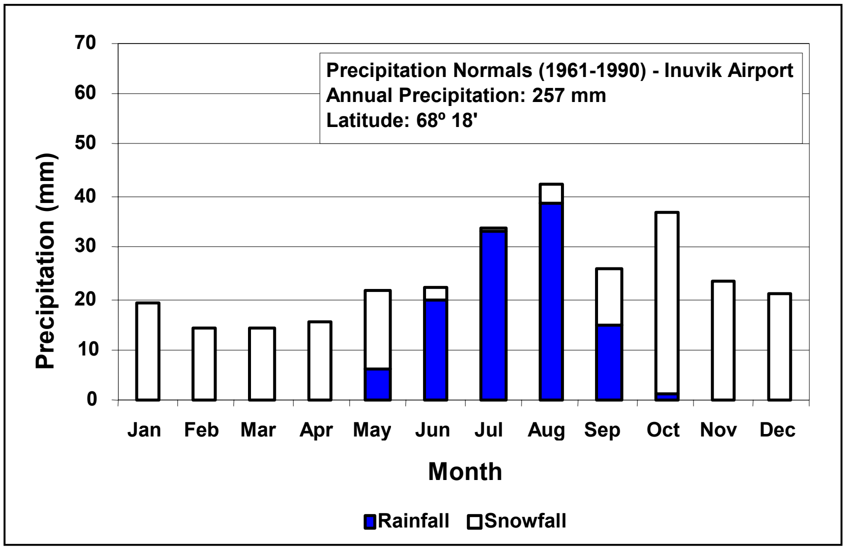


Figure 5-11: Precipitation as Rainfall and Snowfall at Inuvik

Table 5-6: Intensity-Duration-Frequency Rainfall Data

Location	Duration of Event	Rainfall (mm)				
		Return Period of Rainfall Event				
		2-year	10-year	25-year	50-year	100-year
Inuvik Airport (2202570) Latitude 68°18’ Longitude 133°29’ Elevation 67 m	5 minutes	1.8	3.4	4.2	4.7	5.3
	30 minutes	4.4	8.7	10.8	12.4	13.9
	1 hour	6.0	11.4	14.2	16.2	18.2
	6 hours	12.3	20.3	24.4	27.3	30.3
	12 hours	15.2	26.5	32.1	36.3	40.5
	24 hours	17.3	32.1	39.5	45.0	50.5
Norman Wells Airport (2202800) Latitude 65°17’ Longitude 126°48’ Elevation 67 m	5 minutes	2.5	5.7	7.3	8.4	9.6
	30 minutes	6.0	13.3	17.0	19.8	22.5
	1 hour	8.1	16.4	20.6	23.8	26.9
	6 hours	16.2	26.0	31.0	34.6	38.3
	12 hours	20.9	34.0	40.5	45.4	50.3
	24 hours	27.8	51.0	62.7	71.4	80.0
Fort Simpson Airport (2202101) Latitude 61°45’ Longitude 121°14’ Elevation 167 m	5 minutes	4.1	7.0	8.5	9.5	10.6
	30 minutes	10.2	19.0	23.4	26.7	30.0
	1 hour	11.7	21.5	26.4	30.0	33.7
	6 hours	21.2	33.5	39.8	44.4	48.9
	12 hours	25.8	42.1	50.4	56.5	62.5
	24 hours	32.1	57.0	69.5	78.8	88.0
SOURCE: Environment Canada (2002b)						

Among the few studies to have calculated or derived lake evaporation amounts for local conditions in the Northwest Territories are an evaporation study at four mine sites in the central Northwest Territories (Reid 1997), and another at two Mackenzie Delta lakes (Marsh and Bigras 1988). For the open-water seasons that were studied, total evaporation was estimated to be about 220 mm in the far north and about 450 mm near Yellowknife. In the Mackenzie Delta, lake evaporation was estimated to be about 340 mm for Dishwater Lake and 230 mm for NRC Lake.

There is limited long-term evaporation data available in the study region. Only the Inuvik and Norman Wells climate stations record the data necessary to calculate lake evaporation. Although evaporation data was not collected at Inuvik, evaporation can be estimated from air temperature, dew point temperature and global radiation monitoring. Morton’s Complementary Relationship Lake Evaporation (CRLE) model (Morton et al. 1985) was used to calculate lake evaporation for Inuvik.

Lake evaporation, calculated for May to September using Environment Canada data, is about 367 mm at Inuvik, i.e., based on the CRLE model, and 528 mm at Norman Wells. Table 5-7 shows the variation in monthly lake evaporation.

Table 5-7: Calculated Lake Evaporation for Shallow Ponds

Station	Evaporation	May (mm)	Jun (mm)	Jul (mm)	Aug (mm)	Sep (mm)	Total (May–Sept) (mm)
Inuvik UA	Lake[1]	32	89	116	88	42	367
Norman Wells	Lake[2]	111	146	135	91	45	528

NOTES:
UA = upper air climate station
1 Calculated lake evaporation using Morton CRLE model for shallow ponds (Ilich 1991) based on 21 years of data
2 Published lake evaporation data from Environment Canada (2000)

5.3.2.4 River and Lake Ice

The ice cover that develops in late fall and persists until late spring characterizes northern lakes and rivers. Ice formation affects surface hydrology, as water is stored as ice for most of the year and is only released months later when temperatures rise and melting begins. Ice formation could result in:

- lower discharge
- blockage of lake outlets
- streams freezing to the channel bottom

Downstream ice jams often cause maximum flood water levels.

Freezeup Process

The freezeup process depends on the:

- thermal regime
- size of a waterbody
- effects of wind and currents

Being less turbulent than rivers, lakes tend to freeze first, from the edges inward. Frazil ice, i.e., crystals fully mixed in the water column, can form and accumulate in pans where wind or stream flow mixes the water. The maximum ice thickness in winter depends on (Allen 1977):

- freezing index, i.e., accumulated degree days of air temperature below freezing point
- depth of snow cover on the ice surface
- depth of the waterbody
- salt content of water
- water currents

Spring Breakup

In the spring, rivers breakup well before lakes because of heat exchange and turbulence associated with moving water. The breakup could be classified as either thermal or dynamic. Thermal breakup refers to the process of melting ice cover. A dynamic breakup might occur if water level or flow rises quickly. Fragmented ice can create an ice jam on a river, and the load can cause the downstream ice cover to fail.

Freeze and Thaw Timing

Allen (1977) provides the most complete analysis of freezeup, breakup and ice thickness in Canada. The study is summarized in a set of maps showing the spatial distribution of the mean dates of the following events:

- mean maximum ice thickness
- first permanent ice
- complete freeze-over
- first deterioration of ice
- complete clearing of ice

Table 5-8 summarizes the mean dates for these events at several locations in the production area and along the pipeline corridor. Freeze and melt dates will usually be earlier for the smaller waterbodies that characterize drainage in the production area.

Table 5-8: Mean Dates of River Ice Conditions

Event or Measurement	Tuktoyaktuk[1]	Inuvik[2]	Fort Good Hope[3]	Norman Wells[3]	Wrigley[3]	Fort Simpson[4]	Northwest Territories Alberta Boundary
First ice	Sep 27	Oct 01	Oct 20	Oct 16	Oct 19	Oct 25	*Nov 01*
Freeze-over	Oct 01	Oct 19	Nov 08	Nov 14	Nov 21	Nov 27	*Nov 15*
First ice deterioration	May 28	May 13	May 17	May 14	May 08	May 12	*May 05*
Clearing of rivers	Jun 19	Jun 5	May 25	May 28	May 22	May 25	*May 15*
River ice thickness[5]	1.55 m	1.32 m	1.42 m	1.68 m	*1.50 m*	1.55 m	*1.00 m*
Lake ice thickness[5]	*1.75 m*	*1.73 m*	*1.70 m*	*1.60 m*	*1.50 m*	*1.40 m*	*1.30 m*

NOTES:
Italics represent estimated dates and ice thickness based on interpolation of isolines.
1 Lake conditions at unnamed lake
2 East Channel of Mackenzie River
3 Mackenzie River
4 Mackenzie River above Liard River
5 Mean maximum thickness

SOURCE: Allen (1977)

5.3.2.5 Permafrost

Permafrost is defined as ground that is continuously below 0°C for two consecutive years or more. It is formed and sustained by intense and persistent cold conditions (Woo 1990). Permafrost extent and degree, i.e., sporadic, widespread or continuous, affects surface water hydrology because of permafrost's influence on water movement. Permafrost restricts water movement from the surface to underground, resulting in reduced storage for attenuation of peak flow and rainfall.

Melting of the active layer above the permafrost also greatly affects surface hydrology. Melting often produces seasonal wetlands and bogs that transfer water as sheetflow or interflow, which is not restricted to defined channels. The high degree of saturation can also lead to severe flooding from intense rainfall. As the season progresses, higher evaporation rates and increased thawing of the ice and frozen ground tend to increase the ground's ability to receive and attenuate flow. Therefore, runoff and summer peak flow depends on prior saturation, evaporation and the timing and magnitude of rainfall.

The active delta area (Niglintgak and Taglu) is located in an intermediate discontinuous permafrost zone. Areas south of Taglu are in a continuous permafrost zone. The boundary between continuous and discontinuous permafrost zones is near Norman Wells. Permafrost becomes increasingly sporadic toward the Northwest Territories–Alberta boundary. Sporadic permafrost in these southern areas can affect drainage characteristics such as the magnitude of summer peak flow and the extent of wetlands.

5.3.3 Stream Flow and Water Levels

Results of the hydrologic analysis are used to estimate flow at ungauged streams that will be crossed by the pipeline or potentially affected by other components of the project. Flow estimates are required for assessing potential hydrologic and geomorphic impacts.

5.3.3.1 Spatial Variability of Flow

Hydrometric stations on the west side of the Mackenzie River were included in initial flow analyses. Evaluation of flow data indicated that rivers draining the Mackenzie Mountains have a higher water yield, i.e., depth of runoff and unit discharge or flow rate per unit area, than those on the east side of the river (see Figure 5-12). Rivers draining the Mackenzie Mountains have flashy discharge regimes because of steeper slopes, resulting in the rapid rise and fall of stream flow in response to rainstorms and snowmelt. As a result, the steep mountain terrain west of the Mackenzie River produces markedly different hydrologic responses than the basins east of the river, which drain mostly low-lying areas. The hydrometric stations on the west side of the Mackenzie River were therefore excluded from further analysis.

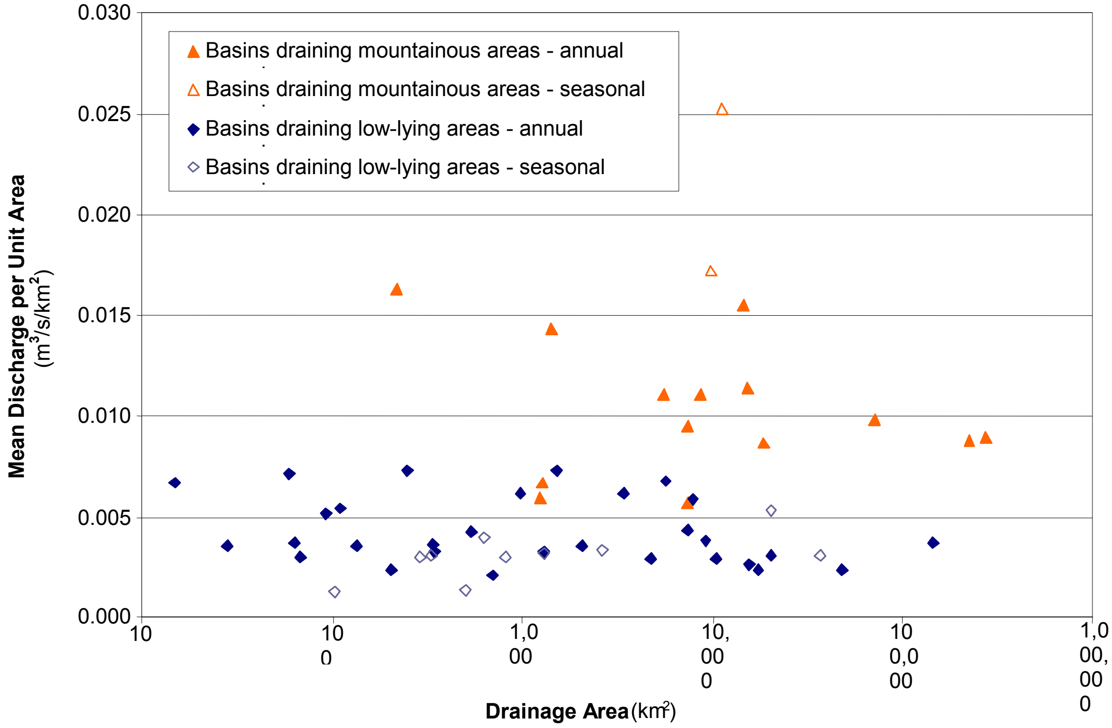


Figure 5-12: Hydrologic Response of Mountainous and Non-Mountainous Basins

5.3.3.2 Hydrographs for Mackenzie River Near the Delta

The Mackenzie River enters the Mackenzie Delta at Point Separation, about 20 km downstream from Tsiigehtchic. Stream flow data from upstream gauging stations along the Mackenzie River was analyzed to determine the river's discharge variability and periods of high and low flow. Figure 5-13 shows selected hydrographs for the year 2000. The stations and their periods of record are shown in Table 5-9.

The hydrographs at Station 10LC014 at Tsiigehtchic show that a first peak in flow usually occurs mid- to late May, and a second peak often occurs mid- to late June or early July. The flow at Strong Point is highly attenuated by Great Slave Lake. The Liard system drains the Mackenzie Mountains and produces a mean annual runoff that is more than double the runoff in the upstream Mackenzie River basin.

Table 5-9: Stream Flow Gauging Stations

Water Survey of Canada Station ID	Station Name	Drainage Area (km^2)	Period of Record
10LC014	Mackenzie at Tsiigehtchic	1,680,000	1972–2002
10KA001	Mackenzie River at Norman Wells	1,570,000	1961–2002
10GC001	Mackenzie River near Fort Simpson	1,270,000	1938–2000
10ED002	Liard River near its mouth	275,000	1972–2000
10FB006	Mackenzie River at Strong Point	995,000	1991–2000
10FB001	Mackenzie River near Fort Providence	980,000	1958–1997

As a result, and despite representing only 20% of the basin area, Liard flow noticeably affects flow hydrographs of the lower Mackenzie River. Figure 5-13, cited previously, also shows the Mackenzie River hydrographs downstream from Fort Simpson and north to the delta, reflecting the quick rise in stream flow in the Liard basin in early May with the onset of warmer weather. These hydrographs also reflect the Liard River's second peak, which is often in June when stream flow increases as snowmelt from higher elevations reaches the lower basin.

Total Delta Inflow

A 27-year record of daily inflow to the Mackenzie Delta was derived by summing the contributions from the Mackenzie River at Tsiigehtchic and the Peel River at Fort McPherson, Station 10MC002. The Mackenzie River is the primary contributor, and the Peel River contributes an additional annual flow volume proportion of about 2%. A frequency analysis of the annual maximum daily inflow to the delta was done to estimate inflow with several probabilities of exceedance or return periods. Table 5-10 shows the results.

5.3.3.3 Water Levels in the Delta

Daily water level records are available for only several locations in the Mackenzie Delta because channel discharge information is limited. Mean seasonal, maximum daily and minimum daily water levels are shown in Table 5-11 along with station details. Table 5-12 shows the frequency analysis results of water levels for various return periods. Geodetic conversions to mean sea level are from Environment Canada.

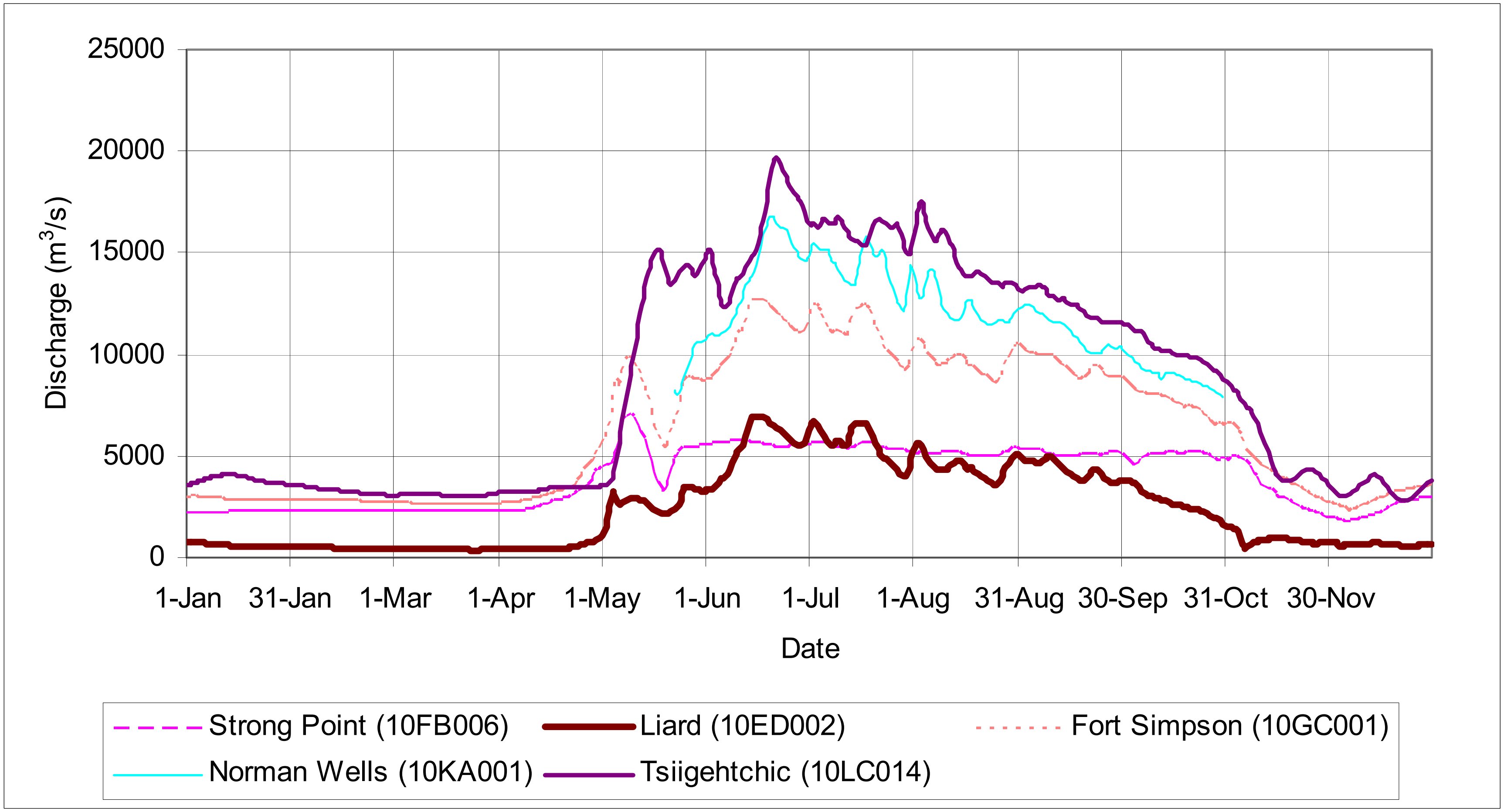


Figure 5-13: Recorded Stream Flow at Stations in Mackenzie River System (2000)

Table 5-10: Maximum Daily Inflow to the Mackenzie Delta

Station Name	Station Number	Drainage Area (km^2)	Years of Record	Maximum Daily Delta Inflow at Various Return Periods[1] (m^3/s)			
				Q_2	Q_{10}	Q_{25}	Q_{100}
Peel River	10MC002	70,600	27	5,410	7,300	7,940	8,870
Mackenzie River at Tsiigehtchic (Arctic Red River)	10LC014	1,680,000	30	28,500	32,700	33,800	35,200
Total delta inflow[2]	N/A	1,750,600	27	32,400	38,400	40,100	42,500

NOTES:
N/A = not applicable
1 Q_T, where T=return period in years
2 Daily flow series was derived by summing the daily flow of the Peel River (10MC002) and the Mackenzie River at Tsiigehtchic (10LC014).

Rating Curves

Recorded water levels at some locations were plotted versus total delta inflow. Total delta inflow was used as a substitute for the relative magnitude of discharge in individual channels. Station 10LC019 on Kumak Channel was of particular interest because of its proximity to Niglintgak and Taglu. The plots in Figure 5-14 show two clear trends, separated by a transition period. One trend is for the early spring breakup period, typically at the end of May to the beginning of June, and a second trend is for late spring and summer, typically in mid-June through September.

The distinct seasonal rating curves indicate that for the same magnitude of delta inflow, water levels are much higher in early spring when the first peak inflow occurs, than in later spring or summer when there is a subsequent peak inflow. The difference in water levels for the same inflow is about 1 m. Possible reasons for this phenomenon include local ice blockages in the channels and flow restrictions because of ice at the Beaufort coast.

Peak spring water levels are not solely a function of channel discharge but also appear to be affected by other factors such as local ice effects. As a consequence, peak water levels for various return periods cannot be directly related to delta inflow of a given recurrence interval.

5.3.3.4 Annual Flow and Water Yield

Table 5-13 summarizes mean annual flow for stations included in the regional analysis. Mean discharges are based on the annual record, where available, or on the seasonal record where the annual record is not available.

Table 5-11: Water Levels in the Mackenzie Delta

Station Name	Station Number	Location in Delta	Period of Record	Years of Record	Operating Season	Geodetic Correction (m)	Mean Seasonal Water Level[1] (m)	Average Annual Maximum Daily Levels[1] (m)	Average Annual Minimum Daily Levels[1] (m)	Maximum Daily Level on Record[1] (m)	Minimum Daily Level on Record[1] (m)	Difference between Maximum and Minimum Level (m)
East Channel above Kittigazuit Bay	10LC013	Outer	1982–2002	18	Jun to Oct	-9.480	9.734	11.14	9.22	11.766	9.108	2.66
Kumak Channel below Middle Channel	10LC019	Outer	1997–2002	6	Jun to Oct	–	9.714	9.52	•	11.129	•	•
Middle Channel at Tununuk Point	10LC012	Lower	1982–2002	21	Jun to Oct	-9.656	10.388	12.89	9.63	13.685	9.399	4.29
Outflow Middle Channel Below Langley Island	10MC010	Lower	1982–2002	7	Jun to Oct	–	10.148	–	–	12.674	9.777	2.90
Reindeer Channel at Ellice Island	10MC011	Lower	1982–2002	20	Jun to Oct	–	9.716	11.48	9.21	11.720	9.094	2.63
Napoiak Channel above Shallow Bay[2]	10MC023	Middle-lower	1997–2002	4	Jun to Oct	–	11.279	13.01	•	13.036	•	•
Peel Channel above Aklavik	10MC003	Middle	1982–2002	17	Jun to Oct	-9.912	11.294	15.19	10.21	16.166	10.082	6.08
Middle Channel below Raymond Channel	10MC008	Middle	1982–2002	17	Jun to Oct	-10.131	11.925	15.57	10.55	16.600	10.310	5.03
East Channel at Inuvik[2]	10LC002	Middle	1984–1990	7	Jan to Dec	–	11.721	–	–	16.192	10.635	5.56
Mackenzie River at confluence of East Channel[2]	10LC015	Upper	1990–2002	12	Jun to Oct	–	3.805	8.74	•	10.539	•	•

NOTES:

– = not available
• = not calculated because of changes in data over period of record or limited seasonal records
1 Water levels relative to arbitrary datum
2 Stations not used in analysis

Table 5-12: Maximum Daily Water Levels in the Mackenzie Delta

Station Name	Station Number	Location in Delta	Period of Record	Years of Record	Maximum Daily Water Levels of Various Return Periods[1] (m MSL)				WL_{10}-WL_2 (m)	WL_{100}-WL_2 (m)
					WL_2	WL_{10}	WL_{25}	WL_{100}		
East Channel above Kittigazuit Bay	10LC013	Outer	1982–2002	12	1.643	2.068	2.191	2.352	0.42	0.71
Middle Channel at Tununuk Point	10LC012	Lower	1982–2002	12	3.246	3.815	3.990	4.229	0.43	0.98
Reindeer Channel at Ellice Island	10MC011	Lower	1982–2002	11	11.4591	11.6681	11.7291	11.8091	0.21	0.35
Peel Channel above Aklavik	10MC003	Middle	1982–2002	7	5.036	5.931	6.366	7.126	0.90	2.09
Middle Channel below Raymond Channel	10MC008	Middle	1982–2002	10	15.357	6.321	6.607	6.986	0.96	1.63

NOTES:
WL = water level
MSL = mean sea level
1 WL_T, where T=return period in years

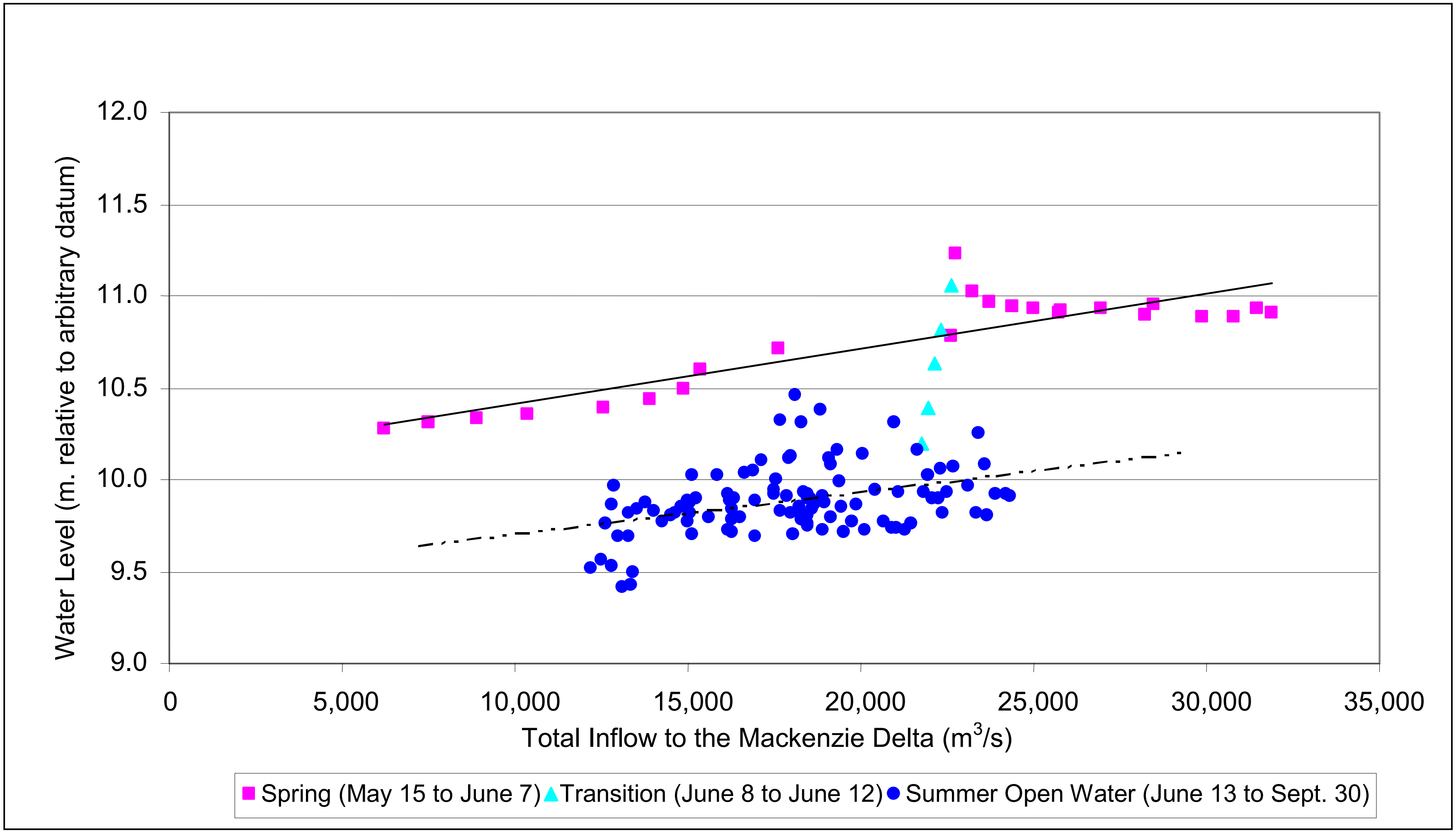


Figure 5-14: Water Level at Station 10LC019 versus Total Inflow to the Mackenzie Delta (2002)

Table 5-13: Mean Annual Flow and Water Yield

Station Name	Station Number	Hydrologic Region	Drainage Area (km^2)	Years of Record	Mean Annual Flow (m^3/s)	Water Yield[2] (mm/a)
Hans Creek above Eskimo Lakes[1]	10ND004	Delta	329	13	1.09	86
Trail Valley Creek near Inuvik	10ND002	Delta	68.3	23	0.20	108
Hans Creek near Inuvik[1]	10ND001	Delta	337	10	1.20	112
Babbage River below Caribou Creek	10MD002	Delta	1,510	19	11	187
Firth River near mouth	10MD001	Delta	5,710	27	38.4	188
Havikpak Creek near Inuvik	10LC017	Delta and northern	15	7	0.100	132
Boot Creek near Inuvik	10LC010	Delta and northern	28.2	10	0.100	87.9
Cabin Creek above Highway 8, Dempster Highway	10LC009	Delta and northern	133	13	0.470	111
Jackfish Creek near Fort Good Hope	10LD002	Northern	62.9	7	0.233	110
Caribou Creek above Highway 8, Dempster Highway	10LC007	Northern	625	26	2.46	87.9
Rengleng River below Highway 8, Dempster Highway	10LC003	Northern	1,310	28	4.05	66.1
Great Bear River at outlet of Great Bear Lake	10JC003	Central (local)	145,000	39	531	96.2
Willowlake River below Metahdali Creek	10GB001	Central (local)	20,500	12	62.6	96.4
Bosworth Creek near Norman Wells	10KA007	Central	109	15	0.585	168
Jungle Ridge Creek near mouth	10KA006	Central	60	14	0.428	315
Whitefish River near mouth	10JD002	Central	4,740	16	13.7	75.6
Blackwater River at outlet of Blackwater Lake	10HC006	Central	7,850	9	46.3	176
Big Smith Creek near Highway 1	10HC003	Central	964	22	5.87	189
Metahdali Creek above Willowlake River	10GB005	Central	344	12	1.12	95.8
Sahndaa Creek at Highway 1	10GC005	Southern	251	9	1.84	231
Martin River at Highway 1	10GC003	Southern	2,050	29	7.2	110
Harris River near mouth	10GC002	Southern	701	23	1.47	66.3
Jean-Marie River at Highway 1	10FB005	Southern	1,310	29	4.27	103
Trout River at Highway 1	10FA002	Southern	9,270	32	35.3	120
Scotty Creek at Highway 7	10ED009	Southern	202	7	0.470	72.9
Rabbit Creek at Highway 7	10ED006	Southern	92.7	7	0.472	161

Table 5-13: Mean Annual Flow and Water Yield (cont'd)

Station Name	Station Number	Hydrologic Region	Drainage Area (km^2)	Years of Record	Mean Annual Flow (m^3/s)	Water Yield[2] (mm/a)
Birch River at Highway 7	10ED003	Southern	542	28	2.31	139
Fontas River near mouth	10CA001	Southern	7,400	10	31.9	131
Whitesand River near Northwest Territories–Alberta boundary	07PA002	Southern	3,410	9	20.9	190
Chinchaga River near High Level	07OC001	Southern	10,400	32	29.6	90
Hutch Lake Tributary near High Level	07OB007	Southern	103	10	0.126[a]	23.3[a]
Lutose Creek near Steen River	07OB006	Southern	292	25	0.860[a]	60.6[a]
Steen River near Steen River	07OB004	Southern	2,610	27	8.51[a]	69.1[a]
Hay River near Meander River	07OB003	Southern	36,900	27	114.0[a]	63.0[a]
Sousa Creek near High Level	07OA001	Southern	819	31	2.40[a]	60.0[a]

NOTES:
a March to October operating period
1 Station 10ND004 was used to characterize peak flow in Hans Creek, data before Station 10ND001 was moved was not used
2 Water yield represents a runoff depth of water per unit area and is estimated by dividing the mean annual discharge by the basin area.
See Figure 5-6, shown previously, for hydrologic regions.

