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Vol I

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ARCTIC ISLANDS PIPELINE PROJECT
WATER QUALITY SURVEY

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VOLUME I

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DEPARTMENT OF FISHERIES AND ENVIRONMENT
INLAND WATERS DIRECTORATE
WATER SURVEY OF CANADA
WINNIPEG, MANITOBA

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1. SUMMARY

This study evaluates surface water quality in terms of the proposed pipeline development along the Arctic Islands Pipeline Corridor. The evaluation is an overview because information on geology, climate, surface and ground water hydrology and permafrost required to support impact assessment predictions is available on a regional basis only. Detailed impact assessment at a site specific level can only be made with site specific data. Nevertheless, the information upon which this report relies is sufficient for discussing water quality in a regional context.

Information for the District of Keewatin indicates a high quality of natural waters that is characteristic of the hard, igneous shield rocks that dominate the region. Some deterioration in water quality by natural processes occurs during the thaw season when the weathered products of glacial till, silt and clay, are removed to watercourses by surface runoff. These high quality waters are particularly susceptible to possible wide pH variations from man's intervention, whereby relatively small additions of acidic or alkaline pollutants can drastically alter the pH balance and endanger aquatic organisms.

Natural waters within the remainder of the proposed pipeline corridor, including the Boothia Peninsula and Somerset, Prince of Wales, Cornwallis, Bathurst and Melville Islands, are largely influenced by the dominance of calcareous bedrock. Sections of the Boothia Peninsula, Somerset Island, Bathurst Island and the greater part of Melville Island are not dominated by calcareous bedrock. Although natural waters north of the District of Keewatin may be regarded as lower in quality than waters to the south, they are considerably less susceptible to man's intervention because of their greater ability to absorb acidic or alkaline pollutants.

The environmental impact of pipeline construction on water quality in this circumstance is mainly concerned with the possible release of sediment, nutrients, chemical pollutants and heavy metals into adjacent lakes and streams along the proposed route. It also concerns the effect of pipeline construction on fish spawning grounds and migration areas, as well as on other aquatic organisms.

It is important to avoid fish spawning grounds and migration areas along the proposed pipeline corridor especially in the District of Keewatin, and to maintain supervision of pipeline construction crews to help minimize the release of sediment and to prevent the release of chemical pollutants.

Particular attention should be paid to sensitive areas such as river and stream crossings to minimize sediment and possibly nutrient release. Also, engineering factors involving thermokarst and rock heave problems need careful attention to avoid the possibility of pipeline rupture. Other factors requiring careful attention are sewage disposal (from pipeline crews) and the preservation of naturally stable slopes by the prevention of tundra fires.

In general, the nutrient and heavy metal data available for areas along the proposed pipeline corridor indicate that no harmful amounts of nutrients and heavy metals will be released into the environment as a result of pipeline construction. Although nutrient levels were found to be slightly high on Bathurst Island and in the Murchison Lowland of the District of Keewatin, no serious problems are anticipated in these areas. Only on Melville Island, where relatively high nutrient and heavy metal levels are detected in natural waters, does further release as a result of pipeline construction warrant close study.

2. INTRODUCTION

This study is primarily an overview of available data, both published and unpublished, relating particularly to the existing levels of major ions, heavy metals and nutrients in surface waters along the proposed Arctic Island Pipeline Corridor. This includes areas of the District of Keewatin, Boothia Peninsula and the Eastern Arctic Islands.

The specific objective of the study is to relate, where possible, the existing water quality (with emphasis on major ions, heavy metals and nutrients) to geology, climate, surface and ground water hydrology, permafrost, and any other characteristics that are relevant to the proposed pipeline corridor.

On an overview basis, relationships between water quality and geology, and other relevant characteristics as mentioned, allow a general identification of potential impacts by considering the existing water quality in terms of the construction and operating characteristics of the proposed pipeline.

3. CURRENT STATE OF KNOWLEDGE

Most of the water quality research conducted within the proposed pipeline corridor has been performed on a brief reconnaissance survey basis. At strategic locations surface water samples have been anlaysed in the field then sent to regional laboratories for more detailed analyses. However, since this information is consistent, as noted in areas of similar geology, it is adequate for this water quality overview.

In general, the geology along the proposed pipeline corridor is documented on a regional basis rather than a local one, mainly because of the vastness and remoteness of the region. Other characteristics such as site-specific meteorology, hydrology and permafrost are, in general, poorly documented for much the same reason.

Relating geology to water quality is often complex even at a site specific level and is normally dependent on factors such as basement rock type, and soil composition and formation. Most rocks are comprised of minerals that are not very soluble; the composition of a rock is mainly determined by these almost insoluble constituents, and the minerals that do affect water quality are sometimes present only in trace amounts.

In this circumstance, therefore, it is only possible to relate water quality to geology on a regional scale by comparing the field-measured quality with the anticipated quality range that normally characterizes a specific rock type. Likewise, relating water quality to the other characteristics, as mentioned, is difficult without accurate localized data.

4. STUDY AREAS

The proposed Polar Gas Pipeline Corridor extends from Longlac in northern Ontario to Melville Island in the Arctic Archipelago. This study is restricted to that part of the proposed corridor between latitudes 60^{o} N and 77^{o} N. This includes the District of Keewatin, the Boothia Peninsula, Somerset Island, Prince of Wales Island, Cornwallis Island, Bathurst Island and Melville Island.

The vast size of the geographic area involved, combined with the relative scarcity of water quality data along much of the proposed pipeline route, makes comparison of water quality between different parts of the route difficult. To minimize this problem, separate "study areas" were chosen within seven distinct geographic regions. Each study area represents a region in which water quality and geological data are available. These were selected to be representative of the geological and water quality conditions within the larger geographic regions involved, and generally correspond to specific drainage systems or parts thereof.

Locations of the study areas within each geographic region are described in Table 1 and identified on Figure 1.

TABLE 1. STUDY AREAS

Geographic Region	Study Area Designation	Drainage System or Area Represented
District of Keewatin	KWQ1	Edehon Lake/Thlewiaza River
	KWQ2	Maguse/Kogtok River
	KWQ3	Thirty Mile Lake/Kazan River
	KWQ4	Baker Lake/Thelon River
	KWQ5	Meadowbank/Back/Hermann River
	KWQ6	Hayes River
	KWQ7	Murchison Lake/Murchison River
Boothia Peninsula	BPWQ1	Sanagak Lake
	BPWQ2	Amituryouak Lake
Somerset Island	SWQ1	Stanwell-Fletcher Lake
	SWQ2	Cunningham River
Prince of Wales Island*	PWWQ1	Crooked Lake
Cornwallis Island	CWQ1	Nelson/Victory Lakes
Bathurst Island	BTWQ1	Freemans Cove/Dyke Ackland Bay Area
	BTWQ2	Snowbird Creek Basin
Melville Island	MWQ1	Eastern Portion of Melville Island
	MWQ2	Northeastern Portion of Melville Island

* Although the main route of the proposed pipeline does not cross Prince of Wales Island, study area PWWQ1 has been included because a route alternate that does cross the island is also being considered.