Water yield, estimated by dividing the mean annual discharge by the basin area, represents a runoff depth of water per unit area. This provides a useful measure with which drainage basins of different sizes can be compared.

The delta region is characterized by water yields of about 85 to 120 mm/a, with higher yields of up to 190 mm/a in the northwest area near the mountainous terrain, i.e., Station 10MD001 and Station 10MD002. These two stations were used to characterize annual flow, although they were not included in other analyses because they were considered to be hydrologically dissimilar for extreme events.

Water yield varies from 60 to 315 mm/a for different basins along the proposed pipeline route. Water yield in the northern hydrologic region ranges from as low as 66 mm/a at Station 10LC003, and as high as 132 mm/a at Station 10LC017.

Groundwater influence in the central region results in higher water yields than in the other hydrologic regions. In the central region, annual yields range from 95 mm up to 200 mm. The water yield for Jungle Ridge Creek is exceptionally high at over 300 mm/a, though some discrepancy in the station's drainage area has been noted. The published value is 45 km^2, but the drainage area appears to be larger based on NTS mapping. A drainage area of 60 km^2 has been used in the stream flow analysis, resulting in a more reasonable water yield when compared with other stations in the area. The yield is still relatively high, although no further adjustments were made for this study.

5.3.3.5 Seasonal and Monthly Flow

The hydrologic regime of streams in the study area is dominated by snowmelt with peak flow in late May and early June. Discharge typically recedes gradually over the summer with a noticeable reduction in flow at freezeup when water is stored as ice. High flow rates can occur in late summer because of rainfall, particularly in the southern hydrologic region. Flow continues to recede over the winter and is lowest in about April, just before the spring breakup and freshet, i.e., the rise in water level and flow that results from snowmelt or heavy rains.

Calculation of Unit Discharge

The seasonal variation in unit discharge was investigated for each of the hydrologic regions discussed in Section 5.3.1, Hydrologic Regions. Unit discharge in winter is dominated by groundwater seepage, lakes and wetlands and is relatively independent of basin size. Average yields recorded at the hydrometric stations in the region are used to estimate the range of winter discharge. During the peak flow months in May and June, larger drainage basins tend to produce smaller unit discharge than smaller basins.

Figure 5-15 shows unit discharge plotted against drainage area for stations in the delta hydrologic region and the 95% confidence limits about the mean. The scatter about the mean appears to be larger for smaller basins. They were derived using the 95% confidence limits as a guide, and based on professional judgement and the assumption that hydrologic response is reduced in large watersheds compared to small ones. Mean monthly discharges were estimated for the open-water period for the hydrologic regions. Figure 5-16 shows the estimated unit discharge for the delta region from May to September.

The unit discharge values in the following tables can be extrapolated to determine conditions at ungauged crossing sites in the study area:

- Table 5-14: Unit Mean Monthly Discharge – Delta Hydrologic Region
- Table 5-15: Unit Mean Monthly Discharge – Northern Hydrologic Region
- Table 5-16: Unit Mean Monthly Discharge – Central Hydrologic Region
- Table 5-17: Unit Mean Monthly Discharge – Southern Hydrologic Region

The values of winter unit discharge shown in the tables were adjusted to reflect the decreasing influence of increasing drainage area on unit discharge under frozen conditions. This decreasing trend can be affected by the presence of large lakes and wetlands and by the shape of the drainage area.

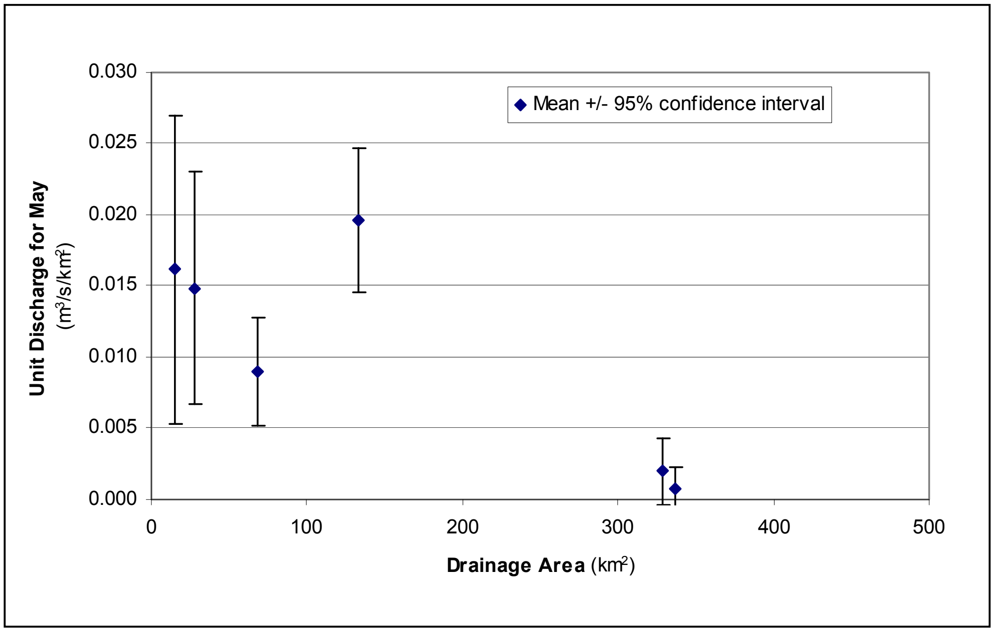


Figure 5-15: Unit Discharge by Drainage Area for May in the Delta Hydrologic Region

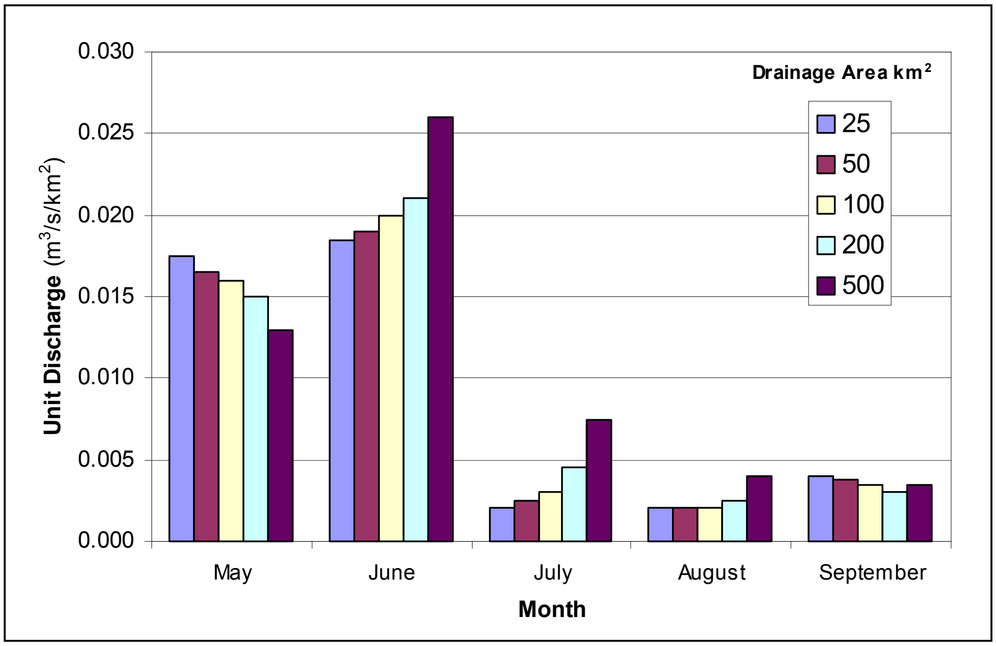


Figure 5-16: Unit Discharge by Month in the Delta Hydrologic Region

Table 5-14: Unit Mean Monthly Discharge – Delta Hydrologic Region

Drainage Area (km^2)	Unit Mean Monthly Discharge (m^3/s/km^2)												Mean Annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	
25	0.000	0.000	0.000	0.000	0.0175	0.0185	0.0020	0.0020	0.0040	0.0015	0.0003	0.000	0.0038
50	0.000	0.000	0.000	0.000	0.0165	0.0190	0.0025	0.0020	0.0038	0.0015	0.0003	0.000	0.0038
100	0.000	0.000	0.000	0.000	0.0160	0.0200	0.0030	0.0020	0.0035	0.0015	0.0003	0.000	0.0039
200	0.000	0.000	0.000	0.000	0.0150	0.0210	0.0045	0.0025	0.0030	0.0015	0.0003	0.000	0.0040
500	0.000	0.000	0.000	0.000	0.0130	0.0260	0.0075	0.0040	0.0035	0.0015	0.0003	0.000	0.0047

Table 5-15: Unit Mean Monthly Discharge – Northern Hydrologic Region

Drainage Area (km^2)	Unit Mean Monthly Discharge (m^3/s/km^2)												Mean Annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
25	0.0000	0.0000	0.0000	0.0000	0.0200	0.0170	0.0026	0.0024	0.0045	0.0013	0.0003	0.0000	0.0040
50	0.0000	0.0000	0.0000	0.0000	0.0185	0.0150	0.0026	0.0024	0.0045	0.0013	0.0003	0.0000	0.0037
100	0.0000	0.0000	0.0000	0.0000	0.0175	0.0130	0.0026	0.0024	0.0045	0.0013	0.0003	0.0000	0.0035
200	0.0000	0.0000	0.0000	0.0000	0.0150	0.0110	0.0027	0.0024	0.0045	0.0013	0.0003	0.0000	0.0031
500	0.0004	0.0002	0.0001	0.0002	0.0100	0.0100	0.0030	0.0024	0.0035	0.0017	0.0012	0.0008	0.0028
1000	0.0004	0.0002	0.0001	0.0001	0.0075	0.0100	0.0030	0.0022	0.0020	0.0010	0.0004	0.0002	0.0023
5000	0.0003	0.0001	0.0001	0.0001	0.0075	0.0100	0.0025	0.0015	0.0015	0.0010	0.0004	0.0002	0.0021

Table 5-16: Unit Mean Monthly Discharge – Central Hydrologic Region

Drainage Area (km^2)	Unit Mean Monthly Discharge (m^3/s/km^2)												Mean Annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	
25	0.0000	0.0000	0.0003	0.0007	0.039	0.012	0.005	0.005	0.005	0.0013	0.0003	0.0001	0.0057
50	0.0001	0.0001	0.0006	0.0007	0.038	0.012	0.005	0.005	0.005	0.0026	0.0005	0.0001	0.0058
100	0.0015	0.0013	0.0019	0.0007	0.038	0.012	0.005	0.005	0.005	0.0030	0.0024	0.0018	0.0065
200	0.0007	0.0006	0.0008	0.0007	0.037	0.012	0.005	0.005	0.005	0.0015	0.0012	0.0009	0.0059
500	0.0003	0.0002	0.0004	0.0007	0.034	0.013	0.005	0.005	0.005	0.0030	0.0010	0.0006	0.0057
1,000	0.0003	0.0002	0.0004	0.0007	0.030	0.013	0.005	0.005	0.005	0.0030	0.0010	0.0006	0.0054
5,000	0.0005	0.0003	0.0004	0.0007	0.015	0.015	0.005	0.005	0.004	0.0040	0.0015	0.0009	0.0044
10,000	0.0005	0.0003	0.0004	0.0007	0.015	0.013	0.005	0.005	0.003	0.0040	0.0015	0.0009	0.0041

Table 5-17: Unit Mean Monthly Discharge – Southern Hydrologic Region

Drainage Area (km^2)	Unit Mean Monthly Discharge (m^3/s/km^2)												Mean Annual
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
25	0.0000	0.0000	0.0000	0.0022	0.035	0.010	0.013	0.005	0.005	0.002	0.0008	0.0003	0.0061
50	0.0000	0.0000	0.0000	0.0022	0.034	0.010	0.013	0.005	0.004	0.002	0.0009	0.0003	0.0060
100	0.0001	0.0001	0.0001	0.0022	0.033	0.009	0.013	0.005	0.004	0.003	0.0010	0.0004	0.0059
200	0.0001	0.0001	0.0001	0.0022	0.029	0.008	0.010	0.004	0.003	0.002	0.0008	0.0003	0.0050
500	0.0001	0.0001	0.0001	0.0040	0.020	0.008	0.007	0.004	0.002	0.002	0.0008	0.0003	0.0040
1,000	0.0003	0.0002	0.0002	0.0022	0.010	0.006	0.003	0.003	0.002	0.002	0.0008	0.0003	0.0025
5,000	0.0002	0.0002	0.0002	0.0022	0.010	0.005	0.002	0.003	0.002	0.002	0.0008	0.0003	0.0023

Regional Seasonal Flow Relationships

The highest monthly yield in the central and southern hydrologic regions is in May, and the highest yield in the northern hydrologic region is in late May to early June.

The lowest monthly yield on tributary streams to the Mackenzie River is in March or April before the spring melt. Runoff increases rapidly in May, peaks in late May or June, and subsides quickly in July except in the southern hydrologic region, where higher flow continues through July. Muskeg and wetlands insulate the active layer and therefore retain large amounts of water for attenuated discharge through the summer. Starting in July and August for the southern hydrologic region, basin yield remains fairly constant over fall and winter.

Small to medium-sized streams in the northern hydrologic region, i.e., with drainage areas less than 200 km^2, are also expected to have zero-flow conditions from December to April. Larger streams likely maintain a minimum flow during this period.

Streams are highly influenced by groundwater inflow in the central hydrologic region, where streams with drainage areas larger than 50 km^2 likely maintain some flow over the winter because of groundwater contribution. In some cases, groundwater input results in substantial icings at a site. Depending on local groundwater conditions, stream drainages smaller than 25 km^2 might also exhibit stream flow over the winter, whereas others with less groundwater inflow might freeze completely to the streambed.

As mentioned, higher flow in the southern hydrologic region is maintained through June and July because of the attenuating effects of wetland and muskeg areas. Most small streams, i.e., less than 50 km^2, in the southern hydrologic region freeze to the bottom in winter. Deep ponds created by beavers might be exceptions. Larger streams might also have minimal flow in February and March before temperatures start to rise and melting begins.

5.3.3.6 Peak Flow

A peak flow analysis was done for each hydrologic region to characterize regional peak flow conditions. Limited data on stream sizes and types means that the peak flow characteristics of ungauged streams estimated from regional analysis might not be suitable for design purposes.

Calculation of Peak Flow

The peak flow analysis procedure involved the following four steps:

1. Selecting regional hydrometric stations based on mean annual yield and hydrologic regime.

2. Compiling instantaneous peak flow records for each site. Missing data was estimated by applying a correction factor to maximum daily flow where available. Assumptions of linear relationships between the two flow records were verified.

3. Analyzing flood frequency based on peak instantaneous flow for the selected hydrometric stations in each region. This gave 2-year, 10-year, 25-year and 100-year flood discharge values.

4. Applying relationships among peak discharge, drainage area and physical characteristics of the basins in the region to ungauged streams.

A frequency analysis was done for each station using the peak instantaneous discharge data for every year in the period of record. The Pearson III distribution was selected as the best fit for data in the delta hydrologic region. Table 5-18 shows peak instantaneous discharge values for return periods of 2, 10, 25 and 100 years.

Station 10LD002 was not included in the northern region because it had a period of record for only five years. There are two hydrometric stations at the outlet of lakes in the southern hydrologic region, including:

- Station 10HC006 on the Blackwater River
- Station 07OB005 at the outlet of Hutch Lake

Data at these stations was not included in the regional analysis because peak flow was highly attenuated. Results of the frequency analysis were used to develop regional regression equations relating peak instantaneous discharges to drainage area. These relationships were used to transfer peak flow estimates to local ungauged sites in the study area.

Regional Peak Flow Relationships

Table 5-19 shows the estimated peak flow relationships derived from the regional analysis.

During screening and selection of hydrometric stations, only three stations in the northern hydrologic region were found suitable for use in the regional hydrologic analyses. As a result, data at these stations was supplemented with data from stations in the delta hydrologic region.

Table 5-18: Peak Discharge for Hydrometric Stations

Station Name	Station Number	Hydrologic–Geomorphic Region	Drainage Area (km^2)	Years of Record	Typical Months of Peak Flow	Flood Discharges, Q_T[1] (m^3/s)			
						Q_2	Q_{10}	Q_{25}	Q_{100}
Hans Creek above Eskimo Lakes[2,3]	10ND004	Delta and northern	329	13	May, June	18.7	28.7	33.1	38.9
Trail Valley Creek near Inuvik	10ND002	Delta and northern	68.3	23	May, June, Aug	9.31	11.6	12.7	13.1
Hans Creek near Inuvik[2]	10ND001	Delta and northern	337	10	June	18.7	28.7	33.1	38.9
Babbage River below Caribou Creek[3]	10MD002	Delta and northern	1,510	19	May, June, Aug	239	450	568	748
Firth River near mouth[3]	10MD001	Delta and northern	5,710	27	May, June, July, August	621	1,000	1,160	1,380
Havikpak Creek near Inuvik	10LC017	Delta and northern	15	7	May, June	2.01	4.28	5.36	6.88
Boot Creek near Inuvik	10LC010	Delta and northern	28.2	10	May, June	2.67	4.48	5.18	6.07
Cabin Creek above Highway 8, Dempster Highway	10LC009	Delta and northern	133	13	May	18.6	23.8	26.9	28
Jackfish Creek near Fort Good Hope	10LD002	Northern	62.9	7	May	4.32	5.12	5.23	5.28
Caribou Creek above Highway 8, Dempster Highway	10LC007	Northern	625	26	May	28.8	53.7	64.8	77.8
Rengleng River below Highway 8, Dempster Highway	10LC003	Northern	1,310	28	May, June	38.2	92.9	122	167
Great Bear River at outlet of Great Bear Lake	10JC003	Central (local)	145,000	39	July-October	600	722	784	873
Willowlake River below Metahdali Creek	10GB001	Central (local)	20,500	12	May, July (1)	770	1,080	1,210	1,380
Bosworth Creek near Norman Wells	10KA007	Central	109	15	May	11.1	18.1	21.2	25.4
Jungle Ridge Creek near mouth	10KA006	Central	41.3	14	May, July (1)	8.76	12.6	14.0	15.6
Whitefish River near mouth	10JD002	Central	4,740	16	May, June	186	266	295	330

Table 5-18: Peak Discharges for Hydrometric Stations (cont'd)

Station Name	Station Number	Hydrologic–Geomorphic Region	Drainage Area (km^2)	Years of Record	Typical Months of Peak Flow	Flood Discharges, Q_T[1] (m^3/s)			
						Q_2	Q_{10}	Q_{25}	Q_{100}
Blackwater River at outlet of Blackwater Lake	10HC006	Central	7,850	9	May, Sep (1)	349	549	620	707
Big Smith Creek near Highway 1	10HC003	Central	964	22	May, Sep (1)	103	149	166	188
Metahdali Creek above Willowlake River	10GB005	Central	344	12	May, July (2)	21.3	51.6	67.7	91.8
Sahndaa Creek at Highway 1	10GC005	Southern	251	9	Apr (1), May, July (2), Aug (1), Sep (1)	25.8	41.5	49.6	61.4
Martin River at Highway 1	10GC003	Southern	2,050	29	May, June, July (2)	80.6	161	210	288
Harris River near mouth	10GC002	Southern	701	23	Apr (2), May, June (1), July, Aug (1)	21.2	40.5	49.1	60.9
Jean-Marie River at Highway 1	10FB005	Southern	1,310	29	Apr (1), May, June (2), July, Aug (2), Sep (1)	39.0	72.1	86.4	106
Trout River at Highway 1	10FA002	Southern	9,270	32	May, June (2), July, Aug (2), Sep (1)	186	342	419	532
Scotty Creek at Highway 7	10ED009	Southern	202	7	Apr (1), May, Aug, Sep (1)	3.66	6.53	7.85	9.69
Rabbit Creek at Highway 7	10ED006	Southern	92.7	7	May, July, Aug (1), Sep (1)	6.60	9.00	9.66	10.3
Birch River at Highway 7	10ED003	Southern	542	28	Apr, May, June (2), July (2), Aug, Sep (1)	32.0	62.1	77.1	98.8
Fontas River near mouth	10CA001	Southern	7,400	10	May, June, July, Aug (1)	365	585	679	805
Whitesand River near Northwest Territories–Alberta boundary	07PA002	Southern	3,410	9	May, June (1), July	252	316	336	358

Table 5-18: Peak Discharges for Hydrometric Stations (cont'd)

Station Name	Station Number	Hydrologic–Geomorphic Region	Drainage Area (km^2)	Years of Record	Typical Months of Peak Flow	Flood Discharges, Q_T[1] (m^3/s)			
						Q_2	Q_{10}	Q_{25}	Q_{100}
Chinchaga River near High Level	07OC001	Southern	10,400	32	Apr, May, June, July, Aug,	334	611	738	914
Hutch Lake Tributary near High Level	07OB007	Southern	103	10	Apr, May, June (1), July (1), Aug (1)	1.26	2.19	2.56	3.03
Lutose Creek near Steen River	07OB006	Southern	292	25	Apr, May, June, July (2), Aug (2)	7.04	14.5	18.2	23.4
Steen River near Steen River	07OB004	Southern	2,610	27	Apr, May, June, July, Aug (1)	60.9	93.0	106	122
Hay River near Meander River	07OB003	Southern	36,900	27	Apr, May, June, July, Aug	449	681	777	905
Sousa Creek near High Level	07OA001	Southern	819	31	Apr (2), May, June, July, Aug	15.7	41.5	56.4	79.4

NOTES:
1 Q_T = flood discharge with a return period of T years
2 Station 10ND004 was used to characterize peak flow in Hans Creek (data collected before Station 10ND001 was moved was not used).
3 Station was considered in the analysis but not included in final derivation of regional relationships.
See Figure 5-6, shown previously, for hydrologic regions.
( ) number of occurrences in that month

Table 5-19: Estimated Peak Flow Relationships

Hydrologic Region		Discharge, Q_T (m^3/s)			
		Q_2	Q_{10}	Q_{25}	Q_{100}
Delta[1]		$0.392\ DA^{0.674}$	$0.549\ DA^{0.712}$	$0.607\ DA^{0.724}$	$0.659\ DA^{0.742}$
Northern		$0.392\ DA^{0.674}$	$0.549\ DA^{0.712}$	$0.607\ DA^{0.724}$	$0.659\ DA^{0.742}$
Central		$0.425\ DA^{0.722}$	$0.699\ DA^{0.724}$	$0.801\ DA^{0.727}$	$0.928\ DA^{0.731}$
Southern	Lakes and wetlands >50% DA	$0.151\ DA^{0.765}$	$0.233\ DA^{0.752}$	$0.247\ DA^{0.769}$	$0.387\ DA^{0.753}$
	Lakes and wetlands <50% DA	$0.497\ DA^{0.716}$	$0.776\ DA^{0.727}$	$0.689\ DA^{0.760}$	$0.960\ DA^{0.743}$

NOTES:
Q_T = discharge with a return period of T years
DA = drainage area in km^2
1 These relationships do not apply to Mackenzie River distributary, delta or channels.
Peak flow relationships are presented in the form $a(DA)^b$ where DA = drainage area in km^2 and a and b are constants.
See Figure 5-6, shown previously, for hydrologic regions.

High variability in peak discharge in the southern hydrologic region suggests that, in addition to drainage area, flood generation processes might be highly affected by the abundance of lakes, wetlands or muskeg in the watershed. Stations in the southern hydrologic region were grouped into two categories based on the extent of lakes and poorly drained land:

- basins with lakes, wetlands and muskeg covering more than 50% of the drainage area
- basins with lakes, wetlands and muskeg covering less than 50% of the drainage area

The regional hydrologic analysis for the southern hydrologic region was based on the two drainage categories.

Results from regional hydrologic analysis suggest that peak flood flow increases from north to south along the proposed pipeline route, though they might actually be markedly lower in southern basins than in other regions because of the influence of lakes and wetlands.

Peak Flow Events

Differences in timing of peak flow between drainage areas of different sizes are important when comparing monthly yields between basins. Figure 5-17 shows that the timing of peak runoff varies with drainage area in the delta hydrologic region. In the delta and northern hydrologic regions, peak runoff is usually at the end of May or in early June, with runoff beginning earlier in larger basins than in smaller ones. In the central and southern hydrologic regions, peak runoff is in May for all basin sizes.

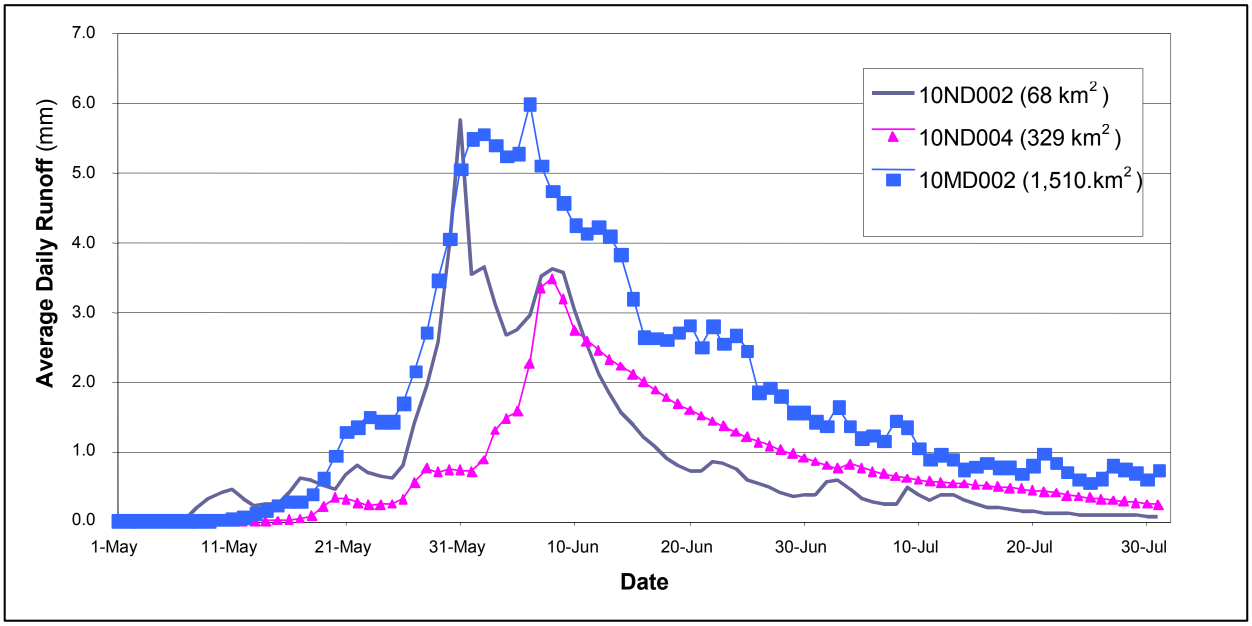


Figure 5-17: Timing of Peak Runoff in the Delta Hydrologic Region

5.3.3.7 Low Flow

Low flow is often used to assess the amount of water that might be present in a channel, the suitability for water withdrawals and the potential for water quality effects on a stream. Whereas flood frequency is usually described in terms of peak instantaneous or maximum daily discharge, low flow frequency is reported in terms of flow magnitude as well as duration, e.g., the seven-day average low flow.

Calculation of Low Flow

The procedure for analyzing low flow involved the following steps:

1. Regional hydrometric stations were selected on the basis of mean annual yield and hydrologic regime.
2. The seven-day moving average of daily flow was calculated for the open-water season, June 1 to September 30, for each year at each gauged stream. Minimum seven-day moving average and minimum daily flow at each gauged stream for each year were determined and compiled in a series for the period of record.

3. Low flow frequency analysis was done for the selected hydrometric stations in the region to obtain $7Q_{10}$ (minimum seven-day) flow and $1Q_{10}$ (minimum daily) flow. $7Q_{10}$ is defined as the seven-day low flow with a return period of 10 years. $1Q_{10}$ is the minimum one-day low flow with a return period of 10 years.
4. Relationships between low flow, drainage areas and physical characteristics of the basins in the delta region were examined.