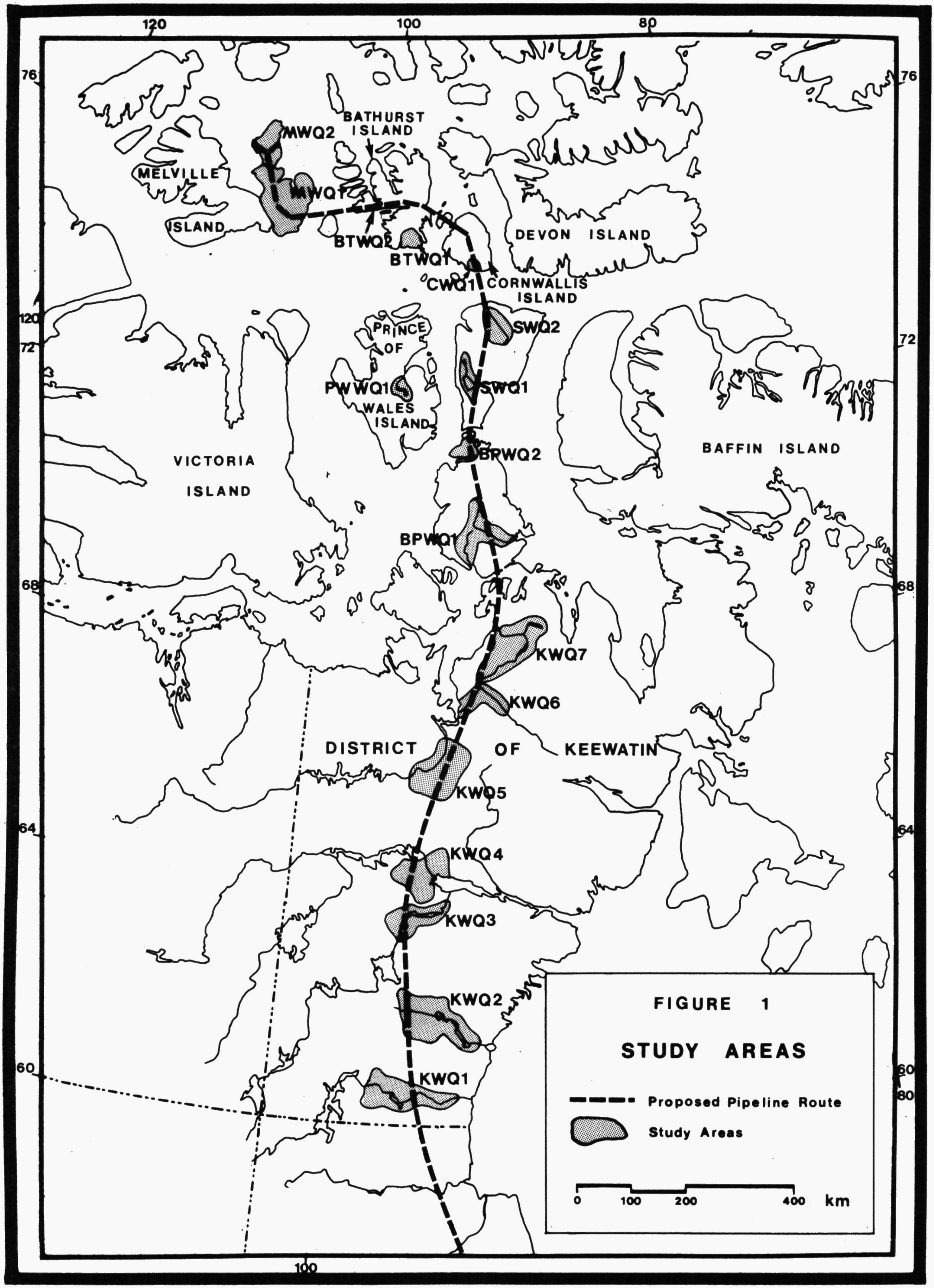

FIGURE 1

STUDY AREAS

5. METHODS AND SOURCES OF DATA

5.1 Sources of Information

The primary sources of water quality data for the surface waters along the proposed Arctic Islands Pipeline Corridor were reports prepared by Environment Canada's Inland Waters Directorate for the Eastern Arctic Islands Pipeline Program. Other sources that also contributed water quality data included consultants reports, scientific journals and reports from other Federal government agencies such as the Geological Survey of Canada.

Information on the geology, physiography, hydrology and climate of the area was collected from similar sources. Maps and papers published by the Geological Survey of Canada provided the bulk of this information although numerous articles in the *Canadian Journal of Earth Sciences* also contributed valuable data.

A complete listing of these information sources can be found in the Reference Section.

5.2 Field and Laboratory Techniques

Because this report is based on a literature review, BEAK personnel did not conduct their own field surveys, but relied on the results of other researchers. For this reason, direct quantitative comparisons of the water quality values derived from different sources should be made with caution. Although the results are comparable in a general sense, unavoidable variations in field and laboratory techniques, and in the analytical precision of the results, exist within the data.

A summary of field and laboratory techniques utilized by those researchers who did contribute water quality data to this report is included in Volume II, Appendix I, in conjunction with the data tables.

5.3 Data Analysis

The available information was evaluated, and pertinent water quality parameters extracted. These parameters appear in Table 2.

TABLE 2. WATER QUALITY PARAMETERS

Physical	Major Ions	Nutrients	Heavy Metals
Temperature	Cations:	Carbon:	
pH	Calcium	Total organic	Aluminum
Conductivity	Magnesium	Total inorganic	Arsenic
Turbidity	Potassium	Suspended	Barium
Colour	Sodium	Nitrogen:	Cadmium
Dissolved oxygen	Anions:	Total	Chromium
Phenolphthalein alkalinity	Bicarbonate	Total dissolved	Cobalt
Total alkalinity	Carbonate	Total Kjeldahl	Copper
Hardness	Chloride	Nitrate	Iron
Reactive silica	Fluoride	Nitrate + nitrite	Lead
Total suspended solids	Silica	Suspended	Manganese
(non-filterable residue)	Sulphate	Phosphorus:	Molybdenum
Redox potential		Total	Nickel
		Ortho-phosphate	Selenium
		Total dissolved	Strontium
			Zinc

Wherever appropriate, data reported by each researcher within individual study areas were averaged so that an overview of the current situation could be obtained. Volume II, Appendix II, contains the results of these analyses.

5.4 Water Quality Criteria

There is no universally accepted classification for evaluating water quality because acceptable levels for water quality parameters vary with water use. For example, levels that are considered high for drinking water may be low for irrigation water.

In this report water quality parameters are discussed as high, medium or low on the basis of criteria for public use as defined by the United States Department of Health, Education and Welfare (1962), the United States Federal Water Pollution Control Administration (1968) and Clark, Viessman and Hammer (1977). These criteria, which set maximum permissible levels for public water use, are considered to represent moderate concentration levels for the waters contained within the Arctic Islands Pipeline Corridor. Thus, references in this report to "high" and "low" concentrations refer to values above and below the levels listed for each of the parameters in Sections 5.4.1, 5.4.2, 5.4.3, and 5.4.4. Such an approach permits a semi-quantitative interpretation of the data.

5.4.1 Criteria for Physical Parameters

Values for the physical parameters listed represent water quality criteria for public supplies:

pH (pH units)	6.5 - 8.3[1]
Turbidity (J.T.U.)	5.0[1]
Colour (APHA units)	15[1]
Dissolved oxygen (mg/ℓ)	$\geq$4.0[1]
Total dissolved solids (mg/ℓ)	500[1]

5.4.2 Criteria for Nutrients

The generally accepted upper concentration limits for lakes free of algal nuisance are:

Nitrate as nitrogen (mg/ℓ)	10.0[2]
Total inorganic nitrogen (mg/ℓ)	0.3[3]
Ortho-phosphate (mg/ℓ)	0.02[3]

[1] U.S. Federal Water Pollution Control Administration. 1968. Raw water quality criteria for public supplies. National Technical Advisory Committee Report, April 1, 1968.

[2] U.S. Dept. Health, Education and Welfare. 1962. Public health service drinking water standards. U.S. Pub. Health Serv. Publication #956:61p.

[3] Clark, Viessman and Hammer. 1977. Water supply and pollution control, 3rd. ed., p. 281.

5.4.3 Criteria for Ions

Maximum permissible levels for ion concentrations in public water supplies are:

Calcium (mg/ℓ)	200.0[2]
Magnesium (mg/ℓ)	125.0[2]
Sodium (mg/ℓ)	200.0[2]
Bicarbonate (mg/ℓ)	500.0[2]
Chloride (mg/ℓ)	250.0[2]
Fluoride (mg/ℓ)	1.5[2]
Silica (mg/ℓ)	10.0[1]
Sulphate (mg/ℓ)	250.0[2]

5.4.4 Criteria for Heavy Metals

Maximum acceptable heavy metal concentration levels in public water supplies are:

Arsenic (mg/ℓ)	0.05[1]
Barium (mg/ℓ)	1.0[1]
Calcium (mg/ℓ)	0.01[1]
Chromium (mg/ℓ)	0.05[1]
Copper (mg/ℓ)	1.0[1]
Iron (mg/ℓ)	0.3[1]
Lead (mg/ℓ)	0.05[1]
Manganese (mg/ℓ)	0.05[1]
Selenium (mg/ℓ)	0.01[1]
Zinc (mg/ℓ)	5.0[1]

1 U.S. Federal Water Pollution Control Administration. 1968. Raw water quality criteria for public supplies. National Technical Advisory Committee Report, April 1, 1968.

2 U.S. Dept. Health, Education and Welfare. 1962. Public health service drinking water standards. U.S. Pub. Health Serv. Publication #956:61p.

6. RESULTS

6.1 General

Although the amount of water quality data available for many portions of the Arctic Islands Pipeline Corridor is not large, sufficient information was found to warrant its inclusion in a separate volume. Therefore, the tables of water quality data on which the study is based have been bound under separate cover and appear as Volume II of this report.

6.2 Summary of Results

The sections that follow give an overview summary of the research results in terms of nutrient, major ion and heavy metal concentrations reported within the waters of each designated study area.

6.2.1 Study Area KWQ1 (Vol. II, Tables 1.1, 1.2)

Data on nutrient, major ion and heavy metal concentrations in waters of this study area were meager. At the one location on the Thlewiaza River where nutrient levels were monitored in detail, organic carbon showed a concentration of 4.0 mg/ℓ; inorganic carbon, 3.0 mg/ℓ; total nitrogen as N, 0.41 mg/ℓ; total Kjeldahl nitrogen, 0.2 mg/ℓ; and total phosphorus as P, 0.008 mg/ℓ. At other sampling locations, average suspended carbon levels ranged from 0.235 to 0.409 mg/ℓ and suspended nitrogen from 0.021 to 0.050 mg/ℓ.

Of the major ions analysed, calcium was found to be the most abundant with a concentration of 2.5 mg/ℓ of water. Other ions detected were: sulphate, 2.0 mg/ℓ; magnesium, 0.5 mg/ℓ; sodium, 0.5 mg/ℓ; potassium, 0.3 mg/ℓ; chloride, 0.4 mg/ℓ; and silica, 1.0 mg/ℓ.

All heavy metals analysed had concentrations below their analytical detection limits except barium (0.05 mg/ℓ) and iron (0.08 mg/ℓ).

6.2.2 Study Area KWQ2 (Vol. II, Tables 2.1, 2.2)

The waters of study area KWQ2 were found to have the following ranges in nutrient levels: total organic carbon, 5.5 to 6.0 mg/ℓ; total inorganic carbon, 2.0 to 2.5 mg/ℓ; total Kjeldahl nitrogen, 0.4 mg/ℓ; total nitrogen as N, 0.41 to 0.46 mg/ℓ; total phosphorus as P, 0.008 to 0.01 mg/ℓ; suspended carbon, 0.339 to 0.596 mg/ℓ; and suspended nitrogen, 0.038 to 0.060 mg/ℓ.

Of the major ions, calcium cations had the highest concentration levels with average values ranging from 1.9 to 3.3 mg/ℓ. The other ion concentration levels averaged: magnesium, 0.3 to 0.95 mg/ℓ; potassium, 0.5 to 0.6 mg/ℓ; sodium, 0.65 to 0.8 mg/ℓ; sulphate, 1.3 to 1.55 mg/ℓ; chloride, 0.55 to 0.70 mg/ℓ; silica, 0.3 to 0.8 mg/ℓ.

Most heavy metals analysed had concentrations below the analytical detection limits, with the exception of barium (less than 0.05 to 0.06 mg/ℓ), copper (less than 0.001 to 0.001 mg/ℓ), iron (less than 0.004 to 0.17 mg/ℓ), and zinc (less than 0.001 to 0.004 mg/ℓ).

6.2.3 Study Area KWQ3 (Vol. II, Tables 3.1, 3.2, 3.3)

Averaged recorded concentration levels of nutrients in surface waters of study area KWQ3 were: total organic carbon, 3.7 mg/ℓ; total inorganic carbon, 3.5 mg/ℓ; suspended carbon 0.218 to 0.912 mg/ℓ; total Kjeldahl nitrogen, less than 0.1 to less than 0.5 mg/ℓ; nitrogen as nitrate plus nitrite, less than 0.001 to 0.435 mg/ℓ; total nitrogen, 0.19 mg/ℓ; suspended nitrogen, 0.22 to 0.70 mg/ℓ; ortho-phosphate, less than 0.002 mg/ℓ; and total phosphorus, less than 0.005 to 0.01 mg/ℓ.

The major ions analysed and their average concentrations were: calcium, 3.2 mg/ℓ; magnesium, 0.9 mg/ℓ; potassium, 0.57 mg/ℓ; sodium, 0.7 mg/ℓ; chloride, 1.0 mg/ℓ; fluoride, 0.09 mg/ℓ; bicarbonate, 12.0 mg/ℓ; and sulphate, ranging between less than 1.0 and 1.8 mg/ℓ.

Most heavy metals analysed generally had concentration levels at or below the analytic detection limit with the exception of cadmium (0.003 mg/ℓ), copper (up to 0.014 mg/ℓ), iron (up to 0.18 mg/ℓ), and zinc (up to 0.026 mg/ℓ).

6.2.4 Study Area KWQ4 (Vol. II, Tables 4.1, 4.2, 4.3, 4.4)

In water from the Airplane Lake Basin, nitrogen as nitrate concentrations ranged from 0.10 to 0.57 mg/ℓ while analyses of other waters revealed the following average nutrient concentration levels: total organic carbon, 5.0 to 9.0 mg/ℓ; total inorganic carbon, 2.0 to 2.6 mg/ℓ; suspended carbon, 0.243 to 0.402 mg/ℓ; total Kjeldahl nitrogen, less than 0.5 to 1.16 mg/ℓ; total nitrogen, 0.06 to 0.35 mg/ℓ; suspended nitrogen, 0.019 to 0.038 mg/ℓ; ortho-phosphate, up to 0.007 mg/ℓ; and total phosphorus, 0.009 mg/ℓ.

Analyses of major ions revealed average concentration levels in the following ranges: calcium, 4.4 to 13.4 mg/ℓ; magnesium, 1.5 to 3.3 mg/ℓ; potassium, 0.47 to 5.6 mg/ℓ; sodium, 1.0 to 78.4 mg/ℓ; chloride, 4.7 to 275.9 mg/ℓ; fluoride, up to 0.05 mg/ℓ; sulphate, 1.5 mg/ℓ; and bicarbonate, 9.0 to 13.3 mg/ℓ.

Of the heavy metals analysed only iron, lead and manganese, with concentrations of up to 0.1 mg/ℓ, 0.29 mg/ℓ and 0.6 mg/ℓ, respectively, showed average levels above their analytical detection limits.

6.2.5 Study Area KWQ5 (Vol. II, Tables 5.1, 5.2)

Surface waters within this study area had average nutrient levels in the following ranges: total organic carbon, 1.0 to 4.2 mg/ℓ; total inorganic carbon, less than 1.0 to 3.0 mg/ℓ; total Kjeldahl nitrogen, up to 0.5 mg/ℓ; nitrate plus nitrite, up to 0.18 mg/ℓ; total nitrogen, less than 0.11 to 0.25 mg/ℓ; ortho-phosphate, less than 0.002 mg/ℓ; and total phosphorus, 0.003 to 0.007 mg/ℓ.

Analyses of major ion concentrations showed that bicarbonates and sulphates, with average levels ranging from 1.5 to 3.35 mg/ℓ and up to 7.6 mg/ℓ, respectively, were the most abundant ions. Other ions were found to have average levels in these ranges: calcium, 1.15 to 2.2 mg/ℓ; magnesium, less than 0.1 to 1.0 mg/ℓ; potassium, 0.35 to 0.5 mg/ℓ; sodium, 0.5 to 0.8 mg/ℓ; chloride, 0.65 to 1.1 mg/ℓ; silica, 0.7 to 1.7 mg/ℓ; and fluoride, less than 0.5 mg/ℓ.

Of those parameters analysed (see Vol. II), the heavy metal concentrations were all very low, with most metals having concentrations at or below their analytical detection limits. Notable exceptions were extractable zinc, with an average level of 0.041 mg/ℓ recorded on the Back River, and extractable iron, with average concentrations ranging between 0.04 and 0.08 mg/ℓ.

6.2.6 Study Area KWQ6 (Vol. II, Table 6.1)

At the one sampling location within this study area, on the Hayes River at the proposed pipeline crossing, reported nutrient levels were: total organic carbon, 5.0 mg/ℓ; total inorganic carbon, 2.0 mg/ℓ; total phosphorus, 0.079 mg/ℓ; total Kjeldahl nitrogen, less than 0.1 mg/ℓ; and total nitrogen, less than 0.12 mg/ℓ.

The major ions measured in this study area's surface waters and their concentration levels were: calcium, 0.8 mg/ℓ; magnesium, 0.1 mg/ℓ; potassium, 0.6 mg/ℓ; sodium, 1.7 mg/ℓ; chloride, 3.4 mg/ℓ; sulphate, 1.7 mg/ℓ; and silica, 1.4 mg/ℓ.

Heavy metals were not analysed within the surface waters of this study area.

6.2.7 Study Area KWQ7 (Vol. II, Tables 7.1, 7.2)

A detailed analysis of nutrients, major ions and heavy metals was carried out at only one sampling location in this study area. This was on the Murchison River at the proposed pipeline crossing. Water from this point had nutrient levels within the following ranges: total organic carbon, 3.0 to 4.0 mg/ℓ; total inorganic carbon, 2.0 mg/ℓ; total phosphorus, 0.02 to 0.52 mg/ℓ; total Kjeldahl nitrogen, less than 0.1 to 0.2 mg/ℓ; and total nitrogen, less than 0.18 to 0.22 mg/ℓ. A separate analysis of lakes and streams indicated suspended carbon and nitrogen levels ranging from 0.237 to 0.669 mg/ℓ and 0.024 to 0.071 mg/ℓ, respectively.

The major ions analysed in Murchison River water had ranges of concentration levels as follows: calcium, 0.8 to 1.9 mg/ℓ; magnesium, 0.5 to 0.9 mg/ℓ; potassium, 0.7 to 0.8 mg/ℓ; sodium, 2.4 to 4.0 mg/ℓ; chloride, 3.4 to 7.6 mg/ℓ; sulphate, 1.7 to 1.8 mg/ℓ; and silica, 1.0 mg/ℓ.

With the exception of iron and zinc, which indicated mean concentrations of 2.86 mg/ℓ, and 0.007 mg/ℓ, respectively, all heavy metals analysed showed very low concentration levels.

6.2.8 Study Area BPWQ1 (Vol. II, Tables 9.1, 9.2, 9.3)

The surface waters of study area BPWQ1 had average dissolved nitrogen (NO_2 + NO_3) levels between 0.010 and 0.043 mg/ℓ; suspended carbon between 0.158 and

0.44 mg/ℓ; suspended nitrogen between 0.015 and 0.044 mg/ℓ; ortho-phosphate up to 0.004 mg/ℓ; and total phosphorus and total Kjeldahl nitrogen at or below the minimum detectable level.

In order of their decreasing relative abundance, the major cations detected were: calcium, 9.35 to 27.3 mg/ℓ; magnesium, 6.0 mg/ℓ; sodium, 0.4 to 1.14 mg/ℓ; potassium, 0.19 to 0.83 mg/ℓ. The major anions were: bicarbonate, 102.5 mg/ℓ; chloride, up to 1.0 mg/ℓ; sulphate, up to 0.47 mg/ℓ; silica, 0.385 mg/ℓ; and a trace of carbonate.

All heavy metals analysed had concentration levels at or below their minimum detection limits, except zinc and iron, which had concentration levels of 0.010 to 0.055 mg/ℓ, and less than 0.05 to 0.05 mg/ℓ, respectively.

6.2.9 Study Area BPWQ2 (Vol. II, Tables 10.1, 10.2)

None of the available data gave any indication of major ion or heavy metal concentrations within the waters of study area BPWQ2.

Nutrient data were also meager, although an average total dissolved nitrogen level of 0.153 mg/ℓ and an average total dissolved phosphorus level of 0.006 mg/ℓ were reported for Amituryouak Lake. Suspended carbon and suspended nitrogen levels in area waters ranged from 0.13 to 0.77 mg/ℓ and 0.008 to 0.071 mg/ℓ, respectively.

6.2.10 Study Area SWQ1 (Vol. II, Tables 11.1, 11.2)

Study area SWQ1 waters contained generally low nutrient level concentrations. Average total dissolved nitrogen values ranged from 0.011 to 0.152 mg/ℓ, while total Kjeldahl nitrogen levels were all reported to be below the minimum detectable level of 0.5 mg/ℓ. Average total dissolved phosphorus concentrations ranged between trace and 0.021 mg/ℓ, while values for total phosphorus as P were all below 0.055 mg/ℓ.