For each station, minimum seven-day moving averages and minimum daily flow were determined for every year in the period of record. A frequency analysis was done on the resulting data series. Stations with less than 10 years of data were not considered in the low flow analysis. Several probability density functions were considered in the frequency analysis for each station, and the best-fit distribution was selected. Low flow data for stations used in the regional analysis is summarized in Table 5-20. Hydrometric Station 10GB005 in the central hydrologic region was not included in the regional analysis because the low flow data was considered an outlier.

Results of the frequency analysis were used to develop regional relationships between low flow and drainage area. The relationships derived from the regional analysis are summarized in Table 5-21.

5.3.3.8 Flow Duration and Exceedance

Duration of flow over a given period and the probability of exceeding this flow are important aspects of stream flow analysis with respect to fish habitat, water quality and water withdrawals.

An analysis of flow exceedance was done for two periods:

- July 1 to September 30 to represent summer low flow conditions
- November 1 to March 31 to represent winter low flow conditions

Flow from April to June and flow in October was not included in the analysis because of rapidly changing spring conditions and ice formation in the fall. Excluding flow during these months ensured the analysis reflected minimum winter flow before any increases in the spring, and base flow conditions over the summer, not including spring freshet peak flow.

The available records of daily summer and winter stream flow were analyzed to determine flow for different return periods. The 75%, 90% and 95% exceedance flow values were determined for each hydrometric station. These values represent the daily flow threshold that, over the season of interest, is exceeded 75%, 90% and 95% of the time. For example, $Q_{90(\text{winter})} = 0.100\ \text{m}^3/\text{s}$ means that a daily flow of $0.100\ \text{m}^3/\text{s}$ is exceeded 90% of the days from November 1 to March 31.

Table 5-20: Summary of Low Flow Data for Hydrometric Stations

Station Name	Station Number	Hydrologic-Geomorphic Region	Drainage Area (km^2)	Years of Record	Low Flow Discharges DQ_T[3] (m^3/s)	
					$1Q_{10}$	$7Q_{10}$
Hans Creek above Eskimo Lakes	10ND004	Delta and northern	329	13	0.030	0.018
Trail Valley Creek near Inuvik	10ND002	Delta and northern	68.3	23	0.001	0.001
Babbage River below Caribou Creek	10MD002	Delta and northern	1,510	19	0.796	0.963
Firth River near mouth	10MD001	Delta and northern	5,710	27	11.1	12.8
Boot Creek near Inuvik	10LC010	Delta and northern	28.2	10	0.001	0.002
Cabin Creek above Highway 8, Dempster Highway	10LC009	Delta and northern	133	13	0.004	0.005
Caribou Creek above Highway 8, Dempster Highway	10LC007	Northern	625	26	0.468	0.509
Rengleng River below Highway 8, Dempster Highway	10LC003	Northern	1,310	28	0.169	0.179
Bosworth Creek near Norman Wells	10KA007	Central	109	15	0.117	0.149
Jungle Ridge Creek near mouth	10KA006	Central	41.3	14	0.024	0.041
Whitefish River near mouth	10JD002	Central	4,740	16	0.932	0.816
Johnny Hoe River above Lac Ste. Therese	10JB001	Central	17,300	24	9.80	9.66
Big Smith Creek near Highway 1	10HC003	Central	964	22	0.563	0.605
Willowlake River above Metahdali Creek	10GB006	Central	20,200	25	7.04	8.36
Metahdali Creek above Willowlake River	10GB005	Central	344	12	0.003	0.016
Martin River at Highway 1	10GC003	Southern	2,050	29	0.157	0.180
Harris River near mouth	10GC002	Southern	701	23	0.001	0.001
Jean-Marie River at Highway 1	10FB005	Southern	1,310	29	0.152	0.282
Trout River at Highway 1	10FA002	Southern	9,270	32	4.02	5.45

Table 5-20: Summary of Low Flow Data for Hydrometric Stations (cont'd)

Station Name	Station Number	Hydrologic-Geomorphic Region	Drainage Area (km^2)	Years of Record	Low Flow Discharges (m^3/s)	
					$1Q_{10}$	$7Q_{10}$
Birch River at Highway 7	10ED003	Southern	542	28	0.021	0.028
Fontas River near mouth	10CA001	Southern	7,400	10	2.55	2.86
Chinchaga River near High Level	07OC001	Southern	10,400	32	1.65	1.78
Lutose Creek near Steen River	07OB006	Southern	292	25	0.003	0.005
Steen River near Steen River	07OB004	Southern	2,610	27	0.032	0.039
Hay River near Meander River	07OB003	Southern	36,900	27	7.06	7.68
Sousa Creek near High Level	07OA001	Southern	819	31	0.003	0.003

NOTE:
1 $DQ_{T,}$ where D = duration in days and T = return period in years

Table 5-21: Relationships Between Low Flow and Drainage Area

Hydrologic Region	Low Flow DQ_T[2] (m^3/s)	
	$1Q_{10}$	$7Q_{10}$
Delta[1]	$0.0000002\ DA^{2.013}$	$0.000004\ DA^{1.566}$
Northern	$0.0000002\ DA^{2.013}$	$0.000004\ DA^{1.566}$
Central	$0.000941\ DA^{0.903}$	$0.001778\ DA^{0.835}$
Southern – Lakes and Wetlands <50% DA	$0.00002\ DA^{1.239}$	$0.000021\ DA^{1.247}$
Southern – Lakes and Wetlands >50% DA	$0.00000001\ DA^{1.953}$	$0.00000003\ DA^{1.918}$

NOTES:
DA = drainage area
1 These relationships do not apply to Mackenzie River distributary channels in the delta. See Figure 5-6, shown previously, for hydrologic regions.
2 DQ_T, where D = duration in days and T = return period in years

Exceedance calculation results were used to derive regional relationships for exceedance flow. The relationship has the following form:

$$Q_P = 0.001a\,(DA)^b$$

where:

- Q_P is the flow in cubic metres per second (m^3/s) with exceedance P (percent)
- DA = drainage area in km^2
- a and b are constants provided in Table 5-22

The equation can be used to estimate exceedance flow at ungauged locations along the proposed pipeline route.

Based on the available stream flow records, all local streams in the delta and northern hydrologic regions are expected to have periods of zero flow over the winter. This result does not apply to major delta channels such as East Channel or Harry Channel or other rivers with very large drainage areas such as Loon or Hare Indian rivers. In the southern hydrologic region, basins with substantial lake, wetland and muskeg influence have hydrologic characteristics different from those with more defined drainage paths. Two exceedance flow relationships are provided to account for these differences (see Table 5-22). Over the winter when water is less available, a single relationship can be applied to the range of basin types.

Table 5-22: Exponents for Exceedance Flow Relationships ($Q_P = a[DA]^b$)

Season	P (%)	Delta Hydrologic Region		Northern Hydrologic Region		Central Hydrologic Region		Southern Region (Lakes and Wetlands <50% DA)		Southern Region (Lakes and Wetlands >50% DA)	
		a	b	a	b	a	b	a	b	a	b
Jul 1– Sep 30 Summer	75	0.135	1.260	0.260	1.107	0.644	1.089	0.009	1.480	0.460	1.127
	90	0.036	1.285	0.049	1.264	0.294	1.116	0.00003	2.001	0.081	1.228
	95	0.020	1.196	0.033	1.205	0.235	1.119	0.00001	2.019	0.036	1.225
Nov 1– Mar 31 Winter	75	0.000	0.000	0.000	0.000	0.0005	1.402	0.0001	1.470	0.0001	1.470
	90	0.000	0.000	0.000	0.000	0.0004	1.369	0.00005	1.458	0.00005	1.458
	95	0.000	0.000	0.000	0.000	0.0003	1.342	0.00007	1.364	0.00007	1.364

NOTES:
$Q_P = 0.001a^*(DA)^b$ where Q_P is the flow in cubic metres per second (m^3/s) with exceedance P (%)
DA = drainage area in km^2
a and b are constants provided in the table
All sites in the delta and northern hydrologic regions are expected to have zero flow at the 75%, 90% and 95% exceedance levels.
Exceedance relationships for the southern hydrologic region in winter are not affected by the percentage of lake, wetland or muskeg area in the basin.
See Figure 5-6, shown previously, for hydrologic regions.

5.3.4 Results from Stream Flow Field Studies

The hydrometric program conducted in 2002 along the pipeline corridor provided information to assess the hydrologic conditions under which the detailed fish habitat surveys were done that year. In particular, it is of interest to determine if the survey was done in typical or atypical conditions, thereby providing some level of confidence in interpretations of habitat suitability and use. The information also provided insight into the hydrologic response of small basins, which is useful for assessing effects.

Conditions observed during the spring hydrology surveys in Niglintgak and Taglu provide additional baseline information to understand the physical processes in the North and to assist in assessing effects.

5.3.4.1 Temperature and Precipitation

Table 5-23 compares January to October 2002 monthly temperature data with temperature normals from 1961 to 1990. Over this period, mean monthly temperatures at Inuvik and Tuktoyaktuk were about 0.9°C higher than average. The southern stations at Fort Simpson and High Level recorded 2002 temperatures from 0.9°C to 1.1°C lower than normal. March, April and May 2002 were colder than normal in the south and warmer in the north.

Table 5-23: Comparison of Temperatures in 2002 with Station Normals

Station		Temperature (ºC)										
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Mean Jan.–Oct.
Tuktoyaktuk	2002	-25.8	-30.2	-22.4	-16	-2.3	6.2	10.4	7.4	5.6	-5.5	-7.3
	Normal[1]	-27.2	-27.6	-25.7	-16.7	-4.7	5.5	10.9	9.1	2.8	-7.6	-8.1
	Difference	1.4	-2.6	3.3	0.7	2.4	0.7	-0.5	-1.7	2.8	2.1	0.9
Inuvik	2002	–	-27.6	-19.8	-12.4	1.3	9.8	12.8	8.3	6.2	-5.3	-3.0[a]
	Normal[1]	-28.8	-28.5	-24.1	-14.1	-0.7	10.6	13.8	10.5	3.3	-8.2	-4.2[a]
	Difference	–	0.9	4.3	1.7	2.0	-0.8	-1.0	-2.2	2.9	2.9	1.2[a]
Norman Wells	2002	-24.3	-24.9	-18.6	-8.7	3.7	14.5	16.6	11	7.3	-2.6	-2.6
	Normal[1]	-27.4	-25.8	-19.0	-6.5	5.8	14.6	16.7	13.5	6.3	-4.8	-2.7
	Difference	3.1	0.9	0.4	-2.2	-2.1	-0.1	-0.1	-2.5	1.0	2.2	0.1
Fort Simpson	2002	-23.2	-22.5	-16.2	-6.4	3.9	15.9	17.1	12.9	7.3	-1.9	-1.3
	Normal[1]	-26.7	-22.0	-14.2	-1.3	8.5	14.7	16.9	14.3	7.5	-2.0	-0.4
	Difference	3.5	-0.5	-2.0	-5.1	-4.6	1.2	0.2	-1.4	-0.2	0.1	-0.9
High Level	2002	-20.7	-14.4	-16.1	-3.7	5.8	15.6	16.3	14.1	7.4	-1.7	0.5[b]
	Normal[1]	-21.4	-18.0	-10.4	1.9	9.7	14.2	16.2	14.0	8.2	–	1.6[b]
	Difference	0.7	3.6	-5.7	-5.6	-3.9	1.4	0.1	0.1	-0.8	–	-1.1[b]

NOTES:
– = not available
1 Station normal = long-term average (1961–1990)
a Mean from February to October
b Mean from January to September

Table 5-24 shows a comparison of January to October 2002 monthly precipitation with 1961 to 1990 normals, i.e., long-term averages. Inuvik had higher-than-average levels of precipitation in June and August, and summer precipitation in Norman Wells was very high in 2002. Fort Simpson also had more precipitation than average from May to July 2002. High Level was particularly dry in all months where data was available, except in September when precipitation was near normal.

5.3.4.2 Hydrologic Conditions

In general, the summer of 2002 was wetter than average and stream flow was higher than average. The increased runoff resulted from a combination of:

- a large amount of precipitation
- restricted drainage because of permafrost
- high levels of ground saturation

Table 5-25 summarizes average weekly flow recorded at eight local hydrometric stations.

At Inuvik, 35 mm of precipitation fell over five days from August 13 to 17, 2002. A small increase in stream flow of 1 m^3/s was recorded at RPR-075, Unnamed Creek (see Figure 5-18). Flow increased comparably at Holmes Creek by about 1 m^3/s (see Figure 5-19). Before this rainfall event, water levels and flow had been receding since the start of the monitoring program. The low flow recorded before the August rainfall reflects the limited precipitation and dry conditions in July.

The more than 71 mm of rain recorded at Fort Simpson July 28 to 29, 2002 was followed by a quick response in the stream discharge measured at the nearby hydrometric stations, producing a high mid-summer peak flow for RPR-477, Jean-Marie Creek (see Figure 5-20). The water level at RPR-487, unnamed creek, appears to have risen above bankfull, and damaged the data logger at the end of July 2002 (see Figure 5-21). The station was reactivated in September for the remainder of the open-water season.

5.3.4.3 Delta Spring Breakup

Niglintgak and Taglu could be subject to extreme hydrologic events during development and operations, particularly in the spring breakup and flood period. In 2003, a spring hydrology survey acquired additional baseline information for the delta area. Breakup observations included evaluation of ice conditions and documentation of spring flood water levels around Niglintgak and Taglu. Progression of breakup, channel ice conditions, ice jamming, extent and depth of flooding, and areas of overland flow were monitored.

Table 5-24: Comparison of 2002 Monthly Precipitation with Station Normals

Station		Precipitation (mm)										
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Total Jan.–Oct.
Inuvik	2002	7.5	8.5	10.5	23	3.5	26	23.5	64.5	16	13.5	196.5
	Normal[1]	15.6	11.1	10.8	12.6	19.1	22.2	34.1	43.9	24.2	29.6	223.2
	Difference	-8.1	-2.6	-0.3	10.4	-15.6	3.8	-10.6	20.6	-8.2	-16.1	-26.7
Norman Wells	2002	4	17.6	5.8	28	2.2	62.2	60.1	85.3	39.2	31.8	336.2
	Normal[1]	18.7	14.7	11.6	14.4	19.7	43.2	50.4	49	30.6	29.5	281.8
	Difference	-14.7	2.9	-5.8	13.6	-17.5	19	9.7	36.3	8.6	2.3	54.4
Fort Simpson	2002	6.3	14.5	18.9	9.3	47.7	61.4	97.2	44.8	18.1	13	331.2
	Normal[1]	19.6	17.8	17.6	16.4	29.8	44.3	53.3	50.7	30.2	36.1	315.8
	Difference	-13.3	-3.3	1.3	-7.1	17.9	17.1	43.9	-5.9	-12.1	-23.1	15.4
High Level	2002	8.8	6.7	6.4	5.3	10.4	47.5	48.3	26.7	38.6	3.2	201.9
	Normal[1]	22.9	17	19.2	17.1	41.5	65	61	–	34.1	–	–
	Difference	-14.1	-10.3	-12.8	-11.8	-31.1	-17.5	-12.7	–	4.5	–	–

NOTE:
– = not available
1 Station normal = long-term average (1961–1990)

Table 5-25: Flow at Local Hydrometric Stations (2002)

Watercourse Name	Derived Mean Weekly Discharge (m^3/s)													
	14 Jun.– 20 Jun.	**21 Jun.– 27 Jun.**	**28 Jun.– 04 Jul.**	**05 Jul.– 11 Jul.**	**12 Jul.– 18 Jul.**	**19 Jul.– 25 Jul.**	**26 Jul.– 01 Aug.**	**02 Aug.– 08 Aug.**	**09 Aug.– 15 Aug.**	**16 Aug.– 22 Aug.**	**23 Aug.– 29 Aug.**	**30 Aug.– 05 Sep.**	**06 Sep.– 12 Sep.**	**13 Sep.– 19 Sep.**
Unnamed stream	1.177	1.073	0.920	0.818	0.717	0.549	0.391	0.329	0.335	0.510	0.553	0.570	0.570	0.557
Travaillant River	3.979	3.679	2.967	2.364	1.970	1.521	1.058	0.720	0.790	1.558	2.002	1.866	1.749	1.832
South Snafu Creek	5.430[a]	1.935	0.507	0.466	0.144	0	0	0	0	0.563	0.967	0.392	0.218	0.542
Bosworth Creek	1.256[a]	0.997	0.725	0.923	0.766	0.579	0.460	0.458	0.523	0.855	0.909	0.974	0.935	0.887
Steep Creek	–	1.223	1.237	1.240	1.291	1.096	1.133	1.138	1.151	1.227	1.330	1.398	1.204	1.529
Jean-Marie Creek	–	0.679	0.464	0.323	0.407	0.794	2.398	2.858	1.385	0.945	0.511	0.396	0.375	0.303
Unnamed stream	–	0.160	0.061	0	0.374	0.929	1.060[b]	–	–	–	–	–	0.2811	0.150

NOTES:
– = not available
a Estimated from five or six days of data

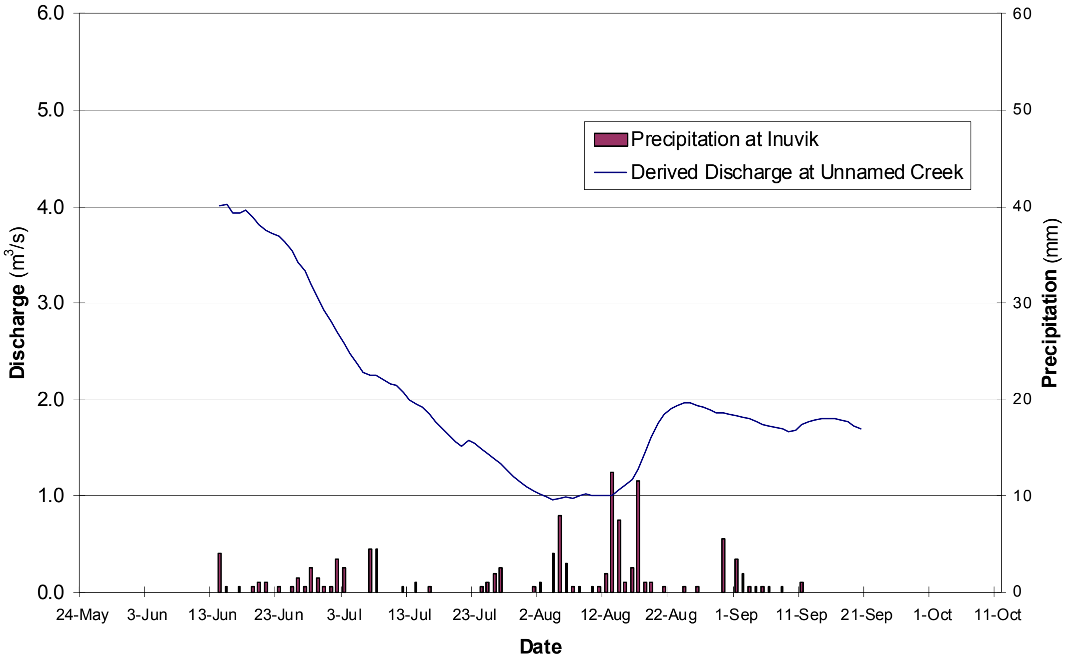


Figure 5-18: Response to Rainfall at RPR-075, Unnamed Creek (2002)

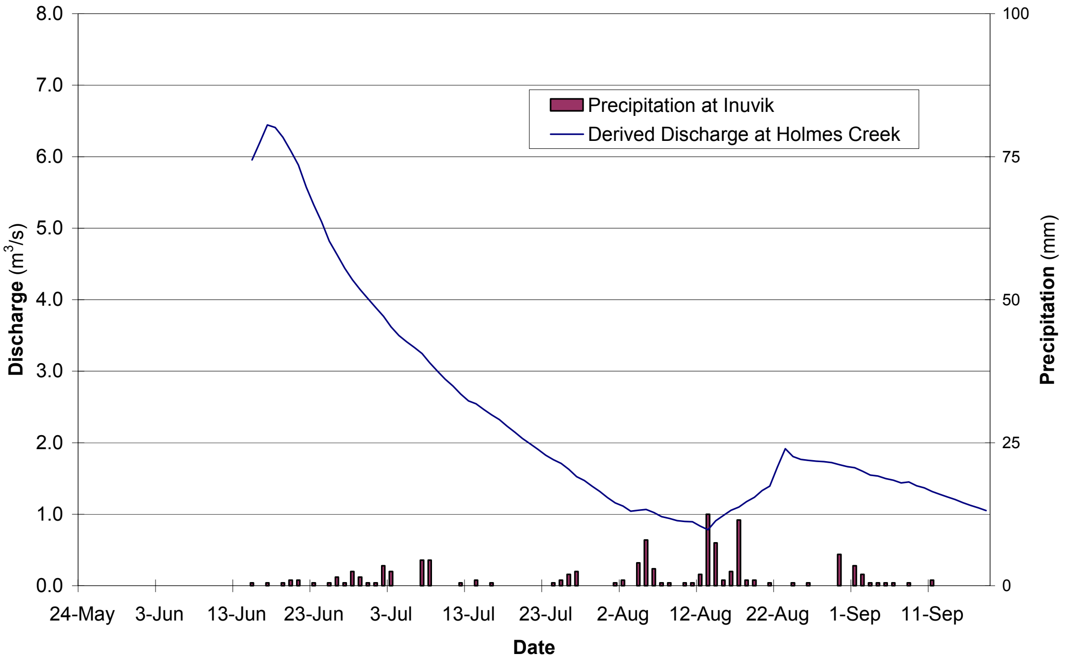


Figure 5-19: Response to Rainfall at Site 23, Holmes Creek (2002)

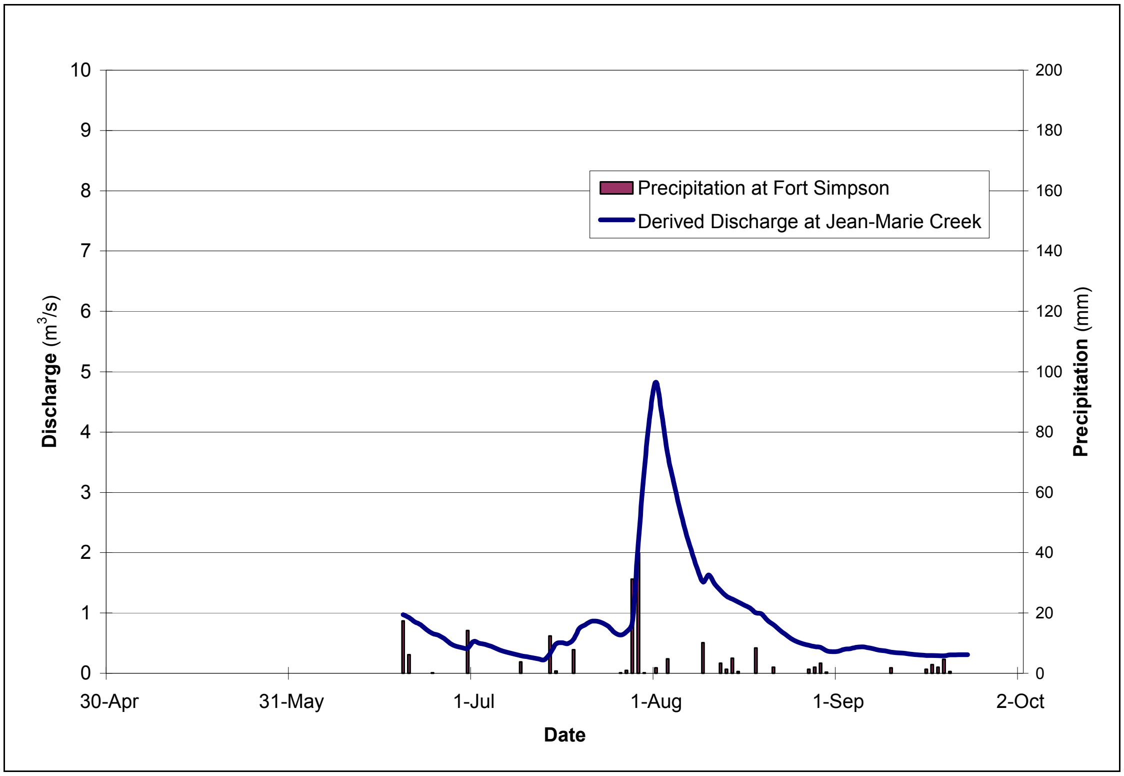


Figure 5-20: Response to Rainfall at RPR-477, Jean-Marie Creek (2002)

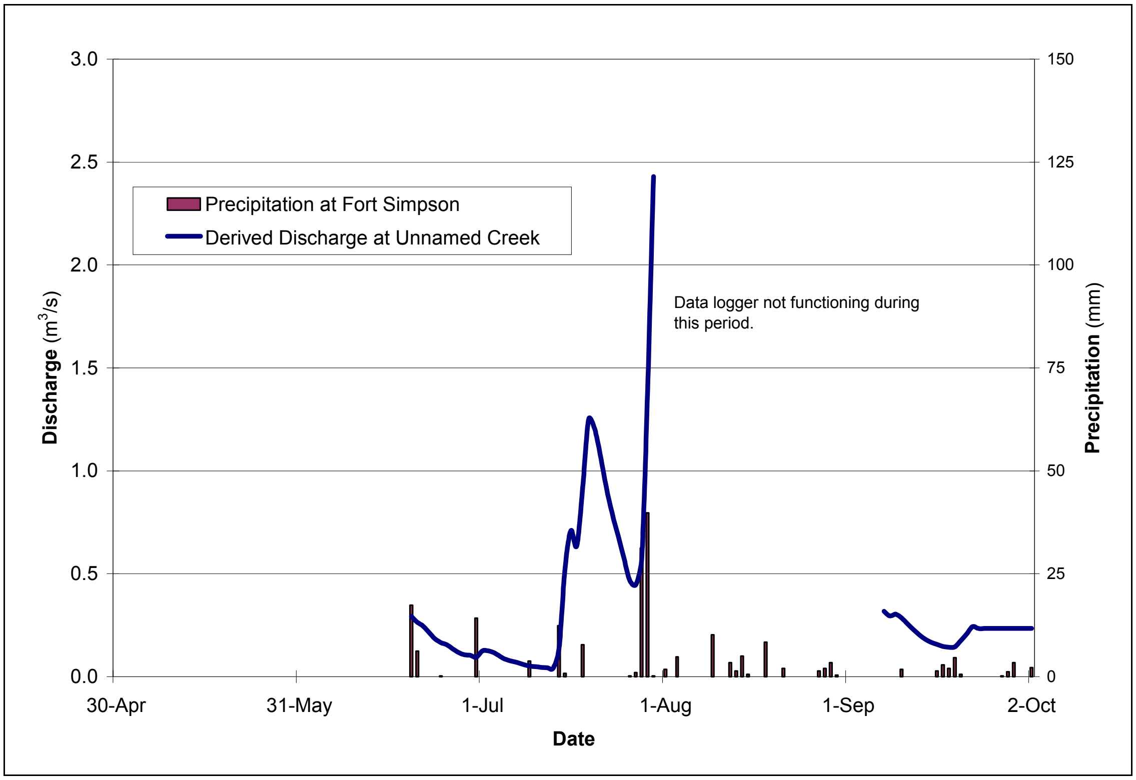


Figure 5-21: Response to Rainfall at RPR-487, Unnamed Creek (2002)

Overview of Spring Breakup Observations

The spring breakup front moved through the Mackenzie River East Channel at Inuvik during the night of June 1 and early morning of June 2, with the highest water level occurring on the evening of June 2. Downstream from Inuvik, the channel ice in Middle Channel moved on the afternoon of June 4 and at Swimming Point the ice moved through East Channel in the early hours of June 5. Near Langley Island, on Middle Channel downstream from East Channel, breakup is believed to have occurred on June 5 based on peak water level data from Water Survey of Canada Station 10MC010.

Spring breakup in Niglintgak and Taglu progressed gradually from May 29 to June 5 and was dominated by thermal processes. Open-water leads developed and increased in size slowly. The channel ice deteriorated over this period but remained intact in the channels with minimal cracking.

The breakup front likely reached the area, coincident with maximum flood levels, on June 6 based on Water Survey of Canada data (Station 10MC010) and on continuous water level data from the Taglu water level station. Breakup at Niglintgak and Taglu became more dynamic on June 6 because of increased inflow and ice floes from upstream reaches. Remaining ice cover was pushed out by the breakup front, and likely broken into smaller pieces. Ice moved quickly through the area and within 12 hours peak water levels receded to pre-flood levels at Taglu. Water levels continued to drop to below bank levels in the following days. Because of the initial thermal breakup at Niglintgak and Taglu, damage and scarring from the dynamic event was minimal.

Open-water leads along the Beaufort Coast occurred at various levels at all channel outlets during the first observations on May 31.

According to area residents, the 2003 spring breakup and subsequent flood levels passed quickly through Niglintgak and Taglu. The degree of flooding was considered to be low to average.

5.3.5 Sediment Conditions

Construction of the proposed gathering pipelines can increase the amount of sediment entrained in streams at watercourse crossings whenever methods other than trenchless or aerial crossings are employed. The following section summarizes basin sediment yield, potential extent of sediment transport within stream reaches and fine sediment deposition in lakes.

5.3.5.1 Mackenzie River Sediment

The amount of sediment reaching the Mackenzie Delta is influenced by the amount of sediment generated in tributary sub-basins and carried along the main stem. Bank erosion, landslides and general alluvial processes all contribute to the amount of sediment transported into the delta.

Most of the sediment information for the Mackenzie Delta was acquired, analyzed and synthesized as part of a 1991 to 1994 Environment Canada and Northern Oil and Gas Action Program. A sediment budget and a sediment flux were developed and channel stability and sedimentation were assessed. Carson (1994a, 1994b), estimated the Mackenzie, Arctic Red and Peel rivers contribute about 127 Mt of suspended sediment to the head of the delta each year, an amount modelled over the 1974 to 1990 period using a one-dimensional model developed and maintained by Environment Canada. Carson also estimated about 112 Mt of sediment leaves the lower subaerial delta each year and enters the tidal and offshore areas by way of the East, Middle and Reindeer channels at the head of Richards Island. The model estimated net sediment trapping in the delta to be 15 Mt, which is half the estimate based on sedimentation data for levees, lake basins and lake beds.