The major ions detected and the ranges of their average concentration levels were: calcium, 2.8 to 23.0 mg/ℓ; sodium, 0.43 to 4.75 mg/ℓ; magnesium, 2.8 to 3.4 mg/ℓ; potassium, 0.13 to 0.53 mg/ℓ; bicarbonate, 23.0 to 31.3 mg/ℓ; sulphate, less than 1.0 to 9.0 mg/ℓ; chloride, 1.25 to 7.5 mg/ℓ; and silica, 0.01 to 0.74 mg/ℓ. Only a trace of carbonate was detected at one sampling location, while fluoride concentrations were below the limit of detection.

Of the heavy metals analysed, all but zinc had concentrations below the minimum detectable levels. Zinc values ranged from 0.008 to 0.01 mg/ℓ.

6.2.11 Study Area SWQ2 (Vol. II, Tables 12.1, 12.2)

Of those nutrients analysed in the waters of study area SWQ2, only total dissolved nitrogen, with a value of 0.096 and dissolved nitrogen (NO_2 + NO_3) with an average value of 0.228 mg/ℓ, had concentration levels above the minimum detectable level.

The most abundant major ion was bicarbonate, with a reported value of 74.0 mg/ℓ at the proposed pipeline crossing of the Cunningham River. Other ions recorded and their average concentration levels were: calcium, 22.4 to 26.3 mg/ℓ; magnesium, 2.4 mg/ℓ; sodium, 0.73 to 1.0 mg/ℓ; potassium, 0.2 mg/ℓ; sulphate, 1.47 to 4.0 mg/ℓ; chloride, 1.47 to 2.5 mg/ℓ; and silica, 0.14 mg/ℓ.

All heavy metals analysed had concentration levels below the minimum detectable level with the exception of zinc and iron, whose levels ranged from less than 0.001 to 0.950 mg/ℓ, and less than 0.05 to 0.11 mg/ℓ, respectively.

6.2.12 Study Area PWWQ1 (Vol. II, Tables 13.1, 13.2)

The waters of study area PWWQ1 contained average total dissolved nitrogen concentration levels between 0.175 and 0.323 mg/ℓ and total dissolved phosphorus levels between 0.001 and 0.025 mg/ℓ. Dissolved nitrogen (NO_2 + NO_3) was measured at 0.033 mg/ℓ and total phosphorous was less than 0.005 mg/ℓ. Trace amounts of ortho-phosphate were detected in Crooked Lake.

Bicarbonate was the most abundant major ion measured. It had average concentration levels ranging from 74.3 to 97.7 mg/ℓ. Other anions detected and their average concentration levels were: chloride, 4.73 to 6.95 mg/ℓ; sulphate, 1.5 to 4.56 mg/ℓ; silica, 0.302 to 0.405 mg/ℓ; and carbonate, trace. Of the cations analysed, calcium recorded the highest concentration levels with average values ranging from 24.7 to 35.3 mg/ℓ. Also present were magnesium, 3.6 to 4.34 mg/ℓ; sodium, 1.5 to 3.15 mg/ℓ; and potassium, 0.45 to 1.0 mg/ℓ.

With the exception of iron, heavy metals were only analysed in water from one sampling location, the Dolphin River below Crooked Lake. The results of this analysis revealed concentrations below the minimum detectable levels for all metals analysed except zinc, which showed a value of 0.22 mg/ℓ. At other locations in study area PWWQ1, iron was reported in trace amounts.

6.2.13 Study Area CWQ1 (Vol. II, Tables 14.1, 14.2)

Measurements of nutrients in this area's waters showed a range of average concentration levels for total dissolved nitrogen between 0.06 and 0.20 mg/ℓ and for ortho-phosphate between 0.004 and 0.02 mg/ℓ. Dissolved nitrogen (NO_2 + NO_3) had a concentration of 0.03 mg/ℓ. Trace amounts of dissolved phosphorus were detected while concentrations of total Kjeldahl nitrogen were below the laboratory detection limits.

Bicarbonate was the most plentiful major ion found, with average concentration levels ranging from 41.0 to 70.4 mg/ℓ. Calcium was also relatively abundant, its average concentration levels falling in the 15.2 to 24.2 mg/ℓ range. The other major ions detected were: magnesium, 2.9 to 4.8 mg/ℓ; potassium, 0.13 to 0.92 mg/ℓ; sodium, 1.0 to 2.7 mg/ℓ; chloride, 2.0 to 4.2 mg/ℓ; sulphate, less than 1.0 to 9.1 mg/ℓ; and silica, 0.120 to 0.278 mg/ℓ.

Zinc and iron showed concentration levels of 0.14 mg/ℓ and 0.06 mg/ℓ, respectively, while all other heavy metals analysed were below the minimum detectable level.

6.2.14 Study Area BTWQ1 (Vol. II, Table 15.1)

In the waters of study area BTWQ1 average nutrient levels were: total dissolved nitrogen, 0.078 to 0.126 mg/ℓ; total dissolved phosphorus, 0.003 to 0.013 mg/ℓ; and ortho-phosphate, less than 0.002 to 0.002 mg/ℓ.

Bicarbonate and calcium ions were the most plentiful major ions detected, with average levels ranging from 56.0 to 70.7 mg/ℓ and 10.0 to 15.3 mg/ℓ, respectively. The other major ions analysed and their average concentration level ranges were: magnesium, 4.9 to 6.3 mg/ℓ; potassium, 0.2 to 1.5 mg/ℓ; sodium, 1.8 to 2.4 mg/ℓ; chloride, 0.5 to 2.6 mg/ℓ; sulphate, 0.5 to 8.0 mg/ℓ; and silica, 0.90 to 0.214 mg/ℓ. Trace amounts of the carbonate ion were discovered in lake waters analysed.

Of the heavy metals only iron was analysed. Trace amounts were detected in lake waters of the study area.

6.2.15 Study Area BTWQ2 (Vol. II, Table 16.1)

The concentrations of dissolved nutrients in study area BTWQ2's surface waters were: total organic carbon ranging from 0 to 4.0 mg/ℓ, total nitrogen ranging from less than 0.1 to 0.5 mg/ℓ, total Kjeldahl nitrogen ranging from less than 0.1 to 0.4 mg/ℓ, and total phosphorus ranging from less than 0.003 to 0.121 mg/ℓ.

Major ion concentrations were quite low, the highest levels being recorded by chlorides and bicarbonates, with average concentration levels from 2.4 to 3.8 mg/ℓ and 1.4 to 2.6 mg/ℓ, respectively. Other major ions detected and their average concentration levels were: sodium, 1.2 to 1.8 mg/ℓ; sulphate, 1.2 to 1.3 mg/ℓ; calcium, 0.7 to 1.0 mg/ℓ; magnesium, 0.7 to 1.0 mg/ℓ; potassium, 0.3 mg/ℓ; and nitrate plus nitrite, 0.03 to 0.07 mg/ℓ.

The heavy metal concentrations of those metals analysed were low, with the exception of aluminum and iron. Average aluminum concentrations fell between 0.491 and 0.798 mg/ℓ and iron levels ranged from 0.308 to 0.529 mg/ℓ.

6.2.16 Study Area MWQ1 (Vol. II, Table 17.1)

Of the nutrients measured at the three sampling locations on eastern Melville Island, dissolved nitrogen (NO_2 + NO_3) levels averaged from less than 0.01 to 0.02 mg/ℓ and total phosphorus recorded a range of 0.012 to 0.027 mg/ℓ. At all locations total Kjeldahl nitrogen concentrations were below the analytical detection limit of 0.5 mg/ℓ.

The ranges of average concentrations for every major ion analysed were: calcium, 2.6 to 4.2 mg/ℓ; potassium, 0.3 to 2.44 mg/ℓ; sodium, 0.4 to 4.2 mg/ℓ; sulphate, 1.35 to 5.4 mg/ℓ; chloride, 0.55 to 8.14 mg/ℓ; and fluoride, below the detection limit of 0.05 mg/ℓ.

Of the extractable heavy metals analysed, aluminum and iron were the most abundant metals, having average concentrations ranging from 0.1 to 0.42 mg/ℓ and 0.25 to 0.835 mg/ℓ, respectively. Other heavy metals that recorded average concentrations above the minimum detectable level included: chromium, less than 0.001 to 0.001 mg/ℓ; manganese, up to 0.02 mg/ℓ; and zinc, 0.003 to 0.016 mg/ℓ.

6.2.17 Study Area MWQ2 (Vol. II, Table 18.1)

At the one sampling location within study area MWQ2, average nutrient levels reported were: dissolved nitrogen (NO_2 + NO_3), 0.045 mg/ℓ; and total phosphorus 0.02 mg/ℓ. Total Kjeldahl nitrogen concentrations were below the minimum detectable level of 0.5 mg/ℓ.

Major ion concentration levels were relatively high, with calcium recording an average of 8.15 mg/ℓ; potassium, 3.03 mg/ℓ; sodium, 23.38 mg/ℓ; chloride, 13.25 mg/ℓ; sulphate, 56.9 mg/ℓ; and fluoride, 0.15 mg/ℓ.

Concentrations of most heavy metals analysed were also quite high. Aluminum had a mean value of 2.35 mg/ℓ; cobalt, 0.001 mg/ℓ; copper, 0.035 mg/ℓ; iron 3.05 mg/ℓ; lead, up to 0.012 mg/ℓ; manganese, 0.298 mg/ℓ; nickel, 0.015 mg/ℓ; and zinc, 0.071 mg/ℓ.

7. DISCUSSION

7.1 District Of Keewatin

Water quality throughout the District of Keewatin is remarkably similar for the various water quality parameters. Only in the Murchison lowland, in the northern section of the district, do distinct variations occur. In this area, lake water is higher in alkalinity, total hardness, specific conductivity, total phosphorus and total suspended solids but has a similar pH to the remainder of the District.