The model does not, however, account for delta inundation or lake storage and might therefore overestimate sediment export at high water levels because of higher modelled flow and sediment loads. The reports also note that about 40% of the incoming sediment load is deposited in delta channels, which means a large part of the 112 Mt of sediment leaving the delta comes from re-entrainment of deposited delta sediment or from bank erosion.

Carson et al. (1998) is the most recent discussion on sediment loads in the Mackenzie Delta. This summary report presents available data from 1974 to 1994 and discusses the seasonal variation and annual loads of suspended sediment reaching the delta. As shown in Table 5-26, the Arctic Red and Peel rivers carry their highest sediment loads in May and June, whereas the highest levels in the main stem of the Mackenzie River are in June and July. The timing of these levels corresponds to high sediment input from the Liard River upstream. Sediment load from November to April is very low. The predicted load on the Mackenzie River is 0.3 Mt in November and 0.1 Mt in all other winter months.

Carson (1994a) also reviewed other sediment studies done as part of the Northern Oil and Gas Action Program and estimated mean annual lake-bed sedimentation to be 12 Mt and bank sedimentation to be 38 Mt, not including the main delta channels. Lapointe (1986) used air photographs from the 1950s, early 1970s and early 1980s to investigate channel-bank scour in the Mackenzie Delta. In the sinuous reaches far from coastal channel mouths, annual peak bend shifting rates are about 0.5% of channel width. Straighter sections near channel mouths are often eroded simultaneously on both banks, likely because of reverse flow, wave action and storm surges (Lapointe 1986).

Table 5-26: Mean Monthly Fine Sediment Loads for Delta-Head Rivers

Month	**Mackenzie River**[1] (Mt)	**Arctic Red River**[2] (Mt)	**Peel River**[2] (Mt)	**Total** (Mt)
May	21	3.1	10.1	34
June	34	2.4	8.2	45
July	21	0.6	1.5	23
August	14	1.0	0.7	16
September	4	0.1	0.3	4
October	2	0.1	0.0	2
Total	96	7.3	20.8	124

NOTES:
1 Wash load (d<0.125 mm)
2 Suspended load

SOURCE: Carson et al. (1998)

The main stem of the Mackenzie River from the outlet of Great Slave Lake to Fort Simpson has low sediment concentrations because of the trapping of upstream sediments by Great Slave Lake. A recent synopsis of sediment conditions in the Mackenzie Basin by Carson et al. (1998) provides estimates for key components of the sediment budget. For example, the suspended sediment load for the upper Mackenzie River in this reach is estimated to be 2.5 Mt per year, with concentrations ranging from about 10 to 50 mg/L. The Liard River at Fort Simpson is identified as the main source of sediment entering the Mackenzie River with an annual suspended sediment load of about 41 Mt. Additional input from other west-side tributaries is estimated to be about 36 Mt annually, for a total of 77 Mt.

By comparison, tributaries along the east side of the Mackenzie River are relatively stable, with little erosion and sedimentation. The muskeg drainage in the southern Deh Cho Region tends to yield small amounts of sediment, whereas the steeper terrain to the north produces slightly more. A preliminary estimate of fine sediment input from east-side tributaries along the pipeline route is only 5 Mt per year.

Few studies have been done to estimate the bed material load of the Mackenzie River. Carson et al. (1998) estimated long-term annual total bed material input to the delta to be 4 Mt. This estimate was based on a suspended sediment load of 96 Mt and measurements that indicate 2 to 6% of suspended sediment is larger than 0.125 mm in size, i.e., bed load. Using the same assumptions, the combined bed load of the Arctic Red and Peel rivers is about 1 Mt.

5.3.5.2 Comparison of Sediment Input from West- and East-Side Tributaries

Carson (1988) described a method of estimating the relative sediment contributions of Mackenzie River tributaries based on:

- relative stream power, defined as the product of discharge and stream gradient
- the assumption that discharge is controlled by rainfall and snowmelt, which vary according to elevation
- the assumption that sediment availability is constant between basins

Calculated sediment loads from the Arctic Red River station were used as a basis for scaling yields in other basins. Table 5-27 is a summary of the estimated sediment loads. Sediment contribution from even the largest eastern tributaries, e.g., the Hare Indian and Willowlake rivers, is minute compared with the sediment from basins on the west side of the Mackenzie River.

5.3.5.3 Sediment Data Along Pipeline Corridor

Table 5-27 (cited previously) indicates that the east-side tributaries of the Mackenzie River contribute less sediment than those that drain the mountainous region to the west. The difference can be attributed to their low gradients, the presence of lakes and much less deposited fine-grained glacial sediment than on the western slopes (Carson et al. 1998). Carson et al. (1998) speculated that tributaries on the east side of the Mackenzie River produce less than 5 Mt per year. The relative insignificance of sediment loading from the low-lying terrain to the east is reflected in the scarcity of sediment data available for these streams.

The only suspended sediment data available for Mackenzie River tributaries near the confluence of the main stem, east or west side, is for the Harris, Liard, Martin, Redstone, Trout and Willowlake rivers, though periods of record are limited to very few years. Carson (1988) noted that yields of the Harris, Martin, Trout and Willowlake rivers are so small that they are of little significance in any interpretation of the sediment load of the Mackenzie River. Only five Environment Canada hydrometric stations could be used to characterize sediment loads of streams crossed by the proposed pipeline. The available records are limited to three years of data and date to the early and mid-1970s. Table 5-28 lists the five stations and their recorded sediment yields.

Sediment rating curves were developed from the limited discharge and concentration data recorded at each station. In some cases the data was limited to a single season, and in most cases it reflects the hysteresis, i.e., two concentration levels for the same discharge before and after the peak, associated with a single high flow event. Daily loads for the same period were calculated as the product of mean daily flow and either recorded sediment concentration or sediment concentration estimated from the rating curve. Evaluation of sediment conditions did not include extrapolation to other years and extension of the sediment record. The annual load for each station was derived by summing daily sediment loads.

Table 5-27: Annual Sediment Load Estimates Based on Stream Power

Tributary	East or West Tributary	Maximum Elevation (m)	Basin Area (km²)	Stream Slope (m/m)	Stream Power Index[1]	Suspended Sediment Load[2] (Mt)
Peel	West	1,676	78,746	0.116	15,252	11.1
Keele	West	1,753	27,110	0.265	12,598	9.2
Redstone	West	2,134	15,747	0.366	12,282	8.9
Arctic Red	West	2,286	21,456	0.199	9,754	7.1
Root	West	2,286	9,933	0.413	9,375	6.8
Mountain	West	1,524	14,983	0.398	9,082	6.6
North Nahanni	West	2,286	7,125	0.436	7,095	5.2
Johnson	West	1,219	2,214	0.826	2,229	1.6
Dahadinni	West	1,067	2,709	0.485	1,401	1.0
Wrigley	West	762	1,300	0.820	813	0.6
Ontaratue	West	152	6,853	0.059	61	0.0
Carcajou	East	1,981	9,135	0.036	651	0.5
Willowlake	East	335	21,184	0.051	363	0.3
Between Two Mountains	East	396	3,484	0.223	308	0.2
Hare Indian	East	259	11,352	0.063	184	0.1
Travaillant	East	290	2,911	0.112	94	0.1
Tieda	East	351	945	0.269	89	0.1

NOTES:

1 Stream power index is the product of elevation (m), area (km²) and slope (m/m), divided by 1,000.

2 Estimate of suspended sediment load is derived by scaling down, or up, the actual load of the Arctic Red River by an amount equal to the ratio of the power indices.

SOURCE: Carson (1988)

Table 5-28: Available Sediment Data and Estimated Annual Yield

Station Number	Station Name	Drainage Area (km^2)	Period of Record	Annual Yield (t)	Annual Yield (t/km^2)	Mean Annual Flow (m^3/s)	Maximum Daily Flow (m^3/s)
10GB001	Willowlake River	20,500	1973	101,000	4.9	61.3	85.0
10GC002	Harris River	701	1973	255	0.4	0.526	8.44
			1974	1,100	1.6	1.38	24.8
			1976	63	0.1	1.70	36.2
10GC003	Martin River[1]	2,050	1973	15,800	7.7	4.94	68.5
			1974	20,600	10.0	6.49	79.9
			1976	3,230	1.6	7.63	113
10FA002	Trout River	9,270	1973	9,700	1.0	35.4	214
			1974	25,000	2.7	42.6	238
10LC003	Rengleng River	1,310	1973	24,000[a]	18.0	–	103

NOTES:
– = not available
a Sediment data is only available for the receding limb of the annual hydrograph (June to October). Summation of daily loads, i.e., product of concentration and daily flow, provides a yield of 24,000 tonnes, though the published load from Environment Canada (2000) is only 6,610 tonnes. The reason for this discrepancy is unknown.
1 Martin River is on the west side of the Mackenzie River but drains less mountainous terrain than other west-side tributaries.

Table 5-28 (cited previously) also indicates a wide variance from year to year in total sediment load from each basin. The sediment yield in 1974 is much higher than the yield in 1973 in all cases. Comparison of stream discharge shows that mean annual flow was comparable for these years, though peak flow was 10% to 50% higher in 1974 than in 1973. As the spring freshet transports most of the sediment load, sediment yield increased proportionately in spring. Although Martin River, i.e., Station 10GC003, is a west-side tributary, it drains considerably less mountainous terrain than other tributaries from the Mackenzie Mountains and was included in the table for comparison. The Rengleng River appears to have carried a very high sediment load of over 24,000 tonnes ($18\ t/km^2$) in 1973, based on a partial record from that year. The published volume, however, is only 6,610 tonnes (Environment Canada 2000) and corresponds to a reduced yield of $5\ t/km^2$, which is comparable to yields observed in other basins.

Because of the scarcity of sediment data for eastern tributaries, it is not possible to derive regional relationships for sediment delivery and predicted concentrations. Sediment concentrations are expected to be relatively low, and input from eastern tributaries to the Mackenzie River is known to be small compared with the western tributaries. Observations from the spring hydrology surveys support these assumptions. Visual observations showed that most streams have low to moderate turbidity levels. Colour levels were elevated in some cases, though suspended sediment levels was not substantial. Water was also observed to be relatively clear with low turbidity levels in summer, even during high-water conditions.

A range of estimated mean annual suspended sediment concentrations along the pipeline route based on the Hydrological Atlas of Canada was provided in Polar Gas (1984). Table 5-29 summarizes the sediment concentrations, which range from 400 mg/L in the northern delta channels to nearly zero in the southern Deh Cho Region and eastern tributaries.

Table 5-29: Suspended Sediment Concentrations along the Pipeline Route

Location	Mean Annual Concentration (mg/L)
Taglu to Campbell Lake	201–400
Campbell Lake to Fort Simpson	51–200
Fort Simpson to northwestern Alberta	0–50
Northwestern Alberta	51–200
SOURCE: Hydrological Atlas of Canada (1978) as provided in Polar Gas (1984)	

5.3.6 Stream Classification

A stream classification system was developed to describe drainage and flow characteristics of the many watercourses that will be crossed by the proposed pipeline. The stream classes were regionally derived and are considered transferable within a given hydrologic region. Stream classes for watercourses crossed by the 2003 refined pipeline route were assigned based on the regional classification relationships and the drainage area and slope of each channel. Table 5-30 defines the stream classes used.

Drainage Area and Slope

Drainage area, which relates directly to the amount of surface flow contributed to a stream, is often used to evaluate and predict hydrologic responses of watersheds. Basin slope also affects the hydrologic characteristics of a drainage because it influences runoff, particularly rainfall and snowmelt response times and flow attenuation because of upland storage.

Geomorphic characteristics of a stream reach are determined by local channel hydraulics. Variations in flow, width, depth and velocity affect the size of bed material that can be transported and the growth of vegetation in and along the flow path. When characterizing streams, channel slope (S_c) can be substituted for flow velocity because according to Manning's equation, i.e., $V \propto S_c^{1/2}$, velocity is proportional to the square root of channel slope.

Table 5-30: Stream Classes

Stream Class	Description
Large River Channel	Large named watercourses with perennial flow Drainage areas >1,000 km^2 and wetted width typically >25 m
Active Channel	Intermittent and perennial streams with drainage areas <1,000 km^2, including those that freeze partially or completely to the bottom in winter Discernible banks and substrate, including silt and organic material Two major subgroups: • Active I – Perennial or partially frozen to bottom in winter, including areas highly influenced by groundwater input or beaver activity that might create open water, and by perennial flow or large pools and water depths • Active II – Frozen to bottom or dry below ice during winter, i.e., smaller drainage basins with low flow and shallow depth
Vegetated Channel	Ephemeral streams including vegetated waterways, depressions and swales Watercourses that flow primarily during spring runoff and are dry in late summer and over winter No discernible banks or evidence of annual sediment transport Areas of dispersed overland flow, i.e., wetland drainage areas Shallow flow through shrubs and trees Very little to no groundwater contribution to flow

The drainage area of each stream at its proposed crossing location was delineated and measured using 1:50,000 scale topographic maps. Smaller-scale (1:250,000) maps were used for watersheds extending beyond the limits of the 1:50,000 scale map atlas. Basin slope and local channel slope were also measured from the topographic maps. In flat regions, e.g., the Mackenzie Delta or streams between two lakes, the local slope was assumed to be 0.002 m/m. This value is a reasonable assumption for low-gradient areas where the intent is limited to providing a rough characterization of streams. Measured slopes were not, for the purpose of stream classification, updated using survey information collected in the summer 2002 surveys. This approach was taken to ensure a consistent method for all streams, because fewer than 20% of all streams were assessed in detail. The available surveyed slopes provided ground-truthing for the desktop exercise and site-specific information for larger watercourse crossings.

Table 5-31 indicates the distribution of drainage areas for each hydrologic region along the pipeline route. For example, 80% of all sites in the delta hydrologic region are less than 13 km^2 in size. Similarly, 90% of all sites in the southern hydrologic region are less than 237 km^2.

In the discussions that follow, assessments of channel types and slopes are presented for each region. These assessments consider only streams with drainage areas greater than 1000 km^2, which are assumed to have perennial flow.

Table 5-31: Drainage Basin Sizes by Hydrologic Region

Percentage of Sites (%)	Drainage Basin Size for Sites in Each Hydrologic Region (km^2)			
	Delta	Northern	Central	Southern
50	<1.6	<2	<5.4	<7
70	<5	<6	<14	<29
80	<13	<13	<33	<60
90	<34	<42	<134	<237
95	<115	<150	<400	<1,500

Table 5-32 summarizes the channel types and stream slopes for each of the hydrologic-geomorphic regions.

Table 5-32: Summary of Channel Types and Stream Slopes by Hydrologic Region

Region	Number of Sites[1]					Average Channel Slope (m/m)	Average Basin Slope (m/m)
	Large River	Active I	Active II	Vegetated	Total		
Delta	6	11	6	54	77	0.011	0.015
Northern	4	15	20	176	215	0.013	0.022
Central	6	25	36	120	187	0.022	0.042
Southern	4	37	10	42	93	0.006	0.007
Total	20	88	72	392	572	N/A	N/A

NOTE:
N/A = not applicable
1 Sites include streams only and do not include lakes adjacent to the proposed pipeline.

5.3.6.1 Delta Hydrologic Region

Most streams crossed by the flow lines and the gathering pipelines are vegetated waterways with either an undefined drainage path or dispersed flow through small shrubs or trees. Remaining streams are watercourses with a discernible channel, some temporary and others perennial or considered to be Large River Channels.

Drainage area, slope and channel type are plotted in Figure 5-22, which illustrates the relationship between these basin characteristics. The figure shows only those sites with drainage areas larger than 1 km^2 and less than 1,000 km^2.

Smaller, flatter watercourses are typically Vegetated Channels, whereas those with larger drainage areas have Active Channels. Small channels connecting two lakes are exceptions, with channels larger than would be expected based on drainage area alone. This is likely because of a low hydraulic gradient that keeps water flowing in the channel throughout the year. The Active II class, Active Channels that freeze to the bottom in winter, is a transition class between Vegetated and Active I Channels.

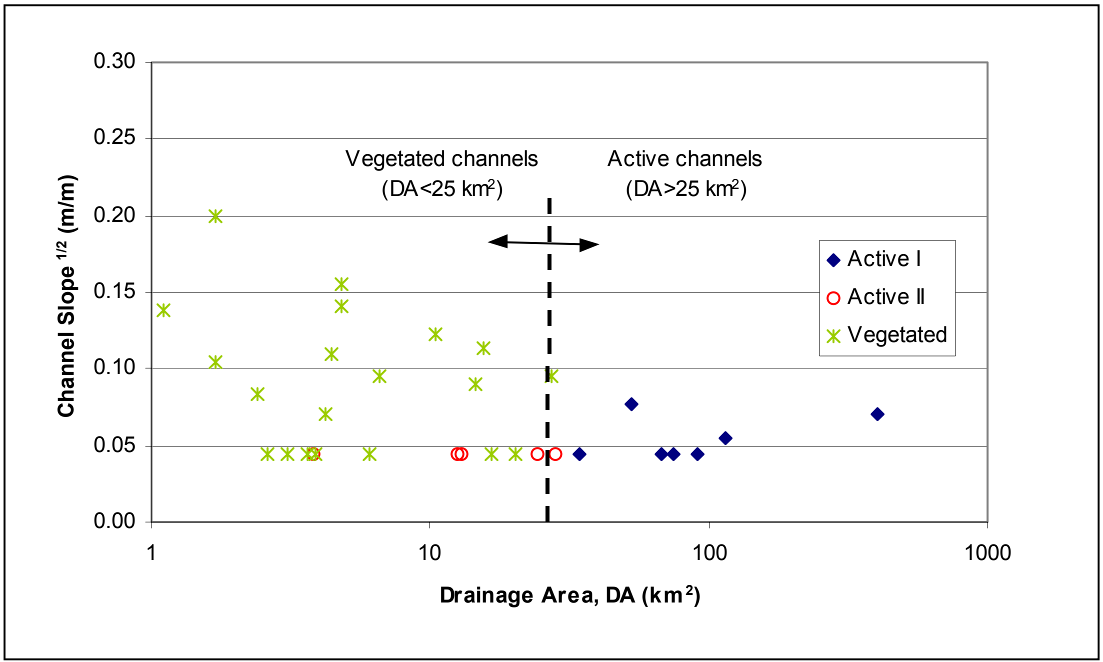


Figure 5-22: Stream Characteristics – Delta Hydrologic Region

Figure 5-22 also shows two classes of streams in the delta region:

- drainage areas less than 25 km^2, usually with Vegetated Channels
- drainage areas larger than 25 km^2, which tend to be Active Channels

Because of low precipitation in the delta region, water yield and streams are relatively small. Most runoff is in the spring from snowmelt. Groundwater contribution is minimal because of the large extent of permafrost and low groundwater gradients.

The result is those catchments with drainage areas smaller than 25 km^2:

- do not generate enough runoff or stream flow to maintain an Active Channel
- do not flow for extended periods
- have vegetation growing in the ephemeral flow path

Catchments with drainage areas larger than 25 km^2 have sufficient flow volume or flow period to maintain an Active Channel with discernible banks and substrate.

Channel slope is not an important factor in determining stream type in the delta region. The hydraulic gradient of a channel, however, particularly between lakes, determines the persistence of water in a channel and affects the growth of vegetation along the flow path. Figure 5-22, shown previously, also shows several Active II-type streams, all of which are small connectors between lakes. Although a low hydraulic gradient keeps water in these streams through most of the year, the shallow depths and low velocities typically result in the streams freezing to the bottom in winter.

5.3.6.2 Northern Hydrologic Region

Figure 5-23 shows the distribution of stream classes with drainage area for the northern region:

- Vegetated Channels with drainage areas smaller than 13 km^2
- Active Channels for drainage areas larger than 50 km^2
- a transition zone including both Vegetated and Active Channels

With stream morphology being a continuum, the transition zone represents an overlap of streams of two or more types, depending on local conditions. For example, characteristics of a specific stream might depend on the local topography and upland storage, and on its geographic location in the region.

Channel slope does not define stream type in the northern region. The channel type depends more on water availability and flow duration, i.e., drainage area, than on flow velocity, i.e., slope. In the northern region, water yield is the factor governing stream type.

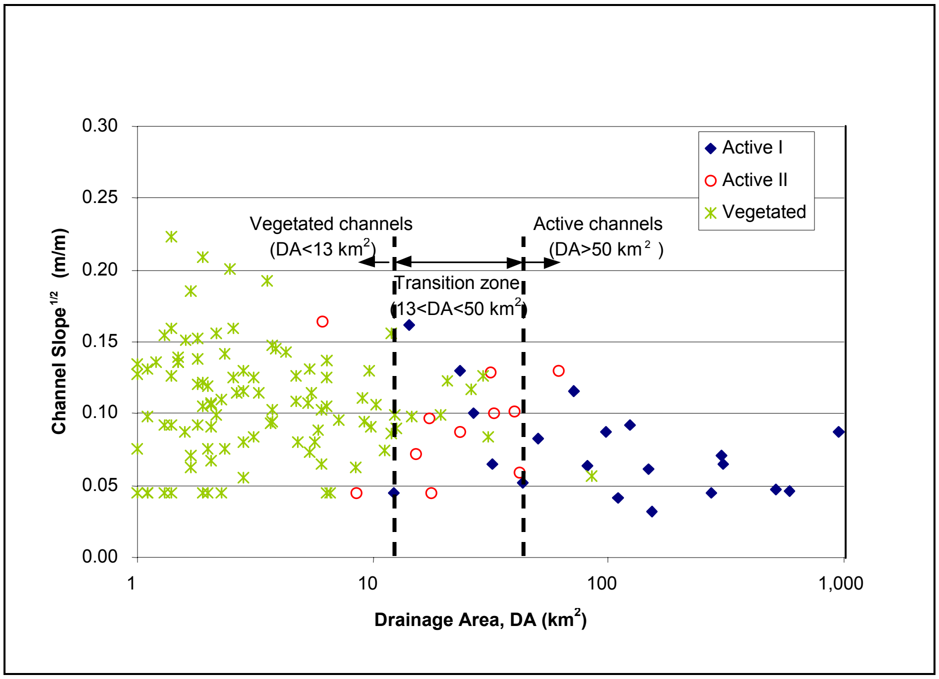


Figure 5-23: Stream Characteristics – Northern Hydrologic Region

5.3.6.3 Central Hydrologic Region

Figure 5-24 shows the stream classification results for the central region, where basin and channel slopes are much higher than in the other hydrologic-geomorphic regions along the pipeline route. The higher slopes are a result of the Franklin Mountains, e.g., Gibson Ridge, Norman Range and McConnell Range, and extend to Ebbutt Hills in the south. The topography and geology of the area result in a high groundwater influence for many streams, particularly near Norman Wells. Because of groundwater inflow, i.e., amount and seasonal duration, effects on stream type and stream classes cannot be defined by drainage area and slope alone.

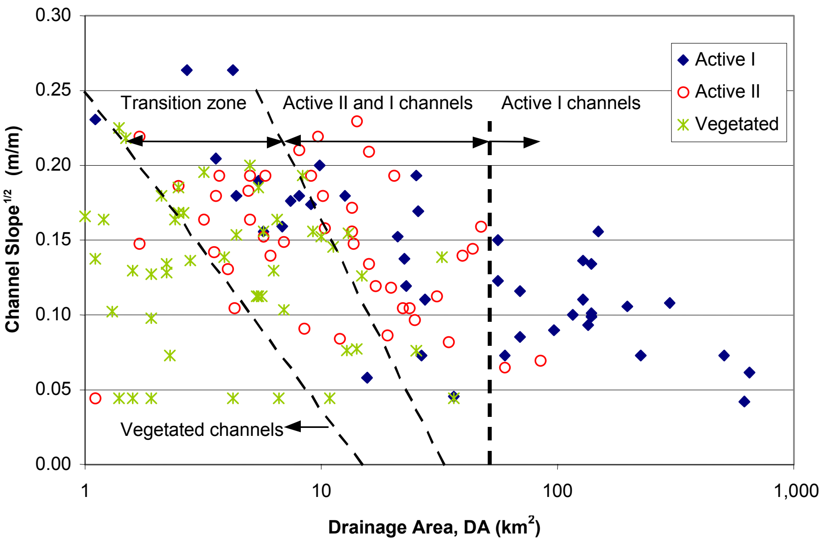


Figure 5-24: Stream Characteristics – Central Hydrologic Region

Figure 5-24 also shows the distribution of stream classes with drainage area and slope for the central region:

- Vegetated Channels
- a transition zone including both Vegetated and Active Channels
- a transition zone between Active I and Active II Channels
- predominantly Active I Channels

An overlap or transition zone between streams of two or more types indicates that several factors besides drainage area and slope affect stream type. The most important is likely groundwater input, though local conditions are also important.

5.3.6.4 Southern Hydrologic Region

Figure 5-25 shows that the stream classes for the southern region are similar to those for the delta and northern regions. The distinction between Vegetated Channel and Active Channel occurs at a drainage area of about 15 km^2. Active I Channels occur above this threshold, and Vegetated Channels and Active II Channels occur when drainage areas are smaller and slope is greater than 0.1 m/m.

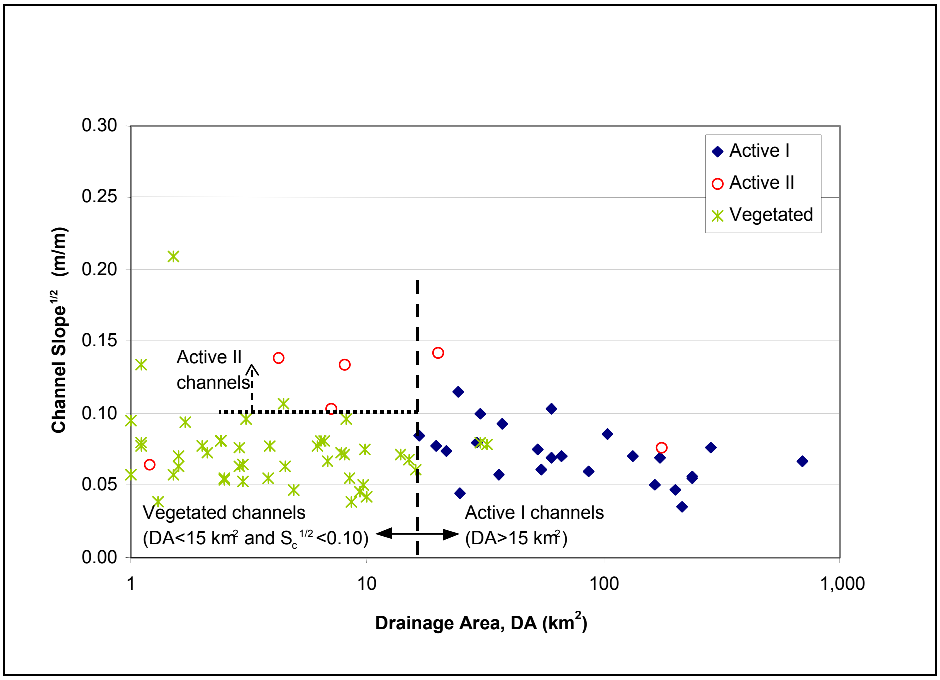


Figure 5-25: Stream Characteristics – Southern Hydrologic Region

Channel slope affects stream type in the southern region. Although average slopes are noticeably lower than in the other hydrologic regions, water yield is higher. In these cases, stream type is not only governed by water availability, but also by flow velocity and hence channel slope. For small drainage areas, i.e., smaller than 15 km^2, channel slopes greater than 0.01 m/m can be related to Active II streams. These small channels are unvegetated because of longer flow durations compared with streams in the north, and higher flow velocities down the slopes. Active II streams are expected to freeze to the bottom or be dry over winter.

5.3.7 Geomorphic Assessment

The geomorphic characteristics summarized in Table 5-33 are representative of typical channels in a given hydrologic region. The availability of sediment and a stream's ability to carry it downstream affect the substrate and the substrate distribution in the channel. Availability of sediment also influences:

- presence of depositional and erosional features
- extent of floodplain development
- riparian vegetation
- bank material
- bank stability

Therefore, it is important to characterize the geomorphic characteristics of different types of streams.

Table 5-33: Summary of Geomorphic Characteristics

Hydrologic Region	**Description**	**Average Channel Slope** (m/m)	**Dominant Substrate** (% of sites)	**Channel Features** (% of sites)
Delta	Mackenzie Delta south to Inuvik	0.0044	Silt (78%) Gravel (11%) Cobble (11%)	Flat (67%) Run (22%) Riffle (11%)
Northern	Inuvik to north end of Franklin Mountains	0.007	Cobble (38%) Gravel (43%)	Run (59%)
Central	Franklin Mountains to Ebutts Hills	0.012	Gravel (38%) Cobble (28%) Boulder (18%)	Run (56%) Riffle (38%)
Southern	South of Ebbutt Hills into northwestern Alberta	0.004	Silt (42%) Cobble (21%) Boulder (25%)	Pool (25%) Run (68%)

NOTES:
Riffle – High-velocity gradient relative to run habitat, surface broken because of submerged or exposed bed material, shallow relative to other channel units, coarse substrate, usually limited instream or overhead cover for juvenile or adult fish (usually ≤0.5 m deep)
Run – Moderate to high velocity, surface largely unbroken, usually deeper than a riffle, substrate size dependent on hydraulics
Flat – Area characterized by low velocity and near-laminar flow, differentiated from pool habitat by high channel uniformity, more depositional than shallow run habitat
Pool – Discrete area of channel featuring increased depth and reduced velocity relative to riffle and run habitats, formed by channel scour

When undisturbed, alluvial streams reach equilibrium conditions that can be described by local relationships of flow, channel size, sinuosity and substrate. These relationships have often been used to estimate stream characteristics such as average width and depth, and type of substrate.

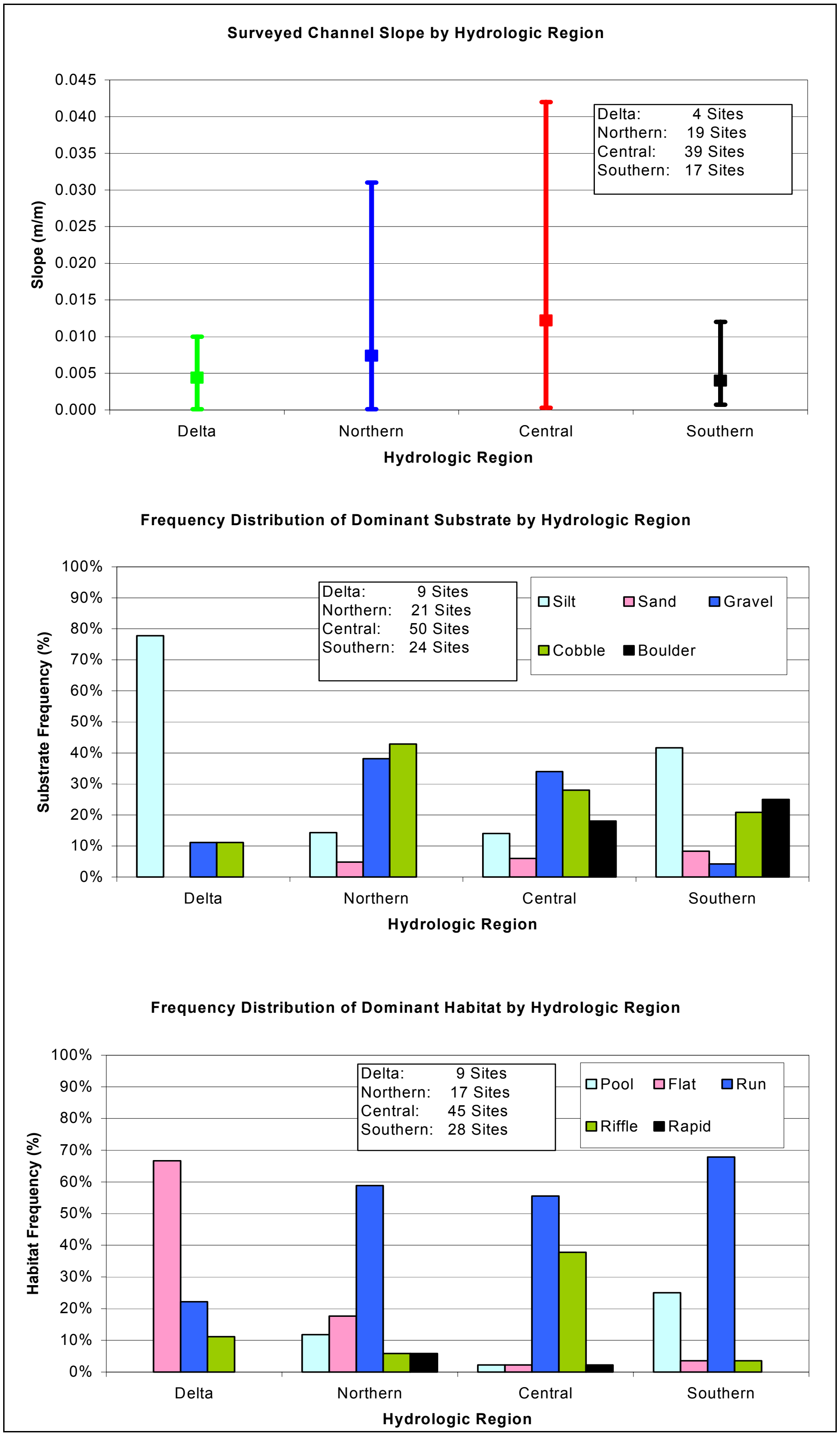
The relationships between stream slope, dominant substrate and channel features were assessed based on data collected during the detailed fish habitat surveys. Figure 5-26 shows the relationships between slope, substrate and channel features for each of the four hydrologic regions.

Table 5-33 (shown previously) and Figure 5-26 both illustrate a direct relationship between channel slope, type of substrate in a stream and the dominant channel features. Low slopes in the delta region have fine substrate and flats whereas streams with moderate slopes in the northern region have cobble-gravel substrate and runs. Streams in the central region have the highest average channel slope and are dominated by gravel, cobble and boulders. The dominant channel feature in this region is a combination of shallow runs and riffles.

Average stream slopes in the southern region are as low as in the delta region, though channel substrate contains cobble and boulder in addition to a high percentage of silt. The larger substrate sizes are not typical of low-gradient streams. They might be relict materials, which are not usually transported by the stream, or could be a result of higher unit flow from intense summer rainstorms. There is a relatively high proportion of pool habitat in the southern region, which is likely a result of extensive beaver activity and ponding behind beaver dams.

Geomorphic characteristics such as substrate and channel features are functions of channel slope. The progression from flat to run to riffle to rapid is evident as local slope increases. Reaches with higher slopes and flow velocities have greater potential for sediment transport. As a result, larger substrate sizes dominate the streambed whereas finer material is carried to downstream reaches. Runs and riffles are usually at higher gradients and are dominated by gravel and cobble, whereas flats and pools are at lower gradients and are characterized by silt or organic matter.

Channel slope can also affect other geomorphic characteristics such as sinuosity and entrenchment. Sinuosity is the ratio of stream length to valley length between two points on the channel. Sinuosity is always greater than one and increases as channel slope decreases. Entrenchment can be related to the degree of floodplain development along a channel. Low entrenchment implies a wide floodplain, whereas high entrenchment implies that floodwaters are restricted to the area immediately adjacent to the channel. The entrenchment ratio is the ratio between flooded width and wetted width, and it increases with floodplain size.


Surveyed Channel Slope by Hydrologic Region

Frequency Distribution of Dominant Substrate by Hydrologic Region

Frequency Distribution of Dominant Habitat by Hydrologic Region

Figure 5-26: Summary of Geomorphic Characteristics by Hydrologic Region

5.3.8 Hydrologic Conditions in the Mackenzie Delta

5.3.8.1 Delta Streams

Most of the few streams in the eastern area of the delta are shallow, i.e., 2 m deep or less, and narrow, i.e., less than 15 m wide. As a result, most of these channels freeze to the bottom in late winter. They usually have clear, flowing water and are bound on one end by river channels or streams and on the other end by a source region such as a lake or another stream. Streams differ from channels in that stream flow is normally one way and is not usually affected by summer storm surges or high tides that might cause reverse flow.

5.3.8.2 Delta Channels

Seasonal Characteristics

Channel discharge, i.e., delta inflow, and water levels were analyzed to determine the spring flood levels for various return periods (see Section 5.3.3.2, Hydrographs for Mackenzie River Near the Delta). The analysis indicates that outside factors, besides flow, influence spring water levels. Further investigation indicates that channels in the outer delta are highly influenced in the spring by the backwater effects of groundfast ice on the Beaufort Sea coast.

Spring flood conditions dissipate quickly following the peak water level. Warm water and air temperatures create larger openings in the coastal ice and allow flood water to dissipate unrestricted into the sea. During the summer open-water period, water levels in the outer delta are below bankfull and are relatively insensitive to variations in channel discharge. They are, however, highly influenced by coastal tides and storm surge. With the onset of freeze-up in the fall, increased hydraulic resistance created by ice cover formation tends to cause water and ice levels to rise. By late winter, water and ice levels are near bankfull levels, i.e., just below typical spring peak levels, and the seasonal cycle begins again.

Spring Breakup and Flood

Channel ice in the outer delta is at bankfull level in the early spring, before extensive melting. This was observed during the 2003 Spring Hydrology survey, and is documented in water level records from the mid-1970s (Hardy 1976 and 1977b; Slaney 1976a, 1976b, 1977).

Ice cover begins to degrade with increased temperatures and solar radiation, and water levels in the channels begin to rise in response to local melt, increased delta inflow and ice restrictions on the coast. Ice cover typically breaks, i.e., hinges upward (see Figure 5-27) because of rising water levels, resulting in a floating ice cover down the middle of the channel and submerged bankfast ice along the edges. Ice cover continues to degrade and eventually break up into smaller pieces as the breakup front moves through the area. Following degradation of the ice cover, continued influx of upstream flood water causes further water level increases and inundation of the surrounding land. The clearing of ice from channels usually coincides with peak water levels.

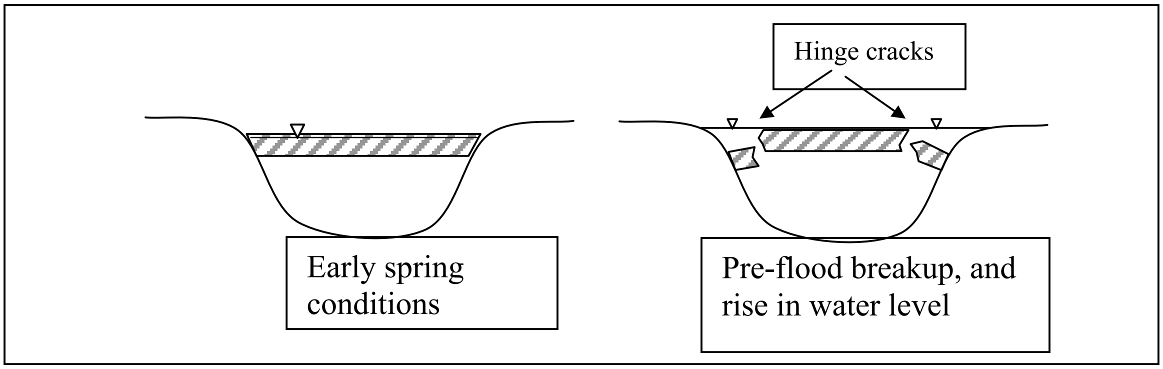


Figure 5-27: Channel Ice Conditions During Spring

Peak water levels occur during the breakup period because of a combination of:

- high flow into the delta
- local ice blockages
- ice restrictions on the coast

Groundfast ice on the coast acts as a barrier and impedes the free flow of water into the Beaufort Sea (Coleman et al. 1986; NRCan 2002). This causes water to back up in the delta and create the spring flood conditions associated with peak water levels above bankfull level and extensive inundation of low-lying land.

Flood conditions tend to dissipate quickly as leads grow in the coastal ice and warmer water and thermal melt open up the restriction. The required depth of flow decreases once the ice cover clears (see the following discussion regarding fall freeze-up). Water levels in 2003 were observed to drop to pre-flood bankfull levels within 24 hours of the peak, and to typical summer levels, roughly 1 m below bank, within one or two weeks (see Figure 5-28).

Open-Water Summer Season

Outer delta water levels in the open-water season are typically about 1 m below the top of the bank and are not very sensitive to variations in channel discharge. They are highly sensitive, however, to coastal processes such as tides and storm surge.

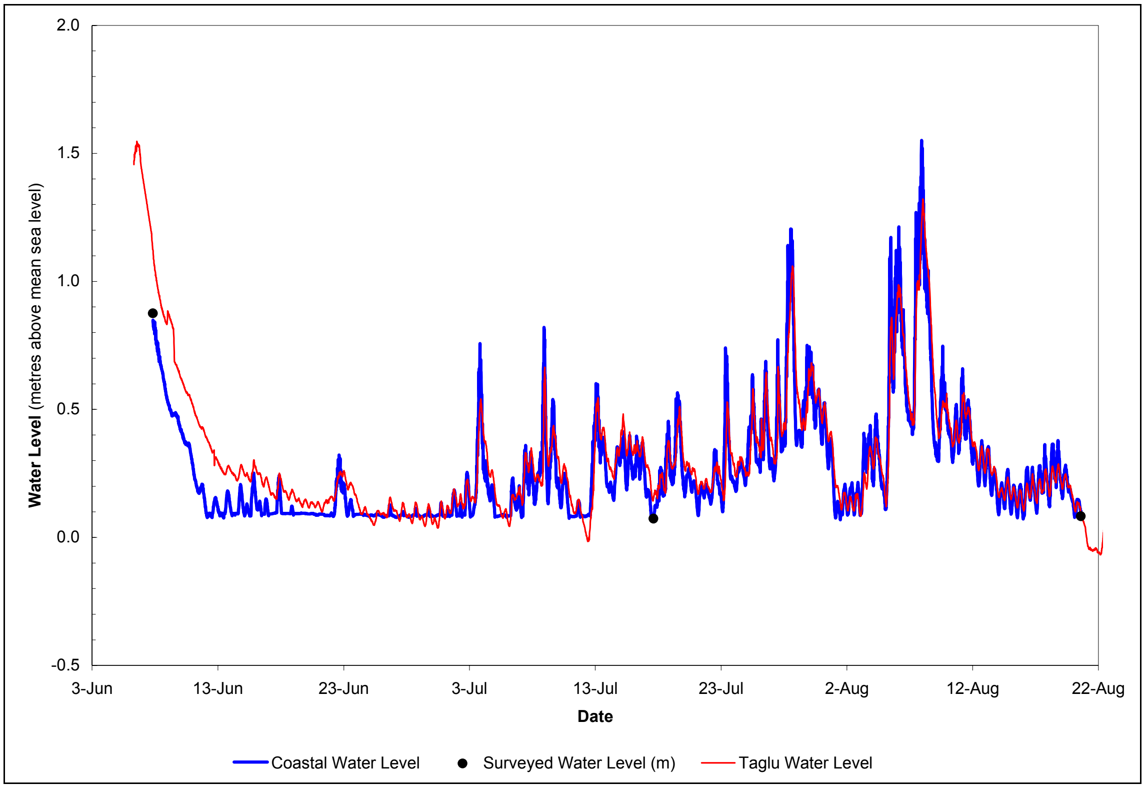


Figure 5-28: 2003 Taglu and Coastal Water Level Records

Figure 5-28, shown previously, shows water level data collected at 15-minute intervals. The influence of tides is clearly noticeable in the oscillations shown in both the coast and Taglu records. Tides are semidiurnal, twice-daily, and have a range of about 0.3 m for mean tides, depending on the location.

Normally, water levels in the delta are slightly higher than at the coast because of the hydraulic gradient between the two locations, i.e., water flows toward the coast. The backwater effect created by higher water levels at the coast might decrease flow at high tides. Because of these tidal influences, the outer delta channels are not well represented by standard rating curves where increased flow is associated with increased water levels. Changing downstream conditions regulate flow.

During storm surges, large water level rises at the coast cause flooding at inland delta locations. The magnitude of a storm surge depends on wind speed, fetch, direction and duration, and on local bathymetry. Rising water levels at the coast cause channel waters to back up, water levels to rise and flow velocities to decrease (see Figure 5-29). Flooding of the delta occurs when water levels exceed bank elevations. Wind setup can also cause upstream sea water to move into the delta channels. Figure 5-28, shown previously, shows a storm surge on August 7 to 8, 2003 that reached near-peak spring levels just above bankfull at Taglu.

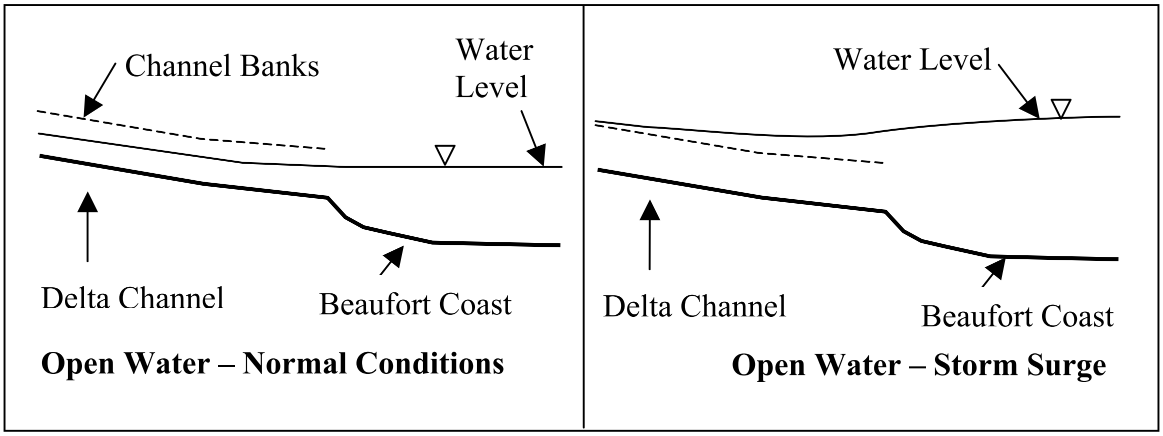


Figure 5-29: Channel Conditions During Summer Open-Water Season

Fall Freeze-up

Channel water levels in the fall, just before freeze-up, are comparable to typical levels over the open-water season. A slight decrease might be observed depending on flow reductions from upstream areas. River stage-up (see following discussion) during fall freeze-up and over the winter brings the top of the river ice layer close to bankfull. Ice begins to form in the north and progress upstream as temperatures drop with the onset of fall. Border ice forms first, adhering to the banks and growing outward into the channel. Flow is typically laminar at this time, and once a cover is established, channel ice tends to grow thermally and to develop as strong columnar ice. The growth of frazil ice, which develops under super-cooled and turbulent conditions, is limited to periods of turbulence caused by strong winds and wave action.

Hydraulic resistance increases as the ice cover forms across the channel because the upper flow boundary is no longer air, but a rough and rigid ice surface. A larger flow area is then required to accommodate a comparable amount of flow. The result is winter *stage-up* where water levels rise:

- to create a larger flow area
- upstream from the ice formation because of a backwater effect caused by increased flow resistance
- because of displacement of water by ice cover, the ice layer being about 90% submerged

The total effect of river stage-up in the fall is a large volume of water stored in the channel and relatively low flow velocities. The stage-up brings the top of the ice layer close to bankfull.

Winter Ice-Covered Season

River hydraulics and ice cover determine water levels from November to May. Kumak Channel downstream from Niglintgak and Kuluarpak Channel downstream from Taglu are relatively deep and maintain flow over this period (Slaney 1974, 1976a), whereas shallower channels, such as Middle Channel downstream from Niglintgak and Harry Channel downstream from Taglu tend to freeze to the bed.

Channel ice continues to grow throughout the winter, with late winter thicknesses typically reaching 1.5 to 2 m. Site-specific ice thicknesses depend on local conditions, temperatures and the amount of snow cover, i.e., insulation. Thickening of the ice cover can cause water-ice levels to rise further. If channel discharge remains constant, i.e., does not drop, the water-ice level can rise to counter the reduced flow area caused by displacement of water, and flow area, by ice cover.

Channel Morphology

Outer Mackenzie Delta

The Mackenzie River is the longest river in Canada and also has the largest delta. The delta has formed through the slow and ongoing process of sediment deposition into the Beaufort Sea since retreat of the glaciers 12,000 to 13,000 years ago. The outer delta is an area of low relief that floods extensively in the spring and sporadically during storm surges from the Beaufort Sea.

Channel stability in a conventional river is controlled by the geology of the surrounding material and river hydraulics, i.e., fast-moving water causing erosion or aggradation, which is slow-moving water causing deposition. Channel stability in a delta is complicated by additional factors, such as:

- hydraulics
- geology
- amount and variability of sediment inputs
- basin into which the river is flowing
- cross-sectional characterization of the sites
- length of the open-water period
- ice conditions

Gradual aggradation can build up the delta channels, occasionally adding to the complexity of the channel network when new channels are formed. Channel stability in a cold, northern climate depends on ice formation and breakup, especially when some channels freeze to the bottom and others continue to flow under an ice cover.

Permafrost and ice-rich soil also affect channel stability in the Mackenzie Delta. Frozen delta soil is very cohesive and resistant to weathering, but destabilizes when melted. The ground surrounding the channels is typically unfrozen because of the thermal influence of the water. When flood waters recede in the spring, weakened banks slump into the channel.

Most processes act in combination to form a dynamic and complex environment. Some of the geomorphic changes in the delta are gradual and predictable, whereas others, e.g., channel avulsion, are infrequent and episodic and have a large degree of uncertainty as to when and where they might happen.

The geologic conditions of the Niglintgak and Taglu areas were studied in the 1970s by Slaney (1976a, 1976b and 1977) and Hardy (1976 and 1977b) and again in the early 1990s by Traynor and Dallimore (1992), who assessed channel stability, near-surface geology and permafrost conditions in Niglintgak and Taglu. Their channel stability work was based on analysis of aerial photographs taken in 1950 and 1985 and on cross-section measurements from 1975 by Slaney (1976a) and from 1990 to 1991 by the Geological Survey of Canada.

This section reports on a similar analysis of channel stability that incorporated 2002 aerial photographs and recent cross-section measurements. Section 5.4, Local Baseline Conditions, describes the results.

5.3.8.3 Delta Lakes

Lake Characteristics

There are about 25,000 lakes in the Mackenzie Delta, covering about 25% of the delta surface (Marsh et al. 1993). These lakes are usually shallow with mean depths of 1 to 1.5 m (Marsh and Hey 1989). Depths at high water are much greater and can be estimated by noting the high-water marks on lakeshore willows (Mackay 1963). Delta lakes are not static features, but are constantly changing. Marsh (1998) attributes the changes to:

- sediment deposition in the lakes and surrounding areas
- lakes draining when main river channels cut into the banks that separate the channels from the lakes
- deltas forming in large lakes, dividing them into several smaller lakes
- permafrost melting in the lake shoreline, i.e., permafrost erosion, which makes lakes larger
- new lakes forming as channels are abandoned

Delta Lakes Flooding

The richness of delta lake habitats is a result of periodic flooding by the Mackenzie River, which introduces water, sediment, energy, chemicals and nutrients (Marsh and Hey 1988). Delta lakes occur over a range of elevations relative to the river and experience various flooding regimes, so vary widely, both physically and biologically. Lakes have a negative water balance and without flooding are subject to drying out over time. The frequency, timing and duration of flooding events are important components of the hydrology of lakes in the Mackenzie Delta.

Water level variations in the Mackenzie Delta's main channels are controlled by:

- runoff, i.e., snowmelt or rainfall, in the Mackenzie Basin
- ice jamming in the delta
- storm surges in the Beaufort Sea (Marsh and Hey 1989)

The frequency and duration of flooding of delta lakes varies spatially within the delta and depends largely on outlet lake sill elevation. Delta lakes are either permanently connected to a channel or unconnected. Most unconnected lakes have a small depression in the surrounding levee that links them to another lake or lake system when delta water levels are sufficiently high (Bigras 1985). Unconnected lakes that are not flooded annually in spring are referred to as high-closure lakes (Marsh and Hey 1989), and those flooded annually in spring are called low-closure lakes. Connected lakes are referred to as no-closure lakes (Marsh et al. 1993).

The National Hydrology Research Institute has done the most research into Mackenzie Delta lake flooding. This research has focused on three study areas on the east side of the delta:

- northern study area in the lower delta just north of Reindeer Station and referred to as Gill Camp area
- central study area, near Inuvik, in the middle delta and called NRC Lake
- southern study area in the upper delta and referred to as Dishwater Lake area

Bigras (1985) collected data at the northern and southern study sites in 1982 and 1983. The field study results demonstrated the control ice jamming has on delta channel and lake water levels. In 1982, the Mackenzie River breakup was dynamic, causing 95% of the delta to flood. In 1983, the breakup was thermal and only the lower delta was flooded.

Marsh and Hey (1988) measured the sill elevations of delta lakes in the central study site (NRC Lake) and compared them with water level records from the Mackenzie River East Channel to determine the frequency and timing of delta lake flooding. Their results showed that two-thirds of the lakes in the study area were flooded every spring and the remaining one-third was flooded every two to five years. They also found that only 20% of the lakes in the study area were flooded annually in summer.

Marsh and Hey (1989) studied the spatial variation of the flooding of lakes in the Mackenzie Delta by comparing lake sill elevations with recorded water levels in the three study areas. Results of their analysis indicated:

- the number of high-closure lakes varied from 13% in the lower delta, to 33% in the central delta, to 44% in the upper delta
- most of the eastern delta lakes are not flooded annually
- some lakes in the Dishwater Lake area are flooded at intervals longer than five years
- delta lakes can only survive a few years without flooding because of:
    - negligible runoff from the land surrounding the lakes
    - lake evaporation rates that are greater than total annual precipitation
    - shallow lake depths often ranging from 1 to 1.5 m

Marsh et al. (1993) documented the 1992 spring flooding of over 3,000 lakes along a 60 km x 5 km transect across the central Mackenzie Delta between Aklavik and Inuvik to examine the cross-delta variation in the timing of lake flooding. The work demonstrated that spring lake flooding started on the east side of the transect and moved west. They also examined the variation in lake sill level along the transect and found the mean sill level was highest in the middle of the transect, lowest in the east and intermediate in the west. As the highest mean water levels were observed in the middle of the transect, they concluded lake flooding is related to sill and water level variations.

Marsh et al. (1993) also reported on the sediment load of three lakes in the eastern delta near Inuvik. Sediment loads were measured from May to August 1987. One lake is a high-closure lake and the other two are no-closure lakes. The results indicated that the spring sediment load accounted for 100% of the high-closure lake’s annual sediment load and for only 42% and 61% of the annual load for the no-closure lakes.

5.3.8.4 Beaufort Sea Coastal Environment

Tides

Tides along the Beaufort Sea coastline are affected by semidiurnal tides, i.e., two high tides and two low tides in a 24-hour period. Table 5-34 shows the tidal range at Tuktoyaktuk, Sachs Harbour and Eskimo Lakes.

Table 5-34: Tidal Information for the Beaufort Sea

Location	Type of Port[1]	Elevation Above Chart Datum				
		Large Tides		Mean Tides		
		Higher High Water (m)	Lower Low Water (m)	Higher High Water (m)	Lower Low Water (m)	Mean Water Level (m)
Tuktoyaktuk	Reference port	0.6	0.2	0.5	0.2	0.4
Sachs Harbour	Secondary port	0.2	0.0	0.2	0.0	0.6
Eskimo Lakes	Secondary port	1.1	0.2	1.0	0.3	1.0

NOTE:

1 Reference port is a place where tide or tidal current constants have been determined from observations, and which is used as a standard for comparison of simultaneous observations at a subordinate or secondary station; secondary port is a port where water level time and height differences are provided relative to a reference port.

SOURCE: CHS (2003)

Wave Conditions

The height of wind-generated waves depends on:

- wind speed and duration
- water depth
- area of open water, i.e., the fetch, over which the wind blows

The Beaufort Sea is unique among ocean areas because of the presence of sea ice, which can limit the open-water fetch depending on the time of year.

Over the past two decades several wave hindcast studies have been done to estimate wave conditions in the Beaufort Sea.

The 100-year significant wave height for the population of hindcast peak-generated waves using the actual ice configuration was predicted to be 5.7 m in deep water.

Wave conditions have not been predicted for nearshore areas on Kugmallit Bay and Kittigazuit Bay.

Ice Conditions in Kugmallit Bay and Tuktoyaktuk Harbour

Kugmallit Bay is described as normally clearing of ice in the first week of July and starting to freeze up in the second week of October. In an abnormal season, ice might prevent navigation until early August. Ice concentrations in the bay are highly variable and winds can cause them to change from reported conditions within a few hours. The average thickness of the winter shorefast or landfast ice in the harbour is about 2 m.

Sedimentation and Dredging

The Mackenzie River deposits large volumes of suspended sediment annually into the Beaufort Sea. Most of the coarse material settles near the mouth of the Mackenzie River. According to Dome Petroleum Ltd. et al. (1982a), the average discharge of sediment from the Mackenzie River exceeds 1 Mt/d during the open-water season from June to September.

Delta environments are typically sites of long-term deposition. Carson (1994a) estimated annual fluvial deposition of about 38 Mt throughout the upper delta area. In the study, Carson reported field observations indicating that channel bed deposition was not a major process in the delta.

Historically, dredging in the Beaufort Sea has been done primarily to build artificial islands and for shipping channels. Artificial islands have been built in water depths up to 60 m, with excavation to 20 m below the sea floor (Dome Petroleum Ltd. et al 1982b). Harbours, channels and mooring basins were dredged in MacKinley Bay, Tuft Point and Tuktoyaktuk, with repeated extensive coastal dredging of Tuktoyaktuk Harbour from 1976 to 1982. Most of the dredging took place during the ice-free season from June to October (Taylor et al. 1985).

5.3.8.5 Storm Surge Analysis

Storm surges occur when strong wind stress on the water surface causes a large net displacement of water (Harper et al. 1988). A surge is categorized as either positive, i.e., an increase in water surface, or negative, i.e., a decrease in water surface. The Beaufort Sea coast from the Mackenzie Delta to Tuktoyaktuk is particularly susceptible to the impacts from positive surges because of its low coastal relief (Harper et al. 1988). The wind-driven water level increases that affect this coastline typically:

- occur during late summer and fall storms
- are associated with strong northwesterly winds (Harper et al. 1988)
- last two days

A study of storm surge in the Tuktoyaktuk area (Harper et al. 1988) suggests water levels can reach elevations of 2 to 3 m above mean sea level (MSL). High water levels might vary by as much as 1 m over a few kilometres along the coast, and areas with northwest exposure tend to have larger waves, further increasing the water level (Harper et al. 1988).

Historical records indicate two large surges occurred along the Beaufort Sea coast in 1944 and 1970 (Harper et al. 1988), though neither was recorded at the Tuktoyaktuk tidal gauge, which was not in operation.

Harper et al. (1988) documented surge elevations along the southern Beaufort Sea by surveying log debris lines in the Kugmallit Bay-Tuktoyaktuk area. Based on these surveys, maximum driftwood levels along the Beaufort coast near Tuktoyaktuk were about 2.4 m above MSL, levels believed to represent high-water marks associated with large storm surges similar in magnitude to the surges of 1944 and 1970. Anecdotal evidence, e.g., local knowledge, suggests these surge levels have not been surpassed in recent years. However, the recurrence interval between surges of historical magnitude is not known.