Water quality of streams and lakes along the proposed pipeline route in the District is excellent, and its excellence is mainly a consequence of the geology and physiography. However, the excellent quality is a disadvantage in one respect; these waters are low in buffering capacity which makes them susceptible to drastic pH alteration from man's intervention.

Generally, the proposed route traverses relatively low, gently rolling terrain formed on hard, igneous shield rocks. The main surficial cover is stoney to bouldery glacial till from the Manitoba border to Henik Lakes, thicker and relatively clay-rich till from there to Baker Lake, and thin and bouldery till north of Baker Lake. Eskers, end moraines, drumlinoid ridges, drumlin fields, and crag and tail hills are prominent and conspicuous throughout the District.

For the most part, surface and ground waters flowing within igneous bedrock are of high quality, and such is the case for the District of Keewatin. Most of the stream courses and lakes are associated with granitic bedrock and any seasonal fluctuations and/or deterioration in water quality parameters, such as conductivity, suspended solids and turbidity, would be associated mainly with climatic and hydrological influences on the glacial till ground cover.

There is considerable evidence of heavy metal mineralization throughout the District of Keewatin but this is not reflected to any great extent in the heavy metal analyses for water quality. Minerals of iron and copper, mainly as the sulphides pyrite, pyrrhotite and chalcopyrite, are common in many areas, especially in the region stretching from Ennadai Lake in the southwest to Rankin Inlet on Hudson Bay and south to the Manitoba border.

The harsh climate of the District has an intense weathering effect on the glacial till, and the products of this weathering, silt and clay, are removed by surface runoff to watercourses during the thaw season or as a result of rainfall. In areas of post-glacial marine submergence such as the Rasmussen Lowland, marine silts and clays are also especially susceptible to erosion. During the thaw season, surface runoff on gently sloped areas removes silt and clay from mudboils, while precipitation in the form of rain, which falls mainly during July and August, also assists in the removal process.

Runoff throughout the District of Keewatin is dominated by snowmelt and is characterized by peak flows occurring in early to late June, after which the flow declines for the remainder of the summer season (Way and Thorne 1977). Rainstorms are rare in the District but when they do occur they have a profound effect on basins with limited surface storage. Rainstorms in the area of the Hayes, Murchison and Hermann rivers for example, can generate flows approaching the magnitude of spring runoff volumes. These storms generally occur in late August and early September. Periods of peak runoff lead to a deterioration in water quality for the duration of the high flow rate, mainly in terms of physical parameters such as suspended solids and turbidity, and by removing silt and clay from the ground surface and disturbing settled silt and clay in water courses and shallow lakes.

In general, the scour and erosion potential of peak snowmelt runoff is inhibited by in-channel snow and ice, and by frozen streambeds and riverbanks. However, substantial fluvial ice activity occurs within the District; substantial ice runs have been observed on the Kazan, Thelon and Hermann Rivers, and on the western tributary to the outlet of Pitz Lake. Riverbank scour attributable to ice runs is evident at most crossings but appears to be minimal, although extensive boulder ridges on the Kazan and Thelon Rivers warrant further explanation (Way and Thorne 1977).

For most rivers in the District of Keewatin, the majority of surface water flow occurs within a very short time period. Up to 80 percent of the annual flow can occur in 10 percent of the time (Way and Thorne 1977), and this flow recedes throughout the remainder of the year. Most streams freeze solid once winter arrives, with freeze-up occurring at low flow or no flow conditions. However, certain river systems such as the Thlewiaza, Kazan and Thelon Rivers have large lakes within their drainage systems so are able to maintain large winter flows.

7.1.1 Study Areas within the District Of Keewatin

Water quality within the designated study areas is discussed below in terms of the local geology, physiography, hydrology and climate. The study areas are:

Study Area KWQ1 - Edehon Lake/Thlewiaza River

Study Area KWQ2 - Maguse/Kogtok River

Study Area KWQ3 - Thirty Mile Lake/Kazan River

Study Area KWQ4 - Baker Lake/Thelon River

Study Area KWQ5 - Meadowbank/Back/Hermann River

Study Area KWQ6 - Hayes River

Study Area KWQ7 - Murchison Lake/Murchison River

Study Area KWQ1 - Edehon Lake/Thlewiaza River

Water quality for the Edehon Lake/Thlewiaza River study area is excellent for most parameters. Sampling was conducted between June and September, 1976. At this time (Lawrence *et al.* 1977), suspended solids were very low, recording less than 2.5 mg/ℓ for all sampling stations except three. The pH ranged from 6.0 to 7.5 and the specific conductance did not exceed 23 μmhos/cm. Total hardness and alkalinity were consistently below the detection limits of the field analytical methods, while results of a survey for the Thlewiaza River at the proposed pipeline crossing (Way and Thorne 1977) were also low at 7.9 and 4.7 mg/ℓ respectively.

The measured levels of heavy metals and major ions for the Thlewiaza River at the proposed pipeline crossing (Way and Thorne 1977) were low. The total nitrogen level was moderately high at 0.41 mg/ℓ but total phosphorus was quite low. Sulphide minerals of iron in the form of pyrite and pyrrhotite have been recorded in considerable, yet uneconomic, quantities in the Edehon and Nueltin Lakes area to the west of the proposed pipeline route. However, the dissolved iron concentration records only 0.08 mg/ℓ within the study area.

The pristine water quality is mainly a consequence of the geology and physiography of the area which consists chiefly of Lower Proterozoic granite with Archaean deposits of gneiss and schist, and displays the effects of the most recent (Wisconsin) glaciation. The area is generally low in relief with glacial till covering much of the bedrock. Due to the granitic bedrock, lake outlines in the area are irregular, and rivers occupy shallow irregular lake basins with links broken by falls and rapids. Eskers, end moraines, drumlinoid ridges, drumlin fields and scattered stones and boulders are prominent throughout the area.

The climate of the study area is harsh with long cold winters and cool short summers. The mean annual air temperature is -9.4°C, with an average minimum of -34°C in January and an average maximum of 17°C in July. Precipitation is moderate with a mean annual total of approximately 380 mm, of which one third falls as snow. The harsh climate has an intense weathering effect on the glacial till producing silt and clay which temporarily deteriorates water quality in streams and lakes during periods of surface runoff.

Study Area KWQ2 - Maguse/Kogtok River

Water quality of the Maguse/Kogtok River study area is nearly as excellent as that of the Edehon Lake/Thlewiaza River area. The suspended solids concentration of stream water only exceeded 2.5 mg/ℓ three times during the sampling period between June and September, 1976 (Lawrence *et al.* 1977). The pH was close to neutral for streams, measuring 6.75 to 7.7, while lake water tended to be slightly more alkaline, measuring 6.5 to 8.0. Specific conductance for stream water did not exceed 26 μmhos/cm, while lake water was measured in the range of 9 to 32 μmhos/cm. For the most part, total hardness was below the detection limits of the field analytical methods for streams and consistently less than 34 mg/ℓ for lake water. Separate analyses carried out during the same period for total hardness of stream water at the proposed Maguse and Kogtok River pipeline crossings (Way and Thorne 1977) showed maxima of 14.5 and 6 mg/ℓ respectively, while total alkalinity at both crossings recorded maxima of 8.3 and 5.5 mg/ℓ respectively.

The Maguse/Kogtok River study area recorded low levels of heavy metals and major ions at the proposed pipeline crossings. As was the case with Study Area KWQ1, the total nitrogen levels were again moderately high, averaging 0.46 mg/ℓ, but the total phosphorous levels were low. Gossans are common in the Henik Lake area to the west of the proposed pipeline and iron and copper mineralizations in the form of magnetite and chalcopyrite have been reported. To the east of the study area in the Kaminak Lake region there is considerable mineralization of iron, copper and nickel although no economic deposits have yet been discovered. The degree of mineralization is not reflected in the heavy metal analyses but much of the mineralization occurs downstream from the proposed pipeline route. High concentrations of environmental mercury have also been reported in the Kaminak Lake area (Hornbrook and Jonasson 1972).

The similarity of geology, physiography and climate of the Maguse/Kogtok River study area to that of the Edehon Lake/Thlewiaza River area accounts for the similar, excellent water quality.

The geology of the area consists of Lower Proterozoic granite and Archaean volcanic rocks (greenstones) with derived schist and gneiss. Lakes in the area are shallow and irregular because of the scour-resistant bedrock. Drumlins and drumlinoid ridges are the dominant glacial patterns, and a large esker closely parallels the entire Maguse/Kogtok River study area from its origin south of Yathkyed Lake to Hudson Bay. Relatively clay-rich glacial till covers much of the ground but the area is devoid of stones and boulders that characterize the Edehon Lake/Thlewiaza River study area. The limit of former marine submergence transects the Maguse River west of Maguse Lake.

Study Area KWQ3 - Thirty Mile Lake/Kazan River

Water quality of the Thirty Mile Lake/Kazan River study area is almost as excellent as the previously mentioned river/lake study areas to the south (Study Areas KWQ1 and KWQ2). With four exceptions, the suspended solids concentration of stream water was less than 2.5 mg/ℓ at the time of sampling from June to September, 1976 (Lawrence *et al.* 1977). The pH varied from 6.5 to 7.5 and the specific conductance ranged from 13 to 31 μmhos/cm. Lake water quality measurements fell within the range observed for streams. However, a relatively high suspended solids concentration (24 mg/ℓ), that was measured at the confluence of the Kazan and Kunwak Rivers, can probably be attributed to the disturbance of bottom sediments by mixing currents. In samples collected between March and September 1972-1975, total alkalinity of stream water downstream from Thirty Mile Lake (above Kazan Falls) ranged from 5.4 to 15.0 mg/ℓ, while total hardness at the same sampling site ranged from 8.1 to 20.1 mg/ℓ.