A limited study of the effects of storm surges on water levels near Niglintgak and Taglu began with a one-dimensional storm surge model developed for Tuktoyaktuk and calibrated based on:

- several historical storm surges of various magnitudes
- theoretical equations for storm surge setup and wave setup

The model was then transposed and used to estimate storm surges at two coastal locations near Niglintgak and Taglu. A synthetic extreme water level record for the three locations was developed based on a Monte Carlo simulation. Input variables for the simulation included the probability distributions for wind speed and direction, tidal elevation and wind fetch. Synthetic water level records were analyzed to estimate extreme water levels of various return periods at Tuktoyaktuk, Niglintgak and Taglu.

The one-dimensional storm surge model is, however, rudimentary and is limited because it:

- is a steady state model that assumes input wind data is constant over an extended period. As a result, the model cannot account for the transient nature of storm surge and wave setup that occur during a storm.

- is a one-dimensional model that doesn’t account for the spatial variability of bathymetry, wind speed, wind direction and wind fetch

- doesn’t account for water level rise resulting from atmospheric pressure setup

- doesn't consider the effects of the surge over land. It assumes a *wall* effect at the coastline and doesn't account for dissipation of flood water over the delta and low-lying areas.

Input Data and Calibration

The following data was required to develop, calibrate and validate the one-dimensional storm surge model:

- bathymetric data along the model traverse line
- hourly wind, water level and tidal data from several historical storm surges
- historical ice charts to estimate the open-water wind fetch during the historical storm surges

Six historical storm surges were used to calibrate the one-dimensional storm surge model at Tuktoyaktuk. They were chosen based on the availability of concurrent model input data including wind, water level, tidal hindcast and wind fetch for the storm surge date. The events and relevant input parameters are in Table 5-35.

Table 5-35: One-Dimensional Storm Surge Model Calibration Events at Tuktoyaktuk

Surge Event					Calibration Data	
Year	Date of Surge Event	Time of Maximum Water Level	Maximum Recorded Water Level[1] (m)	Maximum Wind Speed During Event (km/h)	Time of Maximum Storm Surge and Wave Setup[2]	Maximum Storm Surge and Wave Setup[2] (m)
1975	August 27–28	August 27 5:00 p.m.	1.74	60	August 27 1:00 p.m.	1.37
1980	August 29–30	August 30 6:00 a.m.	1.57	48	August 30 8:00 a.m.	0.92
1986	August 22–23	August 22 10:00 p.m.	1.79	46	August 22 10:00 p.m.	1.54
1991	August 23–24	August 24 3:00 a.m.	1.68	50[a]	August 24 5:00 a.m.	1.02[a]
1993	September 21–22	September 22 8:00 a.m.	2.20	74	September 22 12:00 p.m.	1.68
2000	August 12–13	August 12 4:00 a.m.	2.18	70	August 12 4:00 a.m.	1.74

NOTES:

1 Elevations are referenced to hydrographic chart datum, which is about 0.4 m below mean water level (CHS 2003).

2 Storm surge and wave setup is defined as the recorded water level corrected for tidal influences at a given point in time, i.e., recorded level minus the tidal hindcast.

a No wind data is available between 10 p.m. and 6 a.m. Because of the lack of wind data during the maximum setup, the model was calibrated using the setup on August 23rd.

The Darcy-Weisbach bed friction factor, f, was the calibration parameter used for the one-dimensional storm surge model. The friction factor is a function of the bottom roughness and the properties of the bottom boundary layer, and usually ranges from 0.02 to 0.035 (Kowalik 1984). A friction factor value of f = 0.04 produced the best agreement between the recorded and predicted values for the six calibration events at Tuktoyaktuk. Predicted storm surge water levels for the six events were within ±50% (0.02 to 0.66 m) of the recorded levels.

Figure 5-30 compares the recorded and predicted levels. Observed and predicted values might differ because of discrepancies between the actual wind speed, wind direction and fetch length and the values used for the calibration events.

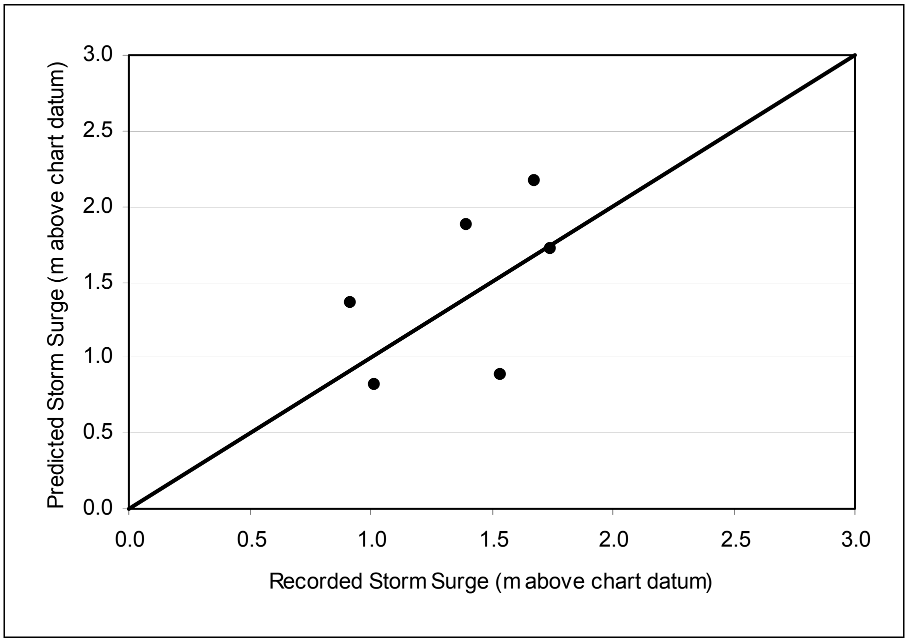


Figure 5-30: Predicted versus Recorded Wind Setup at Tuktoyaktuk

Application of the One-Dimensional Model

Using local bathymetric profiles, the calibrated one-dimensional model was applied to the Niglintgak and Taglu coasts as far as 15 km to the north. Table 5-36 summarizes the theoretical predicted water levels at the Niglintgak and Taglu coasts, where levels were predicted to be slightly higher than at Tuktoyaktuk. This is partly because of differences in bathymetry. Because water levels off Niglintgak and Taglu are shallower than Tuktoyaktuk within 40 km of the shoreline, they have more offshore bottom friction and, consequently, higher theoretical storm surge levels.

Table 5-36: Comparison of Theoretical Storm Surge Levels

Year	**Water Level** (m above chart datum)			
	Recorded at Tuktoyaktuk[1]	**Predicted at Tuktoyaktuk**	**Predicted at Niglintgak Coast**	**Predicted at Taglu Coast**
1975	1.40	1.88	2.20	1.92
1980	0.92	1.36	1.92	1.44
1986	1.54	0.88	1.05	1.00
1991	1.02	0.82	1.19	0.81
1993	1.68	2.17	2.55	2.24
2000	1.74	1.72	2.41	1.69

NOTES:

1 For comparison with predicted values, values in this column have been corrected for tidal influences during the storm surge, i.e., recorded level minus the tidal hindcast.

As mentioned, the one-dimensional model has several limitations that affect interpretation of results. The model cannot account for the transient nature of winds, the spatial effect of bathymetry or changing wind fetches resulting from ice movement. Most importantly in the case of the Niglintgak and Taglu areas, the model assumes a wall effect at the coast and cannot account for the dissipation of flood water over the delta landscape. Because of the flat nature of the delta and the high storage capacity of delta channels, actual storm surge flood levels would likely be lower than predicted by this model.

Storm Surge Predictions

Determining the probability of exceedance of a storm surge level requires analysis of a long-term record of storm surges at a given location. Because of a lack of historical data, a Monte Carlo simulation was used to generate input data for the storm surge model and to develop a synthetic storm surge record at all three locations, i.e., Tuktoyaktuk and the Niglintgak and Taglu coastal areas. Where the resulting water level associated with a storm surge comprises storm surge and tidal effects, i.e., neglecting atmospheric pressure setup, the uncertain variables are:

- wind speed
- wind direction
- wind fetch length
- tidal elevation

The Monte Carlo simulation was used to generate 10,000 independent storm surge events based on the assigned distributions for each parameter. A frequency analysis was done on the resulting 10,000 annual surge water levels to determine the probability of occurrence at each of the three locations. Table 5-37 and Figure 5-31 show the results of the analysis for Tuktoyaktuk. All water levels are relative to hydrographic chart datum, which is about 0.4 m below mean water level (CHS 2003). The predicted water levels are expected to vary by ± 50% based on the calibration results.

Table 5-37: Theoretical Storm Surge Levels

Return Period (a)	Storm Surge Level (m)		
	Tuktoyaktuk	**Niglintgak Coast**	**Taglu Coast**
2	2.0	2.3	2.1
5	2.6	3.0	2.7
10	3.0	3.3	3.0
20	3.3	3.7	3.3
50	3.7	4.1	3.7
100	4.0	4.4	4.1

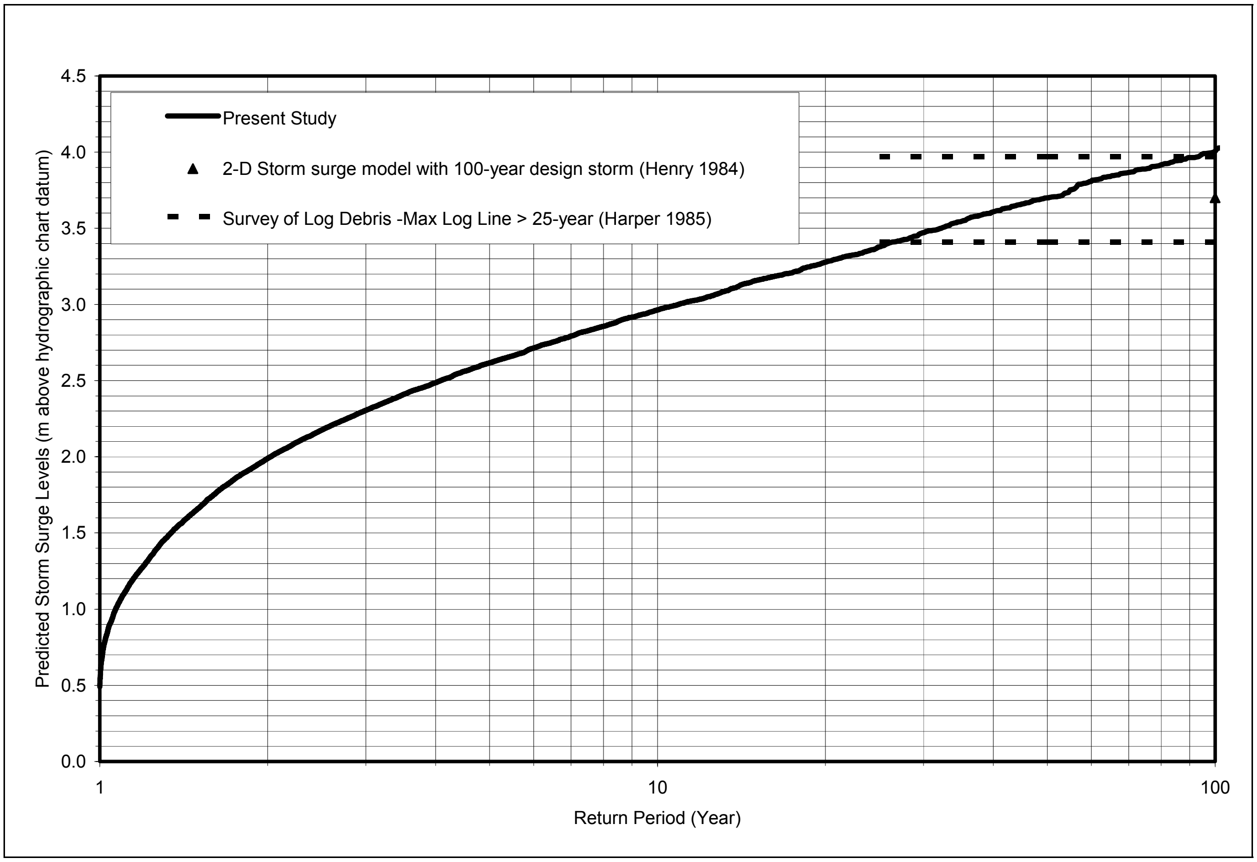


Figure 5-31: Theoretical Storm Surge Levels at Tuktoyaktuk – 2-D Model

Figure 5-31 also shows results from previous studies. Henry (1984) estimated the 100-year storm surge level at Tuktoyaktuk using a 2-D storm surge model of the Beaufort Sea with a 100-year storm as input. Harper (1985) surveyed the log lines along the Beaufort Sea coastline, and based on age of the trees, estimated time of deposition of the log debris, assumed to be associated with the highest storm surge event, to be more than 25 years ago. The broken lines in the figure represent the upper and lower bounds of the error associated with the survey log line elevation (Harper 1985).

Simulation and analysis results indicate that storm surges at the Niglintgak and Taglu coasts are comparable in magnitude to those at Tuktoyaktuk.

Storm Surge at Inland Locations

The one-dimensional storm surge model developed for this analysis provides a theoretical estimate of extreme water levels at the Niglintgak and Taglu coasts. The proposed anchor fields, however, are located about 15 km inland from the coast. As a storm surge moves inland across the floodplain of the Mackenzie Delta, energy dissipation effects are expected to decrease the magnitude of the surge. Storm surges recorded at coastal and inland locations in 1975, 2000 and 2003 were compared with predicted surges at the coast. Recorded storm surge magnitudes at the inland locations were less than those predicted at the coast for the same event. This is consistent with expectations of dissipating effects on storm surges at inland locations.

Results

Based on a rudimentary one-dimensional model, extreme water levels associated with storm surges at Niglintgak and Taglu are comparable in magnitude to those predicted for Tuktoyaktuk. The analysis provides a theoretical representation of possible levels based on local bathymetry and wind characteristics. The model cannot, however, account for spatial and temporal variations associated with storms and does not account for the dissipation of flood water in delta channels and over the delta landscape, e.g., in the extensive floodplain at Niglintgak and Taglu. Therefore, the results of the modelling exercise are considered theoretical upper limits for coastal surge levels. Storm surge levels at inland locations, e.g., at the proposed anchor fields, are expected to be lower than at the coast because of energy dissipation from friction over the floodplain.

The results suggest that the one-dimensional model tends to over- or under-predict surge water levels by 0.3 to 0.6 m. This is consistent with the calibration results for the model and is considered reasonable given the model's limitations.

5.4 Local Baseline Conditions

An overview of the proposed project and watercourse crossings was shown previously in Figure 5-3, Figure 5-4 and Figure 5-5. Survey sites indicated on the figures are for Active I sites only. The production area for the project includes the facilities and flow lines in the Niglintgak, Taglu and Parsons Lake Significant Discovery licence areas and the gathering pipelines. The pipeline corridor extends from Inuvik to the NOVA Gas Transmission Ltd. (NGTL) interconnect facility.

5.4.1 Niglintgak

The Niglintgak Significant Discovery Licence Area is located in the lower Mackenzie Delta, about 10 km west-southwest of Taglu (see Figure 5-1, shown previously). The Significant Discovery Licence Area is about 65 km^2 in size and encompasses most of the Mackenzie River Middle Channel estuary, some smaller unnamed waterbodies and part of Niglintgak Island. For the purposes of the following discussions, Niglintgak also includes a 1-km-wide area outside the lease boundary. The anchor field lies mainly beneath Middle Channel.

5.4.1.1 Previous Studies

Several investigations were done in the mid-1970s to assist engineering studies related to oil and gas development in the Niglintgak region (Hardy 1977a, 1977b; Slaney 1976b), and a more recent study was done in 1992 (Traynor and Dallimore 1992). These studies provide useful background information. A summary of the studies follows.

Comparison of Flood Levels

A recent comparison of recorded flood levels at Niglintgak in 1975, 1976 and 1977 indicates that flood levels were about 2.3 to 2.5 m above Mean Sea Level, as defined in 1976. With ground elevations at about 1.5 m above Mean Sea Level, these peak water levels resulted in inundation depths of 0.8 to 1 m. The maximum expected inundation depth is about 1.6 m based on maximum driftwood elevations in the area.

Ice Conditions

Baseline ice conditions at Niglintgak can be summarized as follows:

- ice was 1.1 to 1.8 m thick (Slaney 1976b) and the variability depends mainly on depth of water and amount of insulating snow cover on the channel (Slaney 1976b; Traynor and Dallimore 1992)

- on April 8, 1975, bottom-fast ice with no available free water was found at test holes in Middle and Kumak channels (Slaney 1976b)
- many of the shallow contributing channels, e.g., Aklak Channel, are constrained by bottom-fast ice and are therefore dormant in the winter months (Traynor and Dallimore 1992)
- on April 10, 1975, a discharge of 875 m^3/s was measured below the ice in Kumak Channel downstream from Aklak Channel (Slaney 1976b)

Spring Breakup

Baseline spring breakup conditions at Niglintgak can be summarized as follows:

- spring breakup in the Niglintgak area was complete between June 1 and 7 in 1975 and 1976 (Hardy 1977b; Slaney 1976b)
- mode of breakup in the Niglintgak area is different from that in upstream parts of the Mackenzie Delta. Middle Channel, downstream from its junction with Kumak Channel, is shallow and the ice cover melts out before the ice cover upstream. The floe ice is then able to move unrestricted past Niglintgak Island through Middle Channel (Hardy 1977a).
- breakup in Kumak Channel downstream from Niglintgak Point might be dominated by thermal degradation (Hardy 1977a)

Ice Jamming

Baseline ice jamming conditions at Niglintgak can be summarized as follows:

- no ice jams were reported in Kumak or Middle channels near Niglintgak Point from 1975 to 1977 (Hardy 1977b)
- ice jams were observed along Aklak Channel in 1975 (Traynor and Dallimore 1992)
- the combination of gentle channel bends and deep thalwegs might reduce the potential for ice jams in the area (Traynor and Dallimore 1992)

Spring Flood

Baseline spring flood conditions at Niglintgak can be summarized as follows:

- peak flood level during breakup in the Niglintgak area usually coincides with passage of the breakup front (Hardy 1977b; Slaney 1976b; Traynor and Dallimore 1992)

- in 1975, flooding in the Niglintgak area began about May 22, and water levels rose to their spring peaks from June 4 to 7 (Slaney 1976a)
- flooding usually precedes breakup. Water levels rose 0.8 to 1.0 m before breakup in 1976, with the high water mark being about 0.6 m lower than the highest level of driftwood occurrence (Hardy 1977a)
- flooding is caused mostly by backwater effects and by water backing up through the several large lakes in the northern parts of the Niglintgak area (Hardy 1977b). As a result:
  - the Niglintgak area floods from these local backwater effects, despite the natural levees along the banks of the main channels (Hardy 1977a)
  - maximum floodplain inundation levels reach 1.6 m, according to maximum driftwood levels

Bathymetry and Discharge

Baseline bathymetry and discharge at Niglintgak can be summarized as follows:

- Kumak Channel discharge was measured at two cross-sections on June 9 and September 28, 1975. Average discharge was 5,380 m^3/s on June 9 and 1,740 m^3/s on September 28. The channel was about 460 m wide (Slaney 1976b).
- a side channel of Kumak Channel, downstream from Aklak Channel, was surveyed on June 9 and September 28, 1975. The channel was 20 m wide with a maximum depth of 2 m. Discharge was 7.5 m^3/s on June 9 and 3.2 m^3/s on September 28 (Slaney 1976b).
- Aklak Channel discharge was 57 m^3/s on June 9, 1975 and 25 m^3/s on September 28, 1975. The channel was 53 m wide, with a maximum depth of 4.5 m (Slaney 1976b).
- in 1992, three surveys were completed on Kumak Channel downstream from Niglintgak Point. The locations were the same as in previous studies to allow comparison of bathymetry (Traynor and Dallimore 1992). The following points summarize the 1992 study:
  - the banks of Kumak Channel upstream from Aklak Channel remained stable, but the 400-m wide thalweg zone shifted 150 m toward the left bank and deepened by 7.7 m between 1975 and 1990 (Traynor and Dallimore 1992)

- the channel cross-section of the Kumak Channel site, downstream from Aklak Channel, showed the thalweg deepening by 14 to 20 m from 1975 to 1990, an increase of 0.35 m/a (Traynor and Dallimore 1992)
- the shift in channel thalweg at the farthest downstream site was 27.5 m toward the right bank. The width of 270 m was maintained over the 15-year period, from 1975 to 1990. The maximum depth of 22.1 m represented only a 0.5 m reduction (Traynor and Dallimore 1992).

5.4.1.2 Niglintgak Channel Morphology

Site Description

Middle Channel approaches Niglintgak from the south and at Niglintgak Island most of the flow is directed to the east down Kumak Channel. Around Niglintgak Island are several small islands and shallow areas. Aklak Channel is a small, east-west orientated, reversing-flow channel (Slaney 1976a) that joins Kumak Channel about 3 km downstream from the junction with Middle Channel. Kumak and Middle channels continue northward until they reach the Beaufort Sea. Based on summer flow measurements, Slaney (1976a) estimated that 98% of the flow into the Niglintgak area flows out through Kumak Channel. Fassnacht (1994) estimated the amount to be 97% based on summer measurements in 1993. Measurements taken during the 2003 spring hydrology field studies indicated that about 70% of the flow passed through Kumak Channel.

Middle and Kumak channels both have shoals 50 to 100 m wide on one or both banks. At the edge of the shoals is an abrupt change in cross-section bottom slope leading to a much deeper middle area in the channels. Kumak Channel is 400 to 600 m wide and about 12 m deep. It is much deeper and narrower than Middle Channel, which is 600 to 900 m wide and about 9 m deep upstream from Niglintgak Island. Downstream of Niglintgak Island, Middle Channel becomes very shallow with many sand bars and a water depth of 1 to 2 m. Aklak Channel is only about 50 m wide and 4 m deep.

Field Observations

Extensive bank slumping was observed during the 2003 spring field studies, mostly on the left downstream bank of Kumak Channel near the tip of Niglintgak Island and on the right downstream bank near the proposed Niglintgak lateral crossing.

Ice shove was also observed in Kumak Channel during spring 2002 and 2003 field studies. Large pieces of ice were shoved up onto the banks, peeling back vegetation and shaving channel banks.

Lateral Accretion of Channels

Landforms in the Niglintgak area provide evidence that channels have moved and changed over time. Remnant channel scars aligned perpendicular to Kumak Channel suggests that Kumak Channel did not exist when those channels were active in the distant past. These channel scars are very old, and evidence suggests Kumak Channel is geologically a relatively new channel. A series of curved lakes on Niglintgak Island could be evidence of historical point bar deposits and the remnants of old channel beds.

Pleistocene uplands, composed of coarse sands and gravels, to the south and east of Kumak Channel are relatively inerodible (Traynor and Dallimore 1992) and could armour Kumak Channel and deter channel migration in that direction.

Observations on channel morphology, based on aerial photographs from 1950, 1985 and 2002, include:

- the left downstream (west) bank of Kumak Channel near the tip of Niglintgak Island has been eroding by 0.8 to 2.1 m/a
- vegetated bank lines along Kumak Island at the entrance to Kumak Channel have been moving eastward, and the island appear to be getting smaller
- the entrance to Kumak Channel has been widening, mostly to the west. The relatively erosion-resistant Pleistocene deposits along the right downstream, (east) side of the channel have protected the bank whereas the left downstream (west) bank erodes 1 to 2 m/a
- sand bars in Middle Channel west of Niglintgak Island have moved and shifted noticeably in the channel over the past 50 years
- the junction of Aklak and Kumak channels has changed noticeably since 1950. In 1950, Aklak Channel joined Kumak Channel via two branches and sediment deposition was into Kumak Channel, suggesting a dominant flow direction from east to west. By 1985, the two branches at the mouth of Aklak Channel had combined to form a single channel. Flow observations in 1975 and 2003 indicate that Aklak Channel reverses flow direction.
- at the northern end of Niglintgak, Kumak Channel has migrated eastward over the years, with sediment deposition along the left downstream bank and erosion along the right bank. The right downstream bank has been eroding by 1.1 to 1.8 m/a. Unlike the changes at the entrance to Kumak Channel, erosion and deposition are relatively equal and the channel has maintained a constant width since 1950.

Rates of erosion and deposition are summarized in Table 5-38.

Table 5-38: Average Rates of Kumak Channel Movement – 1950 and 2002

Location in Kumak Channel	Deposition and Erosion Rates (m/a)		Change in Channel Width (m)
	Left Downstream Bank	Right Downstream Bank	
Southern tip of Niglintgak Island	-1.5	–	–
Inlet to Kumak Channel at south end of Kumak Island	-1.1	-1.8	+151
Downstream end of Kumak Island	-1.8	-1.0	+146
South of Aklak Channel junction	-0.4	+2.8	-125
Near proposed lateral crossing	-0.2	-0.9	+60
At north end of lease boundary near constriction	+2.1	-1.6	-25

NOTES:
- = negative change or erosion
+ = positive change or deposition
– = not available

Channel Cross-Section Changes

Observations on channel cross-section shape, based on available surveys from Slaney (1976a, 1976b, 1977), Hardy (1976 and 1977b) and Traynor and Dallimore (1992) include:

- Middle Channel about 2 km upstream from the Niglintgak lease boundary, (upstream from Kumak Channel and Niglintgak Island) is about 900 m wide and 9 m deep with shoals particularly prominent along the left downstream, (west) side. Farther out from the bank, the sides of the channel drop off to a deep centre section. The channel bed is undulated with bedforms over 2 m high.

- Middle Channel downstream from Kumak Channel and west of Niglintgak Island is very shallow across its width with water depths of 1 to 2 m

- surveyed cross-sections of Kumak Channel near the proposed flow line crossing (1975, 1993 and 2003) indicate that the channel is skewed toward the right downstream bank and is about 600 m wide and about 12 m deep. Two measurements in 1990 and 1991 show a channel depth of over 20 m, much deeper than the other measurements. It is unclear if the anomalous 20-m depths in the 1990 and 1991 cross-sections are evidence of a scour hole that filled within two years or can be considered a survey error.

- cross-sections of Aklak Channel near the proposed flow line crossing, from 1975 and 2003, indicate the channel is at most 4 to 6 m deep

5.4.1.3 Field Investigations

Two sites at Niglintgak were investigated during the spring hydrology survey of June 1 to 11, 2002 (see Table 5-39). Most areas were flooded, preventing ground surveys, though the sites were photographed.

Table 5-39: Channel Survey Sites at Niglintgak

Crossing ID	Name	Description
Not applicable	Kumak Channel	At south flow line crossing, wide delta channel
RNT-02	Aklak Channel	East-west channel at flow line crossing where Aklak joins Kumak channel, narrow delta channel

Following are summarized results of the 2002 spring survey:

- the southern part of Niglintgak Island, including the proposed drill pad locations, was extensively flooded on June 7
- ice conditions at Kumak Channel varied between June 1 and 7. The channel was ice-free on June 1 and subject to a large ice floe by June 7. Water levels peaked around June 7, with extensive flooding observed throughout the area.
- RNT-02 had open water with small patches of snow on the banks. The area was flooded, with water levels overtopping the banks.
- most of the lakes on the island were fully or partially ice covered during the survey
- all channels were ice-free on June 9, though water levels remained high. By June 11, water levels were at bankfull and starting to recede.

Summer field studies were limited to fish and fish habitat surveys at three unnamed lakes and five channels at Niglintgak. No discharge measurements were taken because of the large size of the channels and restricted boat access in shallow areas. Cross-sections were surveyed.

2003 Spring Breakup

In 2003, a spring hydrology survey acquired additional baseline information.

Water Level Surveys

Water levels were surveyed at Niglintgak during the site visit. Table 5-40 summarizes the survey dates and the water levels recorded at each site.

Table 5-40: Water Level Surveys at Niglintgak

Date (2003)	Channel at Niglintgak	
	Site	**Water Level** (m)
May 29	–	–
May 31	Kumak Channel (upstream of Aklak Channel)	9.382
June 3	Kumak Channel (upstream of Aklak Channel) Middle Channel	9.488 9.445
June 7	Kumak Channel (upstream of Aklak Channel) Middle Channel Kumak Channel (downstream of Aklak Channel)	9.579 9.565 9.481
June 8	Kumak Channel (downstream of Aklak Channel)	9.242
June 9	–	–
June 11	Kumak Channel (upstream of Aklak Channel) Middle Channel Kumak Channel (downstream of Aklak Channel)	8.892 8.896 8.842
June 12	–	–
June 13	Kumak Channel (downstream of Aklak Channel)	8.710
June 14	–	–

NOTE:
– = not measured

Sediment

Single samples of surface channel water were collected on June 8 and 9, 2003, following the peak water levels, for suspended sediment analysis. Suspended sediment concentrations were 249 mg/L at Kumak Channel (downstream of Aklak Channel).

Postflood sediment accumulations on sediment plates at Niglintgak were noted on June 7 and 11, and the plates and deposits were collected from Niglintgak on June 11, 2003.

Data collected from the sediment plates is summarized in Table 5-41.

Spring Discharge Measurements and Results

Channel discharges were measured on June 8 and 13 at Niglintgak. The discharge measurements are summarized in Table 5-42.

Table 5-41: Summary of Sediment Deposition at Niglintgak

Plate No.	Pre-flood Ground and Plate Elevation[1] (m)	Approx. Distance from Bank (m)	Depth of Sediment on Plate (m)	Volume of Sediment on Plate[2] (m^3)	Weight of Sediment (kg)	Post-flood Ground Elevation[1] (m)	Post-flood Top of Plate Elevation[1,3] (m)
E1 N 10	9.825	10	<0.001	<9.3E-05	0.01	9.837	9.836
E1 N 30	9.796	30	0	0	0	9.870	9.870
E1 N 50	9.615	50	0	0	0	9.615	9.615
E2 N 10	9.800	10	0	0	0	9.868	9.868
E2 N 30	9.592	30	0.001	9.3E-05	0.085	9.709	9.708
E2 N 50	9.575	50	<0.001	<9.3E-05	0.01	9.623	9.622
W N 10	9.528	10	0.089	8.3E-03	10.5	9.532	9.443
W N 30	9.512	30	0.020	1.9E-03	2.24	9.580	9.560
W N 50	9.486	50	0.010	9.3E-04	1.06	9.476	9.466

NOTES:
1 Elevations are relative to Benchmark 1 (BM1), which was assigned an arbitrary elevation of 10,000 m
2 Depth of sediment multiplied by surface area of plate (0.3048 m x 0.3048 m = 0.093 m^2)
3 Postflood ground elevation – depth of sediment on plate

Table 5-42: Summary of Discharge Measurements

Channel	Near-Peak Spring Discharge (m^3/s)	Post-Peak Spring Discharge (m^3/s)
Niglintgak		
Kumak Channel (downstream of Aklak Channel)	5,329 (at 16:30)	2,577 (at 11:30)
Aklak Channel	Flowing east to west	27 (at 13:30) Flowing west to east
Middle Channel (upstream of Niglintgak)	Not measured	3,324 (at 15:30)
Middle Channel (downstream of Niglintgak)	Not measured	750[1]

NOTES:
1 Estimated from measured upstream flow in Middle Channel and downstream flow in Kumak Channel
Niglintgak survey dates: June 8, 2003 for near-peak spring discharge and June 13, 2003 for post-peak spring discharge

5.4.2 Taglu

The Taglu Significant Discovery Licence Area is located in the lower Mackenzie Delta between Middle and East channels of the Mackenzie River just before they enter the Beaufort Sea (see Figure 5-1, shown previously). The Significant Discovery Licence Area is about 65 km^2 in size and encompasses:

- parts of Kimialuk Lake and Big Lake
- parts of Taglu, Seal and Fish islands
- parts of Harry, Kanguk and Kuluarpak channels
- several unnamed waterbodies and channels

5.4.2.1 Previous Studies

Several investigations were done in the mid-1970s to assist engineering studies related to oil and gas development in the Taglu region (Fenco 1976; Slaney 1976a), and a more recent study was done in 1992 (Traynor and Dallimore 1992). These studies provide useful background information. A summary of the studies follows.

Comparison of Flood Levels

A recent comparison of recorded flood levels at Taglu in Slaney (1976a, 1976b and 1977) and Hardy (1976 and 1977b) indicates that flood levels were 2.4 to 2.6 m above Mean Sea Level, as defined in 1976. With ground elevations at about 1.7 m above Mean Sea Level, the spring peak water levels resulted in inundation depths of 0.7 to 0.9 m. The maximum inundation depth is about 1.8 m based on maximum driftwood elevations in the area.

Ice Conditions

Baseline ice conditions at Taglu can be summarized as follows:

- ice in nearby channels was 1.5 to 1.8 m thick (Slaney 1976a) and the variability depends mainly on water depth and amount of insulating snow cover on the channel (Slaney 1976a; Traynor and Dallimore 1992)
- on April 9, 1975, discharge of 43 m^3/s was measured at Harry Channel and discharge of 26 m^3/s was measured at Kuluarpak Channel. In 1975, there was considerable free-flowing water beneath the ice cover in Harry and Kuluarpak channels (Slaney 1976a).
- free-flowing water beneath the ice cover is limited in winter because of the preponderance of shallow channels in the Taglu area (Traynor and Dallimore 1992)
- no sub-ice flow was detected in Harry Channel downstream of the bifurcation in early January 1972 (Traynor and Dallimore 1992)
- Kuluarpak Channel was deep enough that water continued to flow beneath the ice throughout the winter (Traynor and Dallimore 1992)

Spring Breakup

Baseline spring breakup conditions at Taglu can be summarized as follows:

- in 1975, breakup of channel ice was complete by June 8 (Slaney 1976a)

- in 1975, the first break in the solid ice cover occurred two weeks before the peak water level (Fenco 1976)
- disintegration and thermal degradation of the ice cover continued in place in 1975 without major movement downstream until June 7 (Fenco 1976)

Ice Jamming

Baseline ice jamming conditions at Taglu can be summarized as follows:

- ice jams were observed in Kuluarpak and Back channels in 1975 (Slaney 1976a)
- ice jams were observed upstream in Kuluarpak Channel, at the Harry Channel turnoff, and downstream, at the northward bend of Kuluarpak Channel (Fenco 1976; Traynor and Dallimore 1992)
- major ice jams and bottomfast ice zones can be expected to have a major effect on channel hydraulics during breakup in the Taglu area (Traynor and Dallimore 1992)

Spring Flood

Baseline spring flood conditions at Taglu can be summarized as follows:

- in 1975, maximum flood stage was reached on June 7. Peak stage was 0.15 m less than that recorded in 1973 at Taglu, and nearly identical to that recorded in Kumak Channel in 1975 (Slaney 1976a).
- because of the 1975 flood, the northern bank of Kuluarpak Channel failed at a location downstream of Harry Channel. An average bank degradation rate of 1.5 m every 3 to 5 years is suspected at this location (Slaney 1976a).
- floodplain inundation levels are believed to range as high as 1.8 m, based on maximum driftwood levels

Bathymetry and Discharge

Baseline bathymetry and discharge at Taglu can be summarized as follows:

- Harry Channel discharge was measured at two cross-sections on June 10 and September 27, 1975. Average discharge was 750 m^3/s on June 10 and 260 m^3/s on September 27. The channel was 300 m wide, with an average maximum depth of 12 m (Slaney 1976a).

- average discharge rates in Kuluarpak Channel were 700 m^3/s on June 10, 1975 based on two cross-sections, and 215 m^3/s on September 28, 1975 based on three cross-sections. Discharge in Kuluarpak Channel increased by about 280 m^3/s between June 8 and 10, 1975. Kuluarpak Channel is about 142 m wide, with an average maximum depth of 10 m (Slaney 1976a).

- discharge in Harry and Kuluarpak channels dropped to 20 to 30% of peak discharge in early June 1975 (Slaney 1976a)

- in 1992, additional surveys were completed on Harry and Kuluarpak channels. The locations were the same as in previous studies to allow comparison of bathymetry (Traynor and Dallimore 1992). The following points summarize the 1992 study results:

  - Harry Channel, upstream from Back and Kuluarpak channels, deepened by about 5 m between 1975 and 1990. This value was deemed substantial when compared with the maximum depths of 8 m at an upstream profile and 6 m at a downstream profile (Traynor and Dallimore 1992).

  - Kuluarpak Channel branches off Harry Channel and flows westward around Taglu Island. At the upstream part of the initial bend of Kuluarpak Channel, a 2.8-m aggradation of the channel bed and a maximum depth of 12.1 m were observed over 15 years (Traynor and Dallimore 1992).

  - 1990 surveys indicated a larger thalweg zone compared with 1975 bathymetry at the downstream part of the initial bend in Kuluarpak Channel, and the channel was about 1 m shallower (Traynor and Dallimore 1992)

  - a cross-section of Kuluarpak Channel downstream from the initial bend showed a maximum depth of 7.2 m in 1990. The depth remained similar between 1975 and 1990, though the thalweg zone expanded and the channel margins became steeper (Traynor and Dallimore 1992).

  - downstream from the bifurcation at the exit of a meander bend, the thalweg shifted 15 m toward the right bank of Harry Channel between 1975 and 1991. The 1975 profile showed a bedform rise of 1.5 m between two troughs, and the 1991 profile showed an aggradation of the left trough and bank (Traynor and Dallimore 1992).

  - downstream from the bifurcation, Kuluarpak Channel retains most of the flow compared with Harry Channel. Kuluarpak Channel is 4 to 10 m deep and has a larger cross-sectional area, whereas Harry Channel becomes shallow toward the Beaufort Sea (Traynor and Dallimore 1992).

5.4.2.2 Taglu Channel Morphology

Site Description

Harry Channel, a distributary of Middle Channel, flows northward into Taglu. At Taglu, the channel bifurcates around Taglu Island, with Kuluarpak Channel flowing west and Harry Channel flowing east. Other notable watercourses in Taglu include Kanguk Channel and the northeastern bay of Kimialuk Lake, both of which are west of the proposed development and Kuluarpak Channel. The channels in Taglu are 10 to 15 times wider than they are deep. They typically have steep side slopes and are relatively symmetrical except at sharp bends.

Table 5-43 summarizes the proportion of flow in Harry and Kuluarpak channels measured during different surveys.

Table 5-43: Proportion of Flow to Channels in Taglu

Date	Flow in Harry Channel (upstream) (m^3/s)	Flow to Kuluarpak Channel (%)	Flow to Harry Channel (downstream) (%)	Flow to Back Channel (%)
July 6, 1973[a]	481	65	35 (combined)	
October 6, 1973[a]	277	79	21 (combined)	
April 9, 1975[b]	43	60	40 (combined)	
June 10, 1975[b]	1,120	72	26	2
September 27–28, 1975[b]	~400	65	34	1
June 19, 1976[c]	555	70	30	
August 16–17, 1976[c]	473	55	45	
September 25, 1976[c]	412	52	48	
June 14, 2003	472	69	31	
Average		~65	~35	

SOURCES:
a Slaney (1974)
b Slaney (1976b)
c Slaney (1977)

Field Observations

During 2002 and 2003 field studies, active slumping was observed on outside banks of both bends in Kuluarpak Channel.

Lateral Accretion of Channels

Qualitative analysis of aerial photographs from 1935 (oblique), 1950, 1973, 1985 and 2002 indicate that no major channel movements or avulsions have occurred in the last 68 years. However, there is evidence of historical channel avulsion and abandonment before 1950 that scarred the Taglu landscape. These scars show little change in appearance or vegetation growth in 2002, and given the short growing season and slow growth rates in the Arctic, it is likely they are more than 100 years old.

Comments on channel morphology include:

- point bar deposits on the inside bends of Harry and Kuluarpak channels have the typical arc shape commonly observed in meandering rivers, suggesting the channels are migrating toward their outside banks, a characteristic of meandering rivers
- a long and narrow lake east of the bifurcation was separate from Harry Channel in 1950. Between 1950 and 1973, Harry Channel appears to have migrated eastward and breached the lake. By 2002 most of the lake had been in-filled with sediment, leaving behind a smaller lake.
- Kuluarpak Channel has been eroding at a rate of about 0.6 m/a just downstream from the Harry Channel bifurcation. Farther downstream where Kuluarpak Channel bends sharply to the north, the outside bank is eroding at a rate of about 0.3 m/a. The north-flowing section of Kuluarpak Channel has shifted toward the east at a rate of about 0.5 m/a.

Rates of erosion and deposition are summarized in Table 5-44.

Changes in Channel Cross-Section

Comments on channel cross-section shape, based on surveys from Slaney (1976a, 1976b, 1977), Hardy (1976 and 1977b) and Traynor and Dallimore (1992) include:

- Harry Channel upstream from the proposed development is about 10 m deep and 140 to 180 m wide
- Harry Channel at the proposed Taglu lateral crossing, downstream of the bifurcation is about 100 m wide and 6 m deep. The cross-sectional area of the channel at this point is noticeably smaller than at the section upstream of the development area, reflecting the large amount of flow, about 65%, being diverted to Kuluarpak Channel. Farther downstream in Harry Channel, Traynor and Dallimore (1992) measured much shallower cross-sections that they predicted would be frozen to the bed in winter.

- Kuluarpak Channel at the proposed Niglintgak lateral crossing is about 8 m deep and 100 m wide based on surveys done in the spring of 2003. In 1991, the thalweg of Kuluarpak Channel was skewed toward the inside bank, whereas in 2003 the channel shape was more typical of a bend, with the thalweg skewed toward the outside bank. There are point bar deposits on the right downstream bank and eroding slumping banks on the left downstream bank.

Table 5-44: Average Rates of Channel Deposition and Erosion at Taglu – 1950 and 2002

Description	Deposition and Erosion Rates (m/a)		Change in Channel Width (m)
	Left Downstream Bank	Right Downstream Bank	
Kuluarpak Channel at bifurcation immediately downstream of Harry Channel	+0.2	-0.3	+17
Kuluarpak Channel upstream of proposed development	+0.5	-0.6	+13
Harry Channel at bend after bifurcation	-0.8	+0.4	-6
Harry Channel at bend near the lake	+0.3	-0.5	+16
Kuluarpak Channel immediately downstream of proposed development	no change	-0.3	+8
Kuluarpak Channel at northward bend, upstream	-0.3	+0.1	+8
Kuluarpak Channel at northward bend, downstream	-0.3	+0.5	+22
Kuluarpak Channel in north-flowing section	+0.2	-0.5	+13

NOTES:
- = negative change or erosion
+ = positive change or deposition

Comparison of Morphologic Change at Niglintgak and Taglu

Lateral channel movement seems to be more pronounced and morphological processes more dynamic, in Niglintgak than in Taglu. Possible reasons for these differences include:

- Niglintgak channels are much larger than Taglu channels and carry much more flow. Table 5-45 shows that about six times more flow passes through Niglintgak than Taglu during open-water conditions. The flow measured at Niglintgak in late winter of 1975 was about 20 times greater than the flow at Taglu.
- flooding at Niglintgak is more extensive, particularly on Niglintgak Island, and the inundation of water in the spring accelerates thawing of ice-rich sediments and aggravates bank instability

5.4.2.3 Field Investigations

Two sites in Taglu were investigated during the spring hydrology survey June 1 to 11, 2002 (see Table 5-46). Three other sites were flooded, preventing ground surveys. The sites were photographed, however.

On June 3, 2003, RPR-002 and RPR-005 were mostly ice covered, and on June 7 they had flooded over their banks. Water levels began to recede by June 9 to 11, 2003.

Observations of the other three sites not included in the ground surveys include:

- on June 5, 2002, there was a thin ice sheet of ice in the middle of the channel at RNT-06, and the edges of the ice were melted along the banks. On June 7, the channel was flowing above bankfull, about 5 to 10 m into the floodplain, and the channel was full of broken and refrozen ice. By June 9, the channel was ice-free and the banks showed signs of slumping.
- on June 3, 2002, RNT-04 had mid-channel ice with water overtopping the channel banks. Some bottom ice was also observed. By June 9, most of the channel was ice-free and water had flooded 15 m of the floodplain fringe. On June 11, the channel was ice-free and the water level was still high.
- on June 3, flow was above bankfull at RNT-05, about 10 to 15 m into the floodplain. By June 11, the channel was free of ice on June 9 and the water level had dropped slightly.

Table 5-45: Estimated Flow through Niglintgak and Taglu

Year	Season	Niglintgak	Location of Estimate	Taglu	Location of Estimate
1973	Spring	3,564 m^3/s^a	Middle Channel upstream of Niglintgak	481 m^3/s^d	Harry Channel upstream of Kuluarpak
	Fall	1,667 m^3/s^a	Middle Channel upstream of Niglintgak	277 m^3/s^d	Harry Channel upstream of Kuluarpak
1975	Late winter	878 m^3/s^b	Kumak Channel only	43 m^3/s^e	Harry Channel upstream of Kuluarpak
	Spring	5,623 m^3/s^b	Kumak Channel only	1,120 m^3/s^e	Harry Channel upstream of Kuluarpak
	Fall	1,760 m^3/s^b	Kumak Channel only	408 m^3/s^e	Harry Channel upstream of Kuluarpak
1976	Spring	–	N/A	555 m^3/s^f	Harry Channel upstream of Kuluarpak
	Summer	2,990 m^3/s^c	Middle Channel upstream of Niglintgak	473 m^3/s^f	Harry Channel upstream of Kuluarpak
	Fall	–	N/A	412 m^3/s^f	Harry Channel upstream of Kuluarpak
2003	Spring	3,324 m^3/s	Middle Channel upstream of Niglintgak	472 m^3/s	Harry Channel upstream of Kuluarpak

NOTES:
– = not available
N/A = not applicable
a Slaney (1974)
b Slaney (1976a)
c Hardy (1976)
d Slaney (1974)
e Slaney (1976b)
f Slaney (1977)

Table 5-46: Taglu Site Descriptions

Crossing ID	Name	Drainage Area (km^2)	Hydrologic Region	Stream Class	Width[1] (m)	Dominant Substrate	Upland Storage	2002 Flow Monitoring
RPR-002	Harry Channel at Mackenzie River	N/A	Delta	Active I	120-170	Silt	N/A	No
RPR-005	Unnamed delta channel	N/A	Delta	Active I	65-75	Silt	N/A	No

NOTE:
N/A = not applicable
1 Range of values reflects different widths measured within the study reach

2003 Spring Breakup

In 2003, a spring hydrology survey acquired additional baseline information.

Water Level Monitoring

Taglu Water Level Station

A water level monitoring station was installed May 29, 2003 on Kuluarpak Channel in Taglu, downstream from the bifurcation and adjacent to the old D–43 gravel pad. Station data was downloaded on June 12, 2003. The station was operational until September 23, 2003. (See Figure 5-28, shown previously, for water level data from this station.)

Because Kuluarpak Channel was still frozen on May 29, with bankfast ice on the edges, the pressure transducer was installed at the edge of the ice at an elevation of 9.974 m, relative to BMT1. The ice level receded with increasing air temperatures, and on May 31 and June 1 the elevations were measured and found to be 9.845 m and 9.540 m. As recorded by the transducer, water levels increased above the transducer elevation of 9.974 m on June 6 at 07:49.

Peak water level reached 10.071 m, after which levels dropped below the transducer elevation at 21:19 the same day. On June 7, following the peak water level, the transducer was reinstalled below the water surface at an elevation of 8.301 m. The water level dropped about 1.7 m from June 6 at 21:19 to June 7 at 17:34. Between June 7 and 12 the rate of water level recession decreased. On average, the water level dropped 0.27 m per day.

Coastal Water Level Station

The water level station on the coast was installed on the east side of the Kumak Channel outlet. After installation, the coastal station was not visited for the remainder of the spring program. (For recorded water levels on the coast for the 2003 monitoring season, see Figure 5-28, shown previously.)

Spring Discharge Measurements and Results

Channel discharges were measured June 9 and 14 at Taglu. Discharge measurements are summarized in Table 5-47.

Table 5-47: Summary of Discharge Measurements at Taglu

Channel	**Near-Peak Spring Discharge** (m^3/s)	**Post-Peak Spring Discharge** (m^3/s)
Taglu		
Kuluarpak Channel	501 (at 13:40)	339 (at 11:00)
Harry Channel (downstream of Taglu)	285 (at 16:30)	194 (at 13:45)
Harry Channel (upstream of Taglu)	Not Measured	472 (at 12:05)
NOTE: Taglu survey dates: June 9, 2003 for near-peak spring discharge and June 14, 2003 for post-peak spring discharge		

Water Level Surveys

Water levels were surveyed at Taglu during the site visit. Table 5-48 summarizes the survey dates and the water levels recorded at each site.

Sediment

Single samples of surface channel water were collected June 8 and 9, 2003, following the peak water levels, for suspended sediment analysis. Suspended sediment concentrations were:

- 224 mg/L at Kuluarpak Channel
- 230 mg/L at Harry Channel downstream from the bifurcation

The Taglu sediment plates were observed June 7 and 12, and deposited sediment and the sediment plates were collected June 12, 2003. Data collected from the sediment plates is summarized in Table 5-49.

Table 5-48: Water Level Surveys at Taglu

Date (2003)	Channel at Taglu	
	Site	Water Level (m)
May 29	Kuluarpak Channel (ice level)	9.974
May 31	Kuluarpak Channel (ice level) Back Channel (ice level)	9.845 9.911
June 3	Kuluarpak Channel Back Channel (ice level)	9.540 9.920
June 7	Kuluarpak Channel	9.711
June 8	–	–
June 9	Kuluarpak Channel	9.210
June 11	–	–
June 12	Kuluarpak Channel Back Channel West Kuluarpak Channel	8.835 8.810 8.798
June 13	–	–
June 14	Kuluarpak Channel	8.745

NOTE:
– = not measured

Table 5-49: Summary of Sediment Deposition at Taglu

Plate No.	Pre-flood Ground and Plate Elevation[1] (m)	Approximate Distance from Bank (m)	Depth of Sediment on Plate (m)	Volume of Sediment on Plate (m^3)	Weight of Sediment (kg)	Postflood Ground Elevation[1] (m)	Postflood Top of Plate Elevation[1] (m)
E T 5	9.971	5	<0.001	<9.3E-05	<0.01	9.940	9.940
E T 10	10.122	10	0	0	0	10.109	10.109
E T 15	10.073	15	0	0	0	10.063	10.063
M T 5	10.035	5	0.002	1.9E-04	0.060	10.019	10.017
M T 10	10.026	10	0.001	9.3E-05	0.055	10.002	10.001
M T 15	10.000	15	0	0	0	9.964	9.964
W T 5	10.001	5	0	0	0	9.996	9.996
W T 10	9.923	10	0	0	0	9.903	9.903
W T 15	9.901	15	0	0	0	9.895	9.895

NOTES:
1 Elevations are relative to Benchmark Taglu 1 (BMT1), which was assigned an elevation of 10.000 m
2 Surface area of plate (SA) = 0.3048 m x 0.3048 m = 0.093 m^2

5.4.3 Parsons Lake

The Parsons Lake anchor field includes nearly all of Parsons Lake, all of West Hans and East Hans lakes and several unnamed lakes (see Figure 5-1, shown previously). Some lakes are connected by small channels whereas others are separated by higher ridges. Parsons Lake includes proposed lateral flow line rights-of-way within the lease boundaries, but does not include the part of the lateral flow line leading from the lease boundary to the main gathering pipeline. For the purposes of the following discussions, Parsons Lake also includes a 1-km-wide area outside the lease boundary.

5.4.3.1 Previous Studies

Limited hydrologic studies have been completed in the Parsons Lake area. Zed Creek was monitored in the summer of 1978 and from 1979 to 1982 (Environment Canada 2002d). The gauging station was about 10 km downstream from the proposed crossing location at the outlet of Parsons Lake. Mean monthly flow over the four-year period ranged from 2.3 to 1.8 m^3/s between June and October. Flow in December was minimal, and the station recorded zero-flow conditions between January and May. Additional point discharge measurements by Slaney (1977) estimated flow at about 3 m^3/s in late June 1976 and showed flow in Zed Creek at 1.5 to 2 m^3/s in September 1976.

5.4.3.2 Field Investigations

Four Parsons Lake sites were investigated during the spring hydrology survey of June 1 to 11, 2002 (see Table 5-50). Survey sites included watercourse crossings identified on 1:50,000 topographic maps. At the beginning of the survey, the Parsons Lake sites had varying amounts of snow and ice in the drainage paths and little visible flow. Flow was typically through willows or over bottom ice and snow. Most of the streams were classified as Vegetated Channels.

The lakes in the Parsons Lake anchor field were frozen to the shore at the beginning of the spring study, with the exception of one small lake, which is southeast of Parsons Lake and was ice-free on June 3. Higher elevations and temperatures cooler than at the other anchor fields were likely responsible for the Parsons Lake ice cover. By June 11, most of the smaller lakes had thawed completely and larger lakes had thawed a few metres around the edges. Thermal melting dominated the area, and no dynamic events were observed in the Parsons Lake lease.

RPL-004 still had snow and ice in the channel at the end of the survey, though snowmelt was observed over the survey period.

Table 5-50: Parsons Lake Site Descriptions

Crossing ID	**Name**	**Drainage Area** (km^2)	**Hydrologic Region**	**Stream Class**	**Dominant Substrate**	**Upland Storage**	**2002 Flow Monitoring**	**Mean Annual Flow** (m^3/s)	**Equivalent Runoff**[1] (mm)
RPL-001	Zed Creek	about 300	Delta	Active I	Gravel/Silt	H	No	1.262	133
RPL-002	Unnamed stream	5	Delta	Vegetated	N/A	VH	No	0.004	24.1
RPL-003	Unnamed stream	0.5	Delta	Vegetated	N/A	VH	No	0.000[a]	2.41
RPL-004	Unnamed stream	5	Delta	Vegetated	N/A	VH	No	0.004	24.1

NOTES:
H = high
VH = very high
N/A = not applicable
a Mean annual flow based on regional analysis, might be >0, but <0.0005 m^3/s
1 Equivalent runoff based on mean annual flow

RPL-001, Zed Creek, is the outlet of Parsons Lake and was snow- and ice-free during the survey, though small areas of snow were observed along the channel banks. The channel is about 7 to 15 m wide and had a relatively constant water level with depths of around 0.4 m, an average velocity of 0.11 m/s and flow measured at 1.26 m^3/s. Zed Creek has been classified as an Active I stream because of water depths near the proposed crossing location. Zero-flow conditions have been recorded between January and May at the discontinued hydrometric station downstream from the site, though local conditions are unknown and the stream might freeze only partially to the bottom at the proposed crossing location.

5.4.4 Gathering Pipelines

5.4.4.1 Niglintgak Lateral

The Niglintgak lateral extends from the eastern boundary of Niglintgak to the western boundary of Taglu.

There are five stream or channel crossings along the Niglintgak lateral. Two are Large River Channels and one is an Active I Channel that might partly freeze to the bottom in winter. One stream is an Active II Channel with discernible banks and substrate, but the stream is small and is expected to freeze to bottom in the winter. One of the watercourses crossed by the gathering pipelines is a Vegetated Channel with a poorly defined flow path and dispersed drainage through shrubs or trees.

Extensive flooding of the area south of Kimialuk Lake was observed June 7, 2002 during the spring hydrology survey. Kimialuk Lake and other unnamed lakes were ice covered, and flood conditions extended the length of the flow line with floodwaters estimated to be about 1 m deep. A week after flood conditions were observed, flood levels had completely receded and the area had dried extensively.

5.4.4.2 Taglu and Storm Hills Laterals

The Taglu and Storm Hills laterals extend from the southern boundary of the Taglu lease south to the proposed Inuvik area facility. The following information was compiled for each watercourse:

- photographs and maps showing the surveyed location
- site identification numbers
- watercourse names
- site location, i.e., UTM and latitude or longitude
- drainage areas
- whether the watercourse has a defined drainage path
- extent to which flow is confined in a channel
- observations related to topography, flow quantity, habitat type and vegetation

Table 5-51 shows a summary of stream types determined from the reconnaissance observations. See Section 5.3.6 for a complete discussion of stream classification.

Table 5-51: Watercourse Types along Storm Hills and Taglu Laterals

Watercourse Type	Stream Class	Number of Sites	Percentage of Streams (%)	Approximate Basin Size[1]
Lakes	N/A	7	N/A	Not available
Streams	Large River	2	3	DA>1000 km^2
	Active I	9	15	DA>25 km^2
	Active II	5	8	DA<25 km^2 and S>0.01 m/m
	Vegetated	45	74	DA<25 km^2 and S<0.01 m/m
	Total sites	68	100	

NOTES:
N/A = not applicable
DA = drainage area
S = slope
1 General relationships between drainage area and stream type based on stream classification results for the northern hydrologic region (see Section 5.3, Regional Baseline Conditions). Local conditions might vary.

As shown in the table, 45, or 74%, of the watercourses crossed by the gathering pipelines are Vegetated Channels with poorly defined flow paths or with drainage dispersed through shrubs or trees. Five streams, 8%, are Active II Channels with discernible banks and substrate, though they are small streams expected to freeze to the bottom in winter. The nine Active I Channels might partly freeze to the bottom in winter. East and Harry channels of the Mackenzie River are classed Large River Channel and maintain flow throughout the year.

Field Investigations

Table 5-52 lists the watercourses where detailed fish habitat and hydrologic surveys were done. Flow monitoring was not done at these stations in 2002. The local site descriptions are based on field studies, interpretation of available photographs and the regional hydrology analysis.

5.4.4.3 Parsons Lake Lateral

The Parsons Lake lateral extends from the Parsons Lake gas conditioning facility to the Storm Hills pigging facility.

There are nine stream or channel crossings along the Parsons Lake lateral. One Active I Channel might partly freeze to the bottom in winter. Eight of the watercourses crossed by the gathering pipelines are Vegetated Channels with poorly defined flow paths and dispersed drainage through shrubs or trees.

Table 5-52: Summary of Storm Hills and Taglu Lateral Site Descriptions

Crossing ID	**Name**	**Drainage Area** (km^2)	**Hydrologic Region**	**Stream Class**	**Width**[1] (m)	**Channel Slope** (m/m)	**Dominant Substrate**	**Upland Storage**
RPR-001	Unnamed channel	N/A	Delta	Active I	30–40	–	Silt	N/A
RPR-002	Harry Channel	N/A	Delta	Large River	100–160	–	Silt	N/A
RPR-003	Unnamed channel	N/A	Delta	Active I	30–45	–	Silt	N/A
RPR-005	Unnamed channel	N/A	Delta	Active I	65–70	–	Silt	N/A
RPR-006.1	Yaya River	N/A	Delta	Active II	0.6–26	–	Organic	N/A
RPR-007	Unnamed stream	34.1	Delta	Active I	0.5–2	0.002	Sand	VH
RPR-011	Unnamed channel	N/A	Delta	Active I	100–140	–	Silt	N/A
RPR-012	Unnamed channel	N/A	Delta	Active I	24–26	–	Silt	N/A
RPR-013	East Channel	N/A	Delta	Large River	800–850	–	Silt	N/A
RPR-036	Hans Creek	175	Delta	Active I	7–37	0.001	Silt and gravel	Unknown
RPR-046	Unnamed stream	67.2	Delta	Active I	20– 40	0.002	Silt	M to H
RPR-048	Unnamed stream	115	Delta	Active I	2–8	0.003	Silt	H

NOTES:
N/A = not applicable
– = not determined
L = low
M = medium
H = high
VH = very high
1 Range of values reflects different widths measured within the study reach

5.4.5 Production Area Infrastructure

Project construction and operations include the following infrastructure components in the production area:

- barge landing sites
- road crossings, i.e., ice roads and all-weather roads
- water supply for camps and facilities

Table 5-53 summarizes 2003 surveys at these infrastructure sites.

Reconnaissance surveys of infrastructure sites in July 2003 involved visiting 85 road crossings in the production area. Eighty-three of these crossings will be used in winter only and two are on proposed all-weather roads.

Table 5-53: Infrastructure Sites in the Production Area

Infrastructure Type	Number of Reconnaissance Sites	Number of Detailed Sites
Barge landing	5	5
Road crossing	85	0
Water supply from lakes for camps and facilities	2	2
Fuel storage and equipment stockpile	0	0
Horizontal directional drilling pad	0	0
Airstrip	0	0
Camp, or camp and stockpile	3	0
Stockpile	0	0

All five barge landing sites proposed for the pipeline corridor were visited during the reconnaissance and detailed ground surveys in 2003. Information compiled for each site included:

- photographs and maps showing the surveyed location
- site identification numbers
- watercourse names
- site location, i.e., UTM and latitude or longitude
- drainage areas

5.4.6 Gwich'in Settlement Area

The proposed pipeline crosses very small arctic drainages in the Eskimo Lakes basin and eastern tributaries to the Mackenzie River. These tributaries are in the northern hydrologic region, and flow is usually restricted in winter by freeze-to-bottom conditions.