The measured levels of nutrients, heavy metals and major ions in the Thirty Mile Lake/Kazan River study area (above Kazan Falls) were found to be very low.

The geology of the Thirty Mile Lake/Kazan River area consists mainly of Lower Proterozoic granite and allied rocks, together with areas of sedimentary sandstone, siltstone and breccia that were deposited in former times during marine submergence. Lake outlines in scour-resistant granite areas are irregular basins with links broken by falls and rapids. Relief is generally low with lowland meadows and low rolling hills that do not exceed elevations of 60 m. Drumlins and crag and tail hills, both advancing ice features, are the dominant glacial patterns in the area. The former limit of marine submergence lies to the west of Thirty Mile Lake.

The climate of the area is harsh with cool, short summers and long, cold winters. The mean annual air temperature is -12°C, reaching an average minimum of -37°C in January and an average maximum of 15.6°C in July. The mean annual precipitation tends to be low at 255 mm, two-fifths of which falls as snow. The climate of this area is similar to the study areas to the south (KWQ1 and KWQ2), but tends to be slightly colder and drier.

Study Area KWQ4 - Baker Lake/Thelon River

This study area includes several drainage systems that flow into Baker Lake from the west. It includes both the Pitz Lake and Whitehills Lake drainage systems, and the Thelon River which terminates at Baker Lake. The Thelon River drainage basin is very large, covering thousands of square kilometres but only its foremost downstream section is included in this study area.

Water quality of Baker Lake itself is mainly dependent on the quality of the Thelon River and to a lesser extent on that of the Pitz Lake, Whitehills Lake and Kazan River drainage systems. There are no water quality analyses available for the Thelon River inside the study area but samples taken during the period June-July, 1972-1975 many kilometres upstream (refer to Table 4.4, Vol. II, App. II) within the Thelon Game Sanctuary are evidence of its excellent quality; the pH ranged from 6.6 to 7.1, total hardness recorded a maximum of 26 mg/ℓ, total dissolved solids were measured at a maximum of 38 mg/ℓ and total alkalinity did not exceed 15 mg/ℓ. No values were recorded for suspended solids, but turbidity measurements were very low, recording a maximum of 6.4 JTU (Jackson Turbidity Units).

The Pitz Lake and Whitehills Lake drainage areas also contained water of excellent quality. For stream waters, suspended solids were very low, recording less than 1 mg/ℓ in most cases, and the specific conductivity was measured at a maximum value of 49 μmhos/cm (Lawrence *et al.* 1977). Total hardness and alkalinity were below detection limits in both areas, and pH was constant at 7.5 in the Pitz Lake area but varied from 6.5 to 8.0 in the area of Whitehills Lake. For lake waters, the maximum specific conductivity measured was 29 μmhos/cm, suspended solids were very low, and the pH ranged from 6.5 to 8.0. These measurements were made on samples collected between June and September, 1976.

With the exception of nitrogen, which recorded a slightly elevated mean level of 0.35 mg/ℓ, all nutrients recorded low concentrations, as did results of heavy metals analyses.

Water quality in Baker Lake showed some marked differences from the quality of rivers entering it. Total hardness was a maximum of 83.4 mg/ℓ, and the total dissolved solids maximum was 821 mg/ℓ including 156 mg/ℓ sodium and 550 mg/ℓ chloride. The predominance of sodium and chloride ions is explained by a limited introduction of saline tidal water over the shallow sill at the entrance to Baker Lake from Chesterfield Inlet (McLeod *et al.* 1975).

Further water quality analyses taken in June, 1976, at Airplane Lake (Chyurlia 1976), which is adjacent to the Baker Lake settlement and which flows into Baker Lake, were excellent for all parameters recorded.

The geology of the Baker Lake/Thelon River study area is varied and is responsible for the minor variations in water quality between Pitz and Whitehills Lake areas. The geology of the Pitz Lake area consists of sedimentary sandstone, siltstone and breccia deposited during the former marine submergence. On the other hand, the Whitehills Lake area consists of igneous bedrock of Lower Proterozoic granite together with outcrops of gneiss and schist. These scour-resistant materials give the lake basins in the area their irregular shapes. Also, the rock types found throughout the very large Thelon River drainage basin are similar, in general, to the rock types found in the Pitz Lake/Whitehills Lake areas.

The climate of the Baker Lake/Thelon River study area is very similar to the Thirty Mile Lake/Kazan River study area as described in the previous sub-section.

Study Area KWQ5 - Meadowbank/Back/Hermann River

This area includes the Meadowbank and Hermann River drainage systems (which flow into the Back River), and the section of the Back River that flows between its confluences with the Meadowbank and Hermann Rivers.

The Meadowbank and Hermann Rivers were sampled at much the same time during June 1976 (Way and Thorne 1977) and both rivers showed a distinct similarity for all parameters tested. Low levels of specific conductance, alkalinity, total hardness and turbidity are typical. Maximum values were 17.3 μmhos/cm, 4.1 mg/ℓ, 4.8 mg/ℓ and 0.8 JTU respectively. The pH was slightly acidic, ranging from 6.1 to 6.5.

Further measurements taken on the Hermann River during September 1976 showed a slight deterioration in several water quality parameters including turbidity, specific conductance and hardness, with maxima of 9.9 JTU, 24 μmhos/cm and 6.4 mg/ℓ respectively. This slight deterioration probably is related to increased surface runoff at the time of sampling in September. However, pH showed a considerable decrease to 4.9 and the reason for this decrease is not clear.

Water quality of the Back River also was found to be excellent, and measurements of the main parameters at various times between March and September, 1972-1976, (a total of 11 analyses) were very consistent. Over this period of time, the specific conductance was measured at a maximum value of 43 μmhos/cm, turbidity at 9.4 JTU, total hardness at 16.2 mg/ℓ, total dissolved solids at 22 mg/ℓ and total alkalinity at 9.9 mg/ℓ. The pH was slightly acidic most of the time, averaging 6.7 over the 4 year period.

Measured levels of nutrients, heavy metals and major ions in the study area were found to be very low.

The geology of the study area is consistent, in general, with the previously described study areas to the south. Bedrock consists essentially of hard igneous shield rocks of Late Proterozoic and Archaean age which, if exposed as outcrop, are extremely susceptible to frost shattering and heaving in areas north of Baker Lake. However, in this area, the bedrock surface is usually covered by a thick mantle of sandy till and has therefore escaped post-glacial shattering. South of Baker Lake, rock outcrops are only locally affected by these processes (Rennie 1977). Much of the surficial cover is glacial till which tends to be thin and bouldery. Eskers, drumlinoid ridges and drumlins are prominent throughout the study area.

There is little available information on the climate of the study area, but it is assumed to be similar to that of the Baker Lake region with the possible exception of lower annual precipitation.

Study Area KWQ6 - Hayes River

The Hayes River was sampled during June 1976 (Way and Thorne 1977) and the water quality was found to be excellent. It compared favourably with waters of the Meadowbank/Back/Hermann River study area, although turbidity was relatively high, with a recorded value of 56 JTU. This relatively high turbidity value may simply be related to surface runoff conditions at the time of sampling.

Major ions recorded low values in the Hayes River and no data was available for heavy metals as no samples relative to this parameter were taken. Nutrient values were low except for phosphorus which, on the one sample taken, recorded quite a high value of 0.079 mg/ℓ. Considerable iron mineralization has been reported in the northern portion of the District of Keewatin but it cannot be confirmed in this area through lack of data.

The geology of the Hayes River study area is very similar to that previously described for the Meadowbank/Back/Hermann River study area. It consists of hard igneous shield rocks of Late Proterozoic and Archaean age, with a glacial till surficial cover which tends to be thin and bouldery. Eskers and drumlins are prominent throughout the study area. The lower reaches of the Hayes River consist of marine clays and silts which are a prime source of sediment for rivers in the area.

There is little available information on the climate of the study area, but it is assumed to be similar to the Murchison Lake/Murchison River study area which is described in the following section.

Study Area KWQ7 - Murchison Lake/Murchison River

The Murchison Lake/Murchison River study area consists of the entire Murchison River drainage basin which flows northwesterly into Inglis Bay. The study area is divided into two distinct areas; a Precambrian upland with moderate relief where low granitic hills with a discontinuous overlay of glacial till occur in the valleys, and a flat to gently undulating lowland of thick non-calcareous to weakly calcareous marine silt and clay with minor amounts of marine sand. The lowland area is located mainly in the western section of the study area and to the south of the river mouth. In this area, the Murchison River cuts through a thick mantle of marine silts and clays.

Water quality sampling was conducted between June and September, 1976.

The most notable feature of the water quality of streams in the Murchison River basin is the high degree of variability in suspended solids concentration (Lawrence *et al.* 1977). This characteristic is a reflection of both the marine silts and clays of the lowland, and the Precambrian granitic upland within the study area. Specific conductance of stream waters ranged from 20 to 193 μmhos/cm. Streams in the lowland area were observed to be highly silt laden and to have high conductivities, whereas streams in the upland area were low in conductivity and suspended solids.

Water quality of lakes in the study area also was highly variable with respect to particulate matter. Lakes in the upland area ranged from low to high conductivities and total hardness, whereas lakes in the lowland area had low suspended solids, conductivities and total hardness. The reason for the wide variations in the upland area can only be explained by conducting a site specific study of variations in local geology and erosion potential.

Major ions recorded low values within the study area, as did heavy metals with the exception of iron which recorded a moderately high level of 2.9 mg/ℓ. This value appears to indicate the presence of iron mineralization within the study area upstream from the sampling location. Nutrient levels were found to be low with the exception of phosphorous which recorded a mean value of 0.036 mg/ℓ. A moderately high value was also noted in the previous study area (KWQ6) and it appears that the northern section of the District of Keewatin has an above average content of phosphate-bearing rocks, possibly in the form of apatite.

The climate is harsh with cool short summers and long cold winters, and a mean annual air temperature of -15^{o}C. Air temperatures average a minimum of -37^{o}C in January and reach an average maximum of 11^{o}C in July. Mean annual precipitation is approximately 127 mm, almost all of which falls as snow. Ice break-up in 1976 on Murchison Lake occurred during the last week in July and freeze-up commenced during the second week in September (Lawrence *et al.* 1977).

7.2 Boothia Peninsula

Water quality for the Boothia Peninsula differed considerably from that encountered for the District of Keewatin. Stream and lake water was higher in pH, alkalinity, hardness and specific conductivity compared with drainages further south. The most notable affect of this change is the considerable increase in buffering capacity of these waters, making them less susceptible to wide pH variations.

Variations in water quality between these regions is mainly a result of their different geological settings; bedrock on the Boothia Peninsula is predominantly of Precambrian and Lower Palaeozoic age. The older rocks comprise the Boothia Arch, which occupies the central two thirds of the Boothia Peninsula, as well as narrow strips along most of the west side of Somerset Island and the east side of Prince of Wales Island. Drift is thin or absent over most of the area underlain by Precambrian rocks, except in the southern part of the peninsula where there are large areas with no bedrock exposed. Maximum elevations along the Boothia Arch increase from about a hundred metres in the southern part to 550 m in the central part of the peninsula and northward to Somerset Island.

Lower Palaeozoic rocks flank the Boothia Arch. They are mostly flat-lying to gently dipping except locally near the arch, and are composed mainly of limestone and dolomite with lesser amounts of sandstone and minor shale. Good exposures are found only along scarps and in river valleys.

It is the influence of these calcareous rocks (limestone and dolomite) that produces natural waters of higher pH, alkalinity, hardness and conductivity. The relative abundance of calcareous rocks on Boothia Peninsula dominates, to some extent, the water quality characteristics of the region. Other factors such as climate and physiography play a less significant role in determining water quality characteristics of the Boothia Peninsula.

7.2.1 Study Areas within the Boothia Peninsula

Two designated study areas are discussed in more detail for the Boothia Peninsula. Water quality results for these study areas are presented in Section 6. The study areas are:

Study Area BPWQ1 - Sanagak Lake

Study Area BPWQ2 - Amituryouak Lake

Study Area BPWQ1 - Sanagak Lake

The Sanagak Lake study area includes the Sanagak Lake drainage system itself and the Josephine River basin to the south west.

The Sanagak Lake drainage system lies within the southern section of the Boothia Arch Complex, an area of greatly dissected granites and gneisses. Much of the Sanagak Lake drainage system is rugged upland with elevations ranging from 38 m in the southern portion to 550 m in the northern district. It consists of deeply entrenched river systems and fiord-like valleys in which glacial till is the dominant surface material. Lower Palaeozoic rocks that are composed mainly of limestone and dolomite with lesser amounts of sandstone and minor shale flank the Boothia Arch, including the Sanagak Lake study area.

The Josephine River basin ranges from Precambrian upland at its northern tip to coastal lowland in the southern region and is covered by calcareous glacial till. Esker material is common along the river, as are marine sand and gravel deposits.

Sampling was conducted during the period from May to September, 1974-1976. Results indicate that water quality in the Sanagak Lake study area is influenced to a considerable extent by the existence of calcareous rocks (limestone and dolomite) throughout the region. Water in streams and lakes was high in total alkalinity (maximum of 140 mg/ℓ), moderately high in total hardness (up to about 150 mg/ℓ); pH commonly ranged from 8.0 to 8.5, and specific conductivity ranged from 54 to 315 μmhos/cm (Lawrence *et al.* 1977). In general, water was very low in particulate matter.

The climate is harsh with short summers and long winters, and a mean annual air temperature of $-15^{\circ}C$. Temperatures average a minimum of $-37^{\circ}C$ in January and reach an average maximum of $10^{\circ}C$ in July. Mean annual precipitation is low at approximately 125 mm, almost all of which falls as snow. Ice break-up in 1976 on Sanagak Lake occurred during the first week in August and freeze-up began in the final week of August (Lawrence *et al.* 1977).

Study Area BPWQ2 - Amituryouak Lake

The Amituryouak Lake study area consists of two sampling areas, the area around Amituryouak Lake itself, and an area approximately 25 km to the north just south of Bellot Strait. These were sampled from May to August, 1974 and from June to September, 1976.

The study area lies within the Boothia Arch complex which is predominately a region of greatly dissected granites and gneisses. It is a rugged upland region characterized by steep hills and cliffs to a maximum elevation of 300 m, with deeply entrenched rivers and fiord-like valleys. The dominant surface material is a highly calcareous till (Amituryouak till), most of which forms a thin veneer over bedrock. Frost heaved bedrock is a common feature throughout the area.

Water quality of streams and lakes throughout the study area is influenced by the calcareous nature of the glacial till. This results in high specific conductivities (maximum of 282 μmhos/cm), moderately high total hardness (maximum of 137 mg/ℓ), and pH values of 7.5 to 8.5. Stream water was found to be very low in particulate matter, while lakes were similar but showed significantly higher particulate nitrogen levels (Lawrence *et al.* 1977).

Virtually no data were recorded for major ions and heavy metals, and the limited available data for nutrients showed low values for the study area.

The climate of the Amituryouak Lake study area is similar to the Sanagak Lake study area as described in the previous sub-section.

7.3 Somerset Island

Somerset Island is a northward prolongation of Boothia Peninsula from which it is separated by the narrow and fiord-like Bellot Strait. The Boothia Arch, which forms much of Boothia Peninsula, continues across Bellot Strait and extends along the western side of Somerset Island for most of its length. Therefore, much of the western part of the island, including most of the country around Stanwell-Fletcher Lake, consists of rugged hills of Precambrian granite, gneiss and metamorphic sandstone.

To the east of the Boothia Arch lies a broad belt of sedimentary rock that covers much of the remainder of the island. The sedimentary rocks are nearly all limestone of Palaeozoic age, and these friable rocks shatter into a porous, arid mantle that is meagerly vegetated.

Water quality of Somerset Island is varied but is mainly influenced by the dichotomous geological nature of the island, Precambrian granite to the west and Palaeozoic limestone to the east. Water quality in predominantly limestone areas tends to be higher in pH, alkalinity, hardness and specific conductivity.

7.3.1 Study Areas on Somerset Island

Two study areas have been chosen for Somerset Island; the Stanwell-Fletcher Lake area which occurs within the Precambrian granite complex, and the Cunningham River area which is largely within the limestone region at the extreme north of the island. The areas are:

Study Area SWQ1 - Stanwell-Fletcher Lake

Study Area SWQ2 - Cunningham River.

Study Area SWQ1 - Stanwell-Fletcher Lake

As mentioned, Stanwell-Fletcher Lake lies within the Boothia Arch which consists, in this area, of rugged hills of Precambrian granite, gneiss and metamorphic sandstone. As expected, water quality for the Stanwell-Fletcher Lake region is of high purity that characterizes streams and lakes within the Canadian Shield.

Stanwell-Fletcher Lake was found to be a large cold monomictic Arctic lake, essentially isothermal at about 1.5°C. The lake is essentially isochemical, with very low ionic concentrations. There is a slight increase in calcium, magnesium and chloride content with depth but the differences are probably insignificant, and the main result emphatically shows that the lake has very low ionic concentrations and lacks chemical stratification (Rust and Coakley 1970). The nutrient elements, nitrogen and phosphorus, are also present in only small amounts while oxygen concentrations are high at all depths at all times (de March *et al.* 1977). There are virtually no data to indicate heavy metal concentration levels for lake water although results from the Union River at the outflow of Stanwell-Fletcher Lake show low levels.

The local climate is similar to that for Resolute Bay to the north (Rust and Coakley 1970) where average air temperatures rise above freezing for approximately two and a half months of the year. The average annual precipitation at Resolute Bay between 1951 and 1960 was 130 mm and a similar figure can be expected for Stanwell-Fletcher Lake. Water enters the lake from a number of rivers of which the largest is the Stanwell-Fletcher River. The rivers are fed by the melting of snowfields and ground ice, with small additions from rainfall. The only outlet from the lake is the Union River which flows a short distance to the sea at Creswell Bay. Water quality results for Union River are also presented (see Vol. II., Appendix II) as part of the Stanwell-Fletcher Lake study area.

Water quality results for a small unnamed lake adjacent to Stanwell-Fletcher Lake and close to Creswell Bay are also presented (see Vol. II, Appendix II) as part of this study area (SWQ2). The ionic concentration of this lake is higher than Stanwell-Fletcher Lake and the water quality is probably influenced by adjacent calcareous rocks to the east.

Study Area SWQ2 - Cunningham River

The Cunningham River drainage basin covers an area of 2,200 square kilometres in the far northern region of Somerset Island. The predominant rock type in the area is limestone, together with some dolomite and other rocks with sand-sized detrital material. The river substrate consists of small cobbles and gravel with some sand and silt, while the stream banks are unstable giving rise to a wide gravel flood plain.

Sampling programs were conducted during the periods May to August, 1974 and June to August, 1975. Data indicate that water quality is influenced by the predominance of limestone, resulting in relatively high ionic concentrations and alkalinity, and pH that is distinctively alkaline (7.5-8.3). Measured nutrient levels are all quite low as are heavy metal concentrations with the exception of zinc, which was recorded at 0.95 mg/ℓ in one instance. Since the climate of this area is similar to the Stanwell-Fletcher Lake study area, the dominant influence on water quality is the distinct difference in geology between these areas.