The proposed pipeline will cross no Large River-class watercourses, i.e., drainage basins larger than 1,000 km^2, in the Gwich'in Settlement Area. The largest rivers in the region are the east tributary to Travaillant River, which is 583 km^2, and Thunder River, which is 310 km^2.

5.4.6.1 Reconnaissance

Reconnaissance surveys of 119 watercourses were done August 12, 13 and 15, 2001 and July 11 and 12, 2003. Data compiled for each site included data listed in Section 5.4.5.

Table 5-54 is a summary of watercourse types determined from the reconnaissance and detailed survey observations. See Section 5.3.6 for a complete discussion of stream classification.

Table 5-54: Watercourse Types in the Gwich'in Settlement Area

Watercourse Type	Stream Class	Number of Sites	Percentage of Streams	Approximate Basin Size[1]
Stream	Active I	7	6	DA>50 km^2
	Active II	10	8	13<DA<50 km^2
	Vegetated	101	86	DA<13 km^2
Total		118	100	

NOTES:
DA = drainage area
1 General relationships between drainage area and stream type based on stream classification results for the northern hydrologic region (see Section 5.3, Regional Baseline Conditions). Local conditions might vary.
Active I class refers to streams that have perennial flow or are partially frozen to bottom in winter, Active II class refers to streams that are dry or completely frozen to the bottom in winter and Vegetated indicates ephemeral vegetated drainages or dispersed overland flow.

As shown in the table, 101, or 86%, of watercourses crossed by the proposed pipeline route in the Gwich'in Settlement Area were found to be Vegetated Channels with poorly defined flow paths or with drainage dispersed through shrubs or trees. Ten streams, 8%, are Active II Channels with discernible banks and substrate, though these are small streams that are expected to freeze to bottom in winter. The seven Active I Channels, including the east and west tributaries to Travaillant River, Thunder River and three unnamed streams, might only partly freeze to the bottom in winter.

5.4.6.2 Detailed Field Investigations

Table 5-55 lists the watercourses where detailed fish habitat and hydrologic surveys were done. The local site descriptions are based on:

- field studies
- interpretation of available photographs
- regional hydrology analysis

Table 5-56 provides a summary of the stream characteristics in the Gwich'in Settlement Area.

5.4.7 Sahtu Settlement Area

5.4.7.1 Reconnaissance

Reconnaissance surveys of 208 waterbodies, i.e., 204 streams and four lakes adjacent to the proposed pipeline route, were done from September 25 to 29, 2001, from July 16 to 19, 2003 and from August 26 to 28, 2003. Data compiled for each site included those listed in Section 5.4.5.

Table 5-55: Surveys of Watercourses in the Gwich'in Settlement Area

Crossing ID	Name	Drainage Area (km²)
RPR-065	Unnamed stream	24.2
RPR-069	Unnamed stream	82
RPR-070	Unnamed stream	173
RPR-075	Unnamed stream	71.3
RPR-097	Travaillant River	274
RPR-099	Unnamed stream	583
RPR-117	Unnamed stream	39.7
RPR-134	Unnamed stream	41.7
RPR-141	Thunder River	310

Table 5-56: Site Descriptions in the Gwich'in Settlement Area

Crossing ID	Name	Drainage Area (km^2)	Hydrologic Region	Stream Class	Width[1] (m)	Channel Slope (m/m)	Dominant Substrate	Upland Storage
REV3 AE	Unnamed stream	90	Northern	Active I	–	–	–	–
REV3 AU	Unnamed stream	194	Northern	Active I	–	–	–	–
RPR-065	Unnamed stream	24.2	Northern	Vegetated	–	–	Silt	H
RPR-069	Unnamed stream	82	Northern	Active I	4–5	0.021	Boulder and cobble	L-M
RPR-070	Unnamed stream	173	Northern	Active I	3–9	0.0016	Gravel	M
RPR-075	Unnamed stream	71.3	Northern	Active II	3–6	0.0091	Gravel and cobble	H
RPR-097	Travaillant River	274	Northern	Active I	4–18	0.0019	Cobble and gravel	H
RPR-099	Unnamed stream	583	Northern	Active I	3–9	0.0001	Silt with some cobble and boulder	VH
RPR-117	Unnamed stream	39.7	Northern	Active II	0.5–1	0.01	Silt	H
RPR-134	Unnamed stream	41.7	Northern	Active II	1–2	0.003	Gravel	H
RPR-141	Thunder River	310	Northern	Active I	5–7	0.0039	Gravel	L

NOTES:
L = low
M = medium
H = high
VH = very high
– = not available
N/A = not applicable
1 Range of values reflects different widths measured within the study reach

Table 5-57 summarizes watercourse types in the Sahtu Settlement Area determined from reconnaissance and detailed survey observations. The Sahtu Settlement Area spans the northern hydrologic region north of the Franklin Mountains and the central hydrologic region to the south end of Ebbutt Hills.

Table 5-57: Summary of Watercourse Types in the Sahtu Settlement Area

Watercourse Type	Stream Class	Number of Sites	Percentage of Streams
Lake	N/A	4	N/A
Stream	Large River	6	3
	Active I	25	12
	Active II	26	13
	Vegetated	147	72
Total		208	100

NOTES:
Large River and Active I classes refer to streams that have perennial flow or are partially frozen to bottom in winter, Active II class refers to streams that are dry or completely frozen to the bottom in winter and Vegetated indicates ephemeral vegetated drainages or dispersed overland flow.
N/A = not applicable

Table 5-57 also indicates 147, i.e., 72%, of potential crossing sites in the Sahtu Settlement Area were found to be vegetated drainages with poorly defined flow paths or with drainage dispersed through shrubs or trees. Twenty-five streams, or 13%, are Active II Channels with discernible banks and substrate, though these are small streams that are expected to freeze to bottom in the winter. The 31, 15%, Active I and Large River Channels including the Tieda River, Loon River, Hare Indian River, Donnelly River, Great Bear River and Big Smith Creek, might freeze only partly to the bottom in winter.

5.4.7.2 Detailed Field Investigations

Table 5-58 lists the sites for which detailed hydrologic characteristics are provided. Local site descriptions are based on:

- field studies
- interpretation of available photographs
- regional hydrology analysis

Table 5-59 provides a summary of the stream characteristics in the Sahtu Settlement Area.

Table 5-58: Watercourse Drainage Areas in the Sahtu Settlement Area

Crossing ID 2003	Name	Drainage Area (km^2)
RPR-174	Unnamed stream	23
RPR-201	Unnamed stream	31.2
RPR-204	Unnamed stream	124
RPR-211	Unnamed stream	98.3
RPR-212	Unnamed stream	50.4
RPR-215	Payne Creek	26.9
RPR-221	Tieda River	959
RPR-232	Loon River	3,600
RPR-249	Hare Indian River	23,190
RPR-253	Jackfish Creek	43.5
RPR-255	Unnamed stream	110
RPR-256	Tsintu River	512
RPR-258	Snafu Creek	304
RPR-261	Unnamed stream	148
RPR-266	Donnelly River	1,133
RPR-267	Chick Creek	61.5
RPR-268/269	Portable Bridge Creek	14.5
RPR-285	Hanna River	227
RPR-288	Elliot Creek	22.8
RPR-291	Unnamed Creek	63
RPR-292	Oscar Creek	652
RPR-299	Billy Creek	140
RPR-301	Bosworth Creek	110
RPR-306	Canyon Creek	70
RPR-308	Francis Creek	28
RPR-310	Helava Creek	23
RPR-311	Christina Creek	25
RPR-312	Unnamed stream	9
RPR-313	Prohibition Creek	138
RPR-323	Vermilion Creek	131
RPR-324	Nota Creek	142
RPR-325	Jungle Ridge Creek	60
RPR-330	Great Bear River	156,420
RPR-335	Unnamed stream	85
RPR-342	Unnamed stream	31

Table 5-58: Watercourse Drainage Areas in the Sahtu Settlement Area (cont'd)

Crossing ID 2003	Name	Drainage Area (km^2)
RPR-349	Big Smith Creek	963
RPR-351	Little Smith Creek	510
RPR-353	Seagrams Creek	47.6
RPR-355	Unnamed stream	9.4
RPR-358	Saline River	299
RPR-371	Steep Creek	148
NOTE: N/A = not applicable		

Table 5-59: Summary of Site Descriptions in the Sahtu Settlement Area

Crossing ID	Name	Drainage Area (km^2)	Hydrologic Region	Stream Class	Width[1] (m)	Channel Slope (m/m)	Dominant Substrate	Upland Storage
RPR-174	Unnamed stream	23	Northern	Active II	1–7	0.019	Gravel	L
RPR-201	Unnamed stream	31.2	Northern	Active II	1–5	0.016	Cobble and silt	L
RPR-204	Unnamed stream	124	Northern	Active II	4–10	0.009	Cobble and gravel	L–M
RPR-211	Unnamed stream	98.3	Northern	Active I	3–13	0.006	Gravel	L
RPR-212	Unnamed stream	50.4	Northern	Active I	3–6	0.003	Gravel and cobble	L
RPR-215	Payne Creek	26.9	Northern	Active II	3–4	0.010	Silt	L–M
RPR-221	Tieda River	959	Northern	Large River	8–20	0.009	Cobble	H
RPR-232	Loon River	3,600	Northern	Large River	30–35	0.003	Cobble	H
RPR-249	Hare Indian River	23,190	Northern	Large River	200–275	0.0003	Sand	L–M
RPR-253	Jackfish Creek	43.5	Northern	Active I	5	0.0002	Silt and organic compounds	L–M
RPR-255	Unnamed stream	110	Northern	Active I	20	0.002	Silt	M–H
RPR-256	Tsintu River	512	Northern	Active I	5–15	0.005	Cobble	M–H
RPR-258	Snafu Creek	304	Northern	Active I	6–11	0.003	Gravel and cobble	M
RPR-261	South Snafu Creek	148	Northern	Active I	3–11	0.004	Gravel and cobble	M
RPR-266	Donnelly River	1,133	Northern	Large River	50–60	0.003	Silt and gravel	VH
RPR-267	Chick Creek	61.5	Northern	Active II	4–13	0.017	Cobble	L–M

Table 5-59: Summary of Site Descriptions in the Sahtu Settlement Area (cont'd)

Crossing ID	Name	Drainage Area (km²)	Hydrologic Region	Stream Class	Width[1] (m)	Channel Slope (m/m)	Dominant Substrate	Upland Storage
RPR-268 and 269	Portable Bridge Creek	14.5	Northern	Active I	–	–	–	–
RPR-285	Hanna River	227	Central	Active I	8–11	0.001	Gravel	L–M
RPR-288	Elliot Creek	22.8	Central	Active I	2–5	0.013	Gravel and cobble	L
RPR-291	Unnamed stream	63	Central	Active I	2–5	0.006	Cobble	H
RPR-292	Oscar Creek	652	Central	Active I	11–12.5	0.001	Cobble and gravel	M
RPR-299	Billy Creek	140	Central	Active I	6–18	0.008	Sand	H
RPR-301	Bosworth Creek	110	Central	Active I	6–15	0.005	Gravel and cobble	M
RPR-306	Canyon Creek	70	Central	Active I	5–12	0.014	Gravel and cobble	L–M
RPR-308	Francis Creek	28	Central	Active II	1.5–3	0.016	Cobble and gravel	N–L
RPR-310	Helava Creek	23	Central	Active I	2–4	0.012	Gravel and cobble	N–L
RPR-311	Christina Creek	25	Central	Active I	2–3	0.015	Gravel	N–L
RPR-312	Unnamed stream	9	Central	Active II	1.5–2.5	0.014	Gravel	N–L
RPR-313	Prohibition Creek	138	Central	Active I	5–9	0.014	Gravel and cobble	N–L
RPR-323	Vermilion Creek	131	Central	Active I	7–14	0.011	Gravel	N–L
RPR-324	Nota Creek	142	Central	Active I	4–7	0.009	Cobble and boulder	L–M
RPR-325	Jungle Ridge Creek	60	Central	Active I	4–9	0.005	Gravel and silt	M
RPR-330	Great Bear River	156,420	Central	Large River	320	0.004	Cobble and gravel	H
RPR-335	Unnamed stream	85	Central	Active II	3–18	0.003	Gravel	M–H
RPR-342	Unnamed stream	31	Central	Active I	2–10	–	Organic compounds and silt	H
RPR-349	Big Smith Creek	963	Central	Large River	30–40	0.0001	Sand and cobble	M
RPR-351	Little Smith Creek	510	Central	Active I	5–10	0.005	Gravel and cobble	L

Table 5-59: Summary of Site Descriptions in the Sahtu Settlement Area (cont'd)

Crossing ID	**Name**	**Drainage Area** (km^2)	**Hydrologic Region**	**Stream Class**	**Width**[1] (m)	**Channel Slope** (m/m)	**Dominant Substrate**	**Upland Storage**
RPR-353	Seagrams Creek	47.6	Central	Active II	9–12	0.017	Cobble	N
RPR-355	Unnamed stream	9.4	Central	Active II	1	–	Cobble and gravel	N–L
RPR-358	Saline River	299	Central	Active I	10–20	0.011	Cobble	N–L
RPR-371	Steep Creek	148	Central	Active I	5–12	0.018	Boulder and cobble	N

NOTES:
N = none
L = low
M = medium
H = high
VH = very high
– = not determined
1 Range of values reflects different widths measured within the study reach

5.4.8 Deh Cho Region

5.4.8.1 Reconnaissance

Reconnaissance surveys of 148 waterbodies, i.e., 144 streams and 4 lakes adjacent to the proposed pipeline route, were done July 24 and 25, 2002 and from July 24 to July 28, 2003. Data compiled for each site included data listed in Section 5.4.5.

Table 5-60 summarizes watercourse types determined from the reconnaissance observations. See Section 5.3.6 for a complete discussion of stream classification.

As shown in Table 5-60, 79, or 55% of potential crossing sites in the Deh Cho Region were found to be vegetated drainages with poorly defined flow paths or with drainage dispersed through shrubs or trees. Thirty streams, or 21%, are Active II Channels with discernible banks and substrate, though these are small streams that are expected to freeze to bottom in winter. The 34 Active I and Large River Channels, including River Between Two Mountains and Blackwater, Ochre, Willowlake, Trout and Harris rivers, might freeze only partly to the bottom in winter.

Table 5-60: Summary of Watercourse Types in the Deh Cho Region

Watercourse Type	Stream Class	Number of Sites	Percentage of Streams	Approximate Basin Size and Channel Slope[1]
Lakes	N/A	4	N/A	–
Streams	Large River	7	5	DA>1,000 km²
	Active I	27	19	DA>15 km^2
	Active II	30	21	DA<15 km^2 and S>0.01 m/m
	Vegetated	79	55	DA<15 km^2 and S<0.01 m/m
Total		147	100	

NOTES:

1 General relationships between drainage area and stream type based on stream classification results for the southern hydrologic region (see Section 5.3, Regional Baseline Conditions). Local conditions might vary.

DA = drainage area

S = channel slope

The Large River Channel and Active I classes refer to streams that have perennial flow or are partially frozen to bottom in winter, the Active II class refers to streams that are dry or completely frozen to the bottom in winter, and Vegetated indicates ephemeral vegetated drainages or dispersed overland flow.

N/A = not applicable

– = not available

5.4.8.2 Detailed Field Investigations

Table 5-61 lists watercourses where detailed hydrologic investigations characteristics and fish habitat surveys were done. The local site descriptions are based on:

- field studies
- interpretation of available photographs
- regional hydrology analysis

Table 5-62 summarizes the stream characteristics in the Deh Cho Region.

Table 5-61: Watercourse Drainage Areas in the Deh Cho Region

Crossing ID	Name	Drainage Area (km^2)
RPR-377	Blackwater River	10,400
RPR-379	Unnamed stream	25.4
RPR-381	Dam Creek	69.4
RPR-388	White Sand Creek	292
RPR-391	Ochre River	1,160
RPR-399	Hodgson Creek	127.2

Table 5-61: Watercourse Drainage Areas in the Deh Cho Region (cont'd)

Crossing ID	Name	Drainage Area (km^2)
RPR-403	Unnamed stream	63
RPR-404	Unnamed stream	4
RPR-405	Unnamed stream	1.3
RPR-410	Smith Creek	100
RPR-415	Unnamed stream	43.5
RPR-419	River Between Two Mountains	4,520
RPR-426	Unnamed stream	0.8
RPR-428	Willowlake River	19,900
RPR-430	Unnamed stream	27
RPR-432	Unnamed stream	15
RPR-447	Unnamed stream	16
RPR-457	Trail River	447
RPR-458	Unnamed stream	117
RPR-460	Unnamed stream	138
RPR-466	Harris River	700
RPR-468	Nadia (Bluefish) Creek	60
RPR-470	Mackenzie River	992,000
RPR-472	Manners Creek	120
RPR-473	Manners Creek	24.7
RPR-475	Jean-Marie Creek	1,570
RPR-476	Jean-Marie Creek	286.1
RPR-477	Jean-Marie Creek	104.6
RPR-478	Unnamed stream	131.7
RPR-479	Trout River	6,372.3
RPR-480	Unnamed stream	36.4
RPR-481	Unnamed stream	237
RPR-487	Unnamed stream	60
RPR-489	Unnamed stream	67
RPR-497	Unnamed stream	30
RPR-499	Unnamed stream	37.1
RPR-503	Unnamed stream	53
RPR-506	Unnamed stream	93.9
RPR-507	Unnamed stream	86.5
RPR-509	Unnamed stream	48.2
RPR-510	Unnamed stream	50.9
RPR-511	Unnamed stream	261

NOTE:
N/A = not applicable

Table 5-62: Summary of Site Descriptions in the Deh Cho Region

Crossing ID	Name	Drainage Area (km²)	Hydrologic Region	Stream Class	Width[1] (m)	Channel Slope (m/m)	Dominant Substrate	Upland Storage
RPR-377	Blackwater River	10,400	Central	Large River	90–110	0.0044	Boulder and cobble	M
RPR-379	Unnamed stream	25.4	Central	Active I	2–6	0.015	Cobble and gravel	N–L
RPR-381	Dam Creek	69.4	Central	Active I	6–8	0.0003	Silt and boulder	L
RPR-388	White Sand Creek	292	Central	Active I	15–24	0.015	Boulder and cobble	N
RPR-391	Ochre River	1,160	Central	Large River	23–55	0.011	Boulder and cobble	L
RPR-399	Hodgson Creek	127.2	Central	Active I	7–13	0.0087	Gravel	N
RPR-403	Unnamed stream	63	Central	Active I	4–12	0.016	Boulder and cobble	N–L
RPR-404	Unnamed stream	4	Central	Active II	1.5–2	0.044	Sand and boulder	N
RPR-405	Unnamed stream	1.3	Central	Active II	1.5–2	0.065	Sand	N
RPR-410	Smith Creek	100	Central	Active I	5–7	0.008	Boulder and cobble	N–L
RPR-415	Unnamed stream	43.5	Central	Active II	2–12	0.019	Cobble	N–L
RPR-419	River Between Two Mountains	4,520	Central	Large River	40–70	0.006	Boulder and cobble	M–H
RPR-426	Unnamed stream	0.8	Central	Active II	1–1.5	0.057	Silt	H
RPR-428	Willowlake River	19,900	Central	Large River	200–226	•	Cobble	H
RPR-430	Unnamed stream	27	Central	Active II	4–17	0.010	Silt	L
RPR-432	Unnamed stream	15	Central	Active II	1–2	0.034	Gravel and cobble	L
RPR-447	Unnamed stream	16	Central	Active II	0.5	0.033	Silt	L
RPR-457	Trail River	447	Central	Active I	–	0.010	Cobble and gravel	M–H
RPR-458	Unnamed stream	117	Southern	Active I	5–7	0.0012	Gravel and cobble	H
RPR-460	Unnamed stream	138	Southern	Active I	5–6	0.0008	Sand	H
RPR-466	Harris River	700	Southern	Active I	11–17	0.009	Boulder	M–H
RPR-468	Nadia (Bluefish) Creek	60	Southern	Active I	6–8	0.002	Boulder and cobble	H
RPR-470	Mackenzie River	992,000	Southern	Large River	600–1,000	•	Silt	H

Table 5-62: Summary of Site Descriptions in the Deh Cho Region (cont'd)

Crossing ID	Name	Drainage Area (km²)	Hydrologic Region	Stream Class	Width[1] (m)	Channel Slope (m/m)	Dominant Substrate	Upland Storage
RPR-472	Manners Creek	120	Southern	Active I	7–11	0.003	Silt	H
RPR-473	Manners Creek	24.7	Southern	Active I	–	–	–	H
RPR-475	Jean-Marie Creek	1,570	Southern	Large River	20–25	0.001	Cobble	H
RPR-476	Jean-Marie Creek	286.1	Southern	Active I	6–14	0.007	Boulder	M–H
RPR-477	Jean-Marie Creek	104.6	Southern	Active I	4–6	0.007	Boulder	M
RPR-478	Unnamed stream	131.7	Southern	Active I	3–7	0.0046	Silt and cobble	L–M
RPR-479	Trout River	6,372.3	Southern	Large River	45–80	0.001	Cobble	H
RPR-480	Unnamed stream	36.4	Southern	Active I	2–11	0.001	Silt and Gravel	L–M
RPR-481	Unnamed stream	237	Southern	Active I	11–17	0.002	Boulder	L–M
RPR-487	Unnamed stream	60	Southern	Active I	4–10	0.006	Cobble and silt	L–M
RPR-489	Unnamed stream	67	Southern	Active I	3–12	0.004	Sand	M
RPR-497	Unnamed stream	30	Southern	Active I	5–12	0.002	Silt	M
RPR-499	Unnamed stream	37.1	Southern	Active I	4–12	0.002	Gravel	M
RPR-503	Unnamed stream	53	Southern	Active I	100	0.006	Silt	M
RPR-506	Unnamed stream	93.9	Southern	Active I	2–4	0.0046	Silt	M
RPR-507	Unnamed stream	86.5	Southern	Active II	3–5	0.025	Silt and sand	H
RPR-509	Unnamed stream	48.2	Southern	Active II	4.5–7	0.010	Silt and sand	H
RPR-510	Unnamed stream	50.9	Southern	Active I	3.5–5	0.005	Silt and sand	H
RPR-511	Unnamed stream	261	Southern	Active I	5–7	0.0005	Sand and cobble	H

NOTES:
N = none
L = low
M = medium
H = high
• = not assessed
– = not determined
1 Range of values reflects different widths measured within the study reach

5.4.9 Northwestern Alberta

5.4.9.1 Reconnaissance

Reconnaissance surveys of 30 watercourses in Northwestern Alberta were done August 6, 2002 and between September 28 and October 5, 2003. Data collected for each site included data listed in Section 5.4.5.

Table 5-63 summarizes watercourse types determined from the reconnaissance observations. See Section 5.3.6 for a complete discussion of stream classification.

Table 5-63: Watercourse Types in Northwestern Alberta

Watercourse Type	Stream Class	Number of Sites	Percentage of Streams	Approximate Basin Size and Channel Slope[1]
Lake	N/A	0	N/A	N/A
Stream	Large River	1	3	DA>1,000 km²
	Active I	16	54	DA>15 km^2
	Active II	3	10	DA<15 km^2 and S>0.01 m/m
	Vegetated	10	33	DA<15 km^2 and S<0.01 m/m
Total		30	100	

NOTES:
N/A = not applicable
DA = drainage area
S = channel slope
1 General relationships between drainage area and stream type based on stream classification results for the southern hydrologic region (see Section 5.3, Regional Baseline Conditions). Local conditions might vary.
Large River Channel and Active I classes refer to streams that have perennial flow or are partially frozen to bottom in winter, Active II class refers to streams that are dry or completely frozen to the bottom in winter and Vegetated indicates ephemeral vegetated drainages or dispersed overland flow.

As shown in the table, 10, or 30%, of potential crossing sites in Northwestern Alberta were found to be vegetated drainages with poorly defined flow paths or with drainage dispersed through shrubs or trees. Three streams were Active II Channels that are expected to freeze to bottom in winter. Seventeen Active I and Large River Channels, including the Kakisa and Petitot rivers, might freeze only partially to the bottom in winter.

5.4.9.2 Detailed Field Investigations

Table 5-64 lists the sites for which detailed hydrologic characteristics are provided. Local site descriptions are based on:

- field studies
- interpretation of available photographs
- regional hydrology analysis

Table 5-65 provides a summary of the stream characteristics in Northwestern Alberta.

Table 5-64: Watercourse Drainage Areas in Northwestern Alberta

Crossing ID	Name	Drainage Area (km^2)
NWML-04	Unnamed stream	0.6
NWML-05	Unnamed stream	40
NWML-07	Thinahtea Creek	71
NWML-08	Unnamed stream	52
NWML-09	Unnamed stream	9
NWML-10	Unnamed stream	36
NWML-13	Unnamed stream	12.5
NWML-13.5	Unnamed stream	unknown
NWML-14	Unnamed stream	43
NWML-15	Unnamed stream	7
NWML-16	Unnamed stream	102
NWML-19	Unnamed stream	1.6
NWML-22	Petitot River	7,710
NWML-23	Unnamed stream	15
NWML-26	Unnamed stream	90
NWML-27	Unnamed stream	9
NWML-28	Unnamed stream	260

NOTES:
– = not available

Table 5-65: Site Descriptions in Northwestern Alberta

Crossing ID	Name	Drainage Area (km^2)	Hydrologic Region	Stream Class	Width[1] (m)	Channel Slope (m/m)	Dominant Substrate	Upland Storage
NWML-04	Unnamed stream	0.6	Southern	Active **I**	2	–	Silt and organic compounds	M
NWML-05	Unnamed stream	40	Southern	Active **I**	3.5–5	0.012	Silt and cobble	M–H
NWML-07	Thinahtea Creek	71	Southern	Active **I**	5	0.009	Silt and organic compounds	M–H
NWML-08	Unnamed stream	52	Southern	Active **I**	50	0.004	Silt and organic compounds	M–H
NWML-09	Unnamed stream	9	Southern	Active **I**	–	–	–	M
NWML-10	Unnamed stream	36	Southern	Active **I**	2–50	0.013	Silt, organic compounds and aquatic vegetation	M
NWML-13	Unnamed stream	12.5	Southern	Active **I**	–	–	Silt and organic compounds	M
NWML-13.5	Unnamed stream	unknown	Southern	Active **I**	–	–	–	–
NWML-14	Unnamed stream	43	Southern	Active **I**	1.6–2	0.006	Silt and organic compounds	M
NWML-15	Unnamed stream	7	Southern	Active **I**	>25	–	Silt and organic compounds	M
NWML-16	Unnamed stream	102	Southern	Active **I**	4–5	0.007	Silt and gravel	M–H
NWML-19	Unnamed stream	1.6	Southern	Active **I**	–	–	Organic compounds	M
NWML-22	Petitot River	7,710	Southern	Large River	55–70	0.001	Cobble and boulder	M–H

Table 5-65: Site Descriptions in Northwestern Alberta (cont'd)

Crossing ID	Name	Drainage Area (km^2)	Hydrologic Region	Stream Class	Width[1] (m)	Channel Slope (m/m)	Dominant Substrate	Upland Storage
NWML-23	Unnamed stream	15	Southern	Active I	–	–	Silt and organic compounds	M
NWML-26	Unnamed stream	90	Southern	Active I	4.5–5.5	0.013	Silt and sand	L–M
NWML-27	Unnamed stream	9	Southern	Active I	>25	–	Silt and organic compounds	L–M
NWML-28	Unnamed stream	260	Southern	Active I	8–10	0.0048	Boulder, sand and cobble	L–M

NOTES:
L = low
M = medium
H = high
– = not determined
1 Range of values reflects different widths measured within the study reach

5.4.10 Pipeline Corridor Infrastructure

Project construction and operations include various infrastructure components, including:

- barge landing sites
- road crossings, i.e., ice roads and all-weather roads
- water supply for camps and facilities
- fuel storage and equipment stockpiles
- horizontally directional drilling (HDD) pads
- airstrips
- camps
- stockpiles

Table 5-66 summarizes the surveys done at these infrastructure sites in 2003.

Reconnaissance surveys of infrastructure sites in July 2003 involved visiting 71 road crossings along the pipeline corridor. Thirty-eight will be used in winter only and 31 of the crossings are for proposed all-weather roads. Two of the road crossings are not classified. Detailed ground surveys were done at 10 of the all-weather road crossings in the summer of 2003.

All 11 barge landing sites proposed in the pipeline corridor were visited during the reconnaissance and detailed ground surveys in 2003. Information compiled included:

- photographs and maps showing the surveyed location
- site identification numbers
- watercourse names
- site location, i.e., UTM and latitude and longitude coordinates
- drainage areas

Table 5-66: Infrastructure Sites in the Pipeline Corridor

Infrastructure Type	Administrative Region									
	Gwich'in Settlement Area		Sahtu Settlement Area		Deh Cho Region		Northwestern Alberta (NGTL)		Total	
	Recon Sites	Detailed Sites	Recon Sites	Detailed Sites	Recon Sites	Detailed Sites	Recon Sites	Detailed Sites	Recon Sites	Detailed Sites
Barge landing	0	0	6	6	5	5	0	0	11	11
Road crossing	34	2	26	5	11	3	0	0	71	10
Water supply from lakes for camps and facilities	2	2	0	5	7	6	1	1	10	14
Fuel storage and equipment stockpile	0	0	3	0	0	0	0	0	3	0
Horizontal directional drill pad	0	0	2	0	0	0	0	0	2	0
Airstrip	0	0	3	0	2	0	0	0	5	0
Camp, or camp and stockpile	2	0	6	0	4	0	0	0	12	0
Stockpile	0	0	0	0	2	0	0	0	2	0

NOTE:
Recon = reconnaissance

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