7.4 Prince of Wales Island

The eastern side of Prince of Wales Island is occupied by a portion of the Boothia Arch. As mentioned, the Boothia Arch is composed of Precambrian granite and gneiss that is prominent on the Boothia Peninsula to the east of Prince of Wales Island.

The Boothia Arch reaches an elevation of 550 m on the Boothia Peninsula but slightly lower elevations are found along that part of the Arch on Prince of Wales Island. Most of Prince of Wales Island to the west of the Boothia Arch lies below 80 m in elevation except for several plateau remnants that rise to a maximum elevation of 250 m.

The northern part of Prince of Wales Island to the west of the Boothia Arch is a Palaeozoic plateau which is mostly flat-lying to gently dipping, and is composed mainly of limestone and dolomite with lesser amounts of sandstone and minor shale. Good exposures are found only along scarps and in river valleys. Most of the Palaeozoic plateau is mantled with a thin layer of silty, rubbly glacial till of which nearly all the longer fragments are composed of carbonate rock, the dominant rock type in the area.

The southern three-fifths of Prince of Wales Island is a glacial lowland where the physiography is due almost entirely to glacial landforms. Drift cover in this area is almost continuous. Vast drumlin fields occur in the south-central part of the island but eskers are not numerous except on the western side of the glacial lowland.

The predominance of carbonate rocks throughout Prince of Wales Island accounts for the relatively uniform water quality of streams and lakes. One exception is the notable variation in pH throughout the island; in the centre of the island around Crooked Lake, pH is generally around 8.0 or below, but in the northern and southern sections of the island, pH is usually well above 8.0. The significance of this pH variation is a fundamental change in water chemistry above pH 8.3 where the predominance of bicarbonate ions below 8.3 is altered to a predominance of carbonate ions above 8.3.

Water quality throughout most of Prince of Wales Island is higher in pH, alkalinity, hardness and specific conductivity compared with natural waters derived from the Precambrian granite Boothia Arch complex.

Although two distinct physiographic units exist on Prince of Wales Island, the Palaeozoic plateau to the north and the glacial lowland to the south, only one study area is required to represent the water quality status throughout the island as a result of its relative uniformity. The reasons for variations in pH (as mentioned) are not known and a more detailed site-specific geology/water quality study would be required to assess this; additional study areas solely to highlight this aspect are not considered necessary for this report.

7.4.1 Study Area on Prince of Wales Island

The Crooked Lake drainage basin in the centre of the island was chosen as the study area, mainly because of the abundance of water quality data in the area and the relatively large size of the basin (1,700 sq. km). It was sampled from May to August, 1974 and from June to August, 1975.

The Crooked Lake study area has been designated:

Study Area PWWQ1 - Crooked Lake.

Study Area PWWQ1 - Crooked Lake

The Crooked Lake study area lies in the northern section of the glacial lowland which covers the southern three-fifths of Prince of Wales Island. Glacial drift cover in this area is almost continuous.

Crooked Lake is fed by numerous streams that radiate in all directions, and water quality analyses have been carried out for many of these streams as well as for Crooked Lake itself. Stream and lake waters are of similar quality and display typical characteristics of natural waters in contact with calcareous bedrock. Values for bicarbonate, calcium and specific conductivity are relatively high, and, as mentioned, pH tends to be around 8.0.

Nutrient values in streams and lakes are generally low but there are indications of relatively high nitrogen levels on the lake bottom particularly during winter as a result of increased anaerobic biological activity from low dissolved oxygen levels. There is very little data on heavy metal concentrations.

There is no climatic data available for this area but the local climate is probably similar to that for Resolute on Cornwallis Island where the average air temperature rises above freezing for about two and half months of the year and the average annual precipitation is approximately 130 mm.

7.5 Cornwallis Island

Cornwallis Island consists of complexly folded and faulted sedimentary rocks with some surficial cover of alluvial and glacial deposits. The Cornwallis fold belt, the principal geologic structure on the island, trends northwesterly and is coincident with the regional strike of the Boothia Arch. Grabens are common throughout the island.

Bedrock on the island is Ordovician or younger in age. Middle Devonian and older rocks are mainly calcareous with some shale and minor evaporites. A facies change cuts the island in two, with shale becoming more common on the northern half. Upper Devonian and younger deposits consist of sandstones, sand, shale and clay with Quaternary till and alluvium present in the northwest sector of the island. Most of the exposed surface consists of rocks that are Middle Devonian or older, however, and are predominantly calcareous.

The island can be divided into two physiographic areas: a plateau on the southeast quarter and lower-lying land on the rest of the island. The plateau reaches an average elevation of about 300 m and has an undulating surface. West and northwest of the plateau, elevations decrease and the terrain is more rugged. Streams on the plateau have steep gradients, with numerous waterfalls present. In the lowland regions the drainage network is more integrated with much of the west and northwest coastal areas having long, well-graded stream channels.

Cornwallis Island has been glaciated but only a few moraines, most of which are weakly developed, have been recognized. The plateau area is covered with a thin layer of till but the greatest extent of Quaternary deposits occurs in the northwestern sector of the island.

Water analyses for Cornwallis Island indicate that the calcareous bedrock is the controlling influence on its quality.

7.5.1 Study Area on Cornwallis Island

Only one study area is deemed necessary as representative of Cornwallis Island. This is the area inland from Assistance Bay in the south of the island around Nelson and Victory Lakes. The lakes have been well documented for water quality parameters, as have several nearby streams. The study area on Cornwallis Island has been designated:

Study Area CWQ1 - Nelson/Victory Lakes

Study Area CWQ1 - Nelson/Victory Lakes

The Nelson/Victory Lake study area lies in the southern section of the island where the underlying bedrock is of Devonian to Silurian age.

The calcareous bedrock is evident from water quality analyses. Lake and stream waters show similar characteristics with a distinctively alkaline pH around 8.0, and relatively high values for specific conductivity, calcium and bicarbonate. Nutrient levels in the area are low as are heavy metal concentrations.

The climate of the area is recorded nearby, at Resolute, where the average air temperature rises above freezing for only two and a half months of the year and the average annual precipitation is about 130 mm.

7.6 Bathurst Island

The geology of the Bathurst Island group is complex but consists essentially of Middle to Upper Devonian sediments of quartz sandstone, limestone and siltstone, together with some Triassic quartz sandstone (on Cameron Island) and scattered minor occurrences of Ordovician evaporites and carbonates. Middle Devonian rocks consist mainly of carbonate grading to shale, whereas the Upper Devonian is represented by a thick sequence of paralic and non-marine quartz-rich clastic sediments which blanket the whole island group.

The physiography of the Bathurst Island group is greatly influenced by the underlying geological structure. The region is mainly of low relief with few areas being more than 300 m in elevation. However, much of the topography is rugged with deeply incised streams and V-shaped valleys.

There are three main physiographic divisions within the Bathurst Island group; a low plateau that constitutes the southern quarter of the region, a lowland area in the central and northern parts of Cameron Island, and a ridged upland with broad folds that includes all but the northwestern and southeastern parts of the island group.

The low plateau that constitutes the southern quarter of the region is principally underlain by horizontal to gently dipping carbonate beds. The plateau is relatively flat, featureless and desolate in the central part, and is dissected into narrow, steep-walled valleys and bluffs to the south and along the east coast. For the most part, the drainage pattern is dendritic.

The central and northern parts of Cameron Island comprise an area of lowland where the elevation is generally less than 100 m. Gently dipping, soft, and poorly consolidated shale and sandstone underlie this region. The land slopes gently northward and streams are short and braided, with wide gravel fans at their mouths.

The largest physiographic division of the region, covering all but the northwestern and southeastern areas, is the ridged upland with broad folds that is reflected to various degrees in the topography and drainage pattern. The underlying geological structure is complex but the topography only moderately reflects the structure. Much of the region is covered by felsenmeer or by glacial sands and gravels, and exposures of bedrock are restricted to stream valleys and to a few northerly trending ridges.

The climate on Bathurst Island is expected to be similar to that recorded at Resolute on Cornwallis Island, although detailed information on climate is unavailable.

7.6.1 Study Areas on Bathurst Island

Two study areas were chosen for Bathurst Island. There are:

Study Area BTWQ1 - Freemans Cove/Dyke Ackland Bay Area

Study Area BTWQ2 - Snowbird Creek Basin

Study Area BTWQ1 - Freemans Cove/Dyke Ackland Bay Area

Water quality samples were taken from May to August, 1974. Analyses indicate that the quality of stream and lake waters in this area is similar and is controlled by the calcareous bedrock. Bicarbonate values consistently range from 56 to 72.5 mg/ℓ and pH is characteristically alkaline, ranging from 7.8 to 8.1. Specific conductivity values are relatively high, ranging from 134 to 158 μmhos/cm.

Nutrient values in the area are low and there are virtually no heavy metal analyses. Relatively high values of specific major ions including calcium, magnesium and bicarbonate are characteristic of high alkalinity waters.

Study Area BTWQ2 - Snowbird Creek Basin

Measurements of water quality were taken from June to August, 1976.

A distinct change in bedrock type is noted between Snowbird Creek basin and study area BTWQ1. The calcareous bedrock in study area BTWQ1 gives way to quartz sandstone in Snowbird Creek basin. The change in bedrock type is distinctly noted in the water quality analyses whereby low values are recorded for major ions. These reflect correspondingly low values for alkalinity, conductivity and hardness.

Nutrient analyses show quite high levels for both nitrogen and phosphorous; values up to 0.5 mg/ℓ total nitrogen and 0.12 mg/ℓ phosphorus are recorded. Heavy metal values are low apart from significant levels of aluminum and iron.

7.7 Melville Island

The geology of Melville Island is similar in many respects to Bathurst Island and consists primarily of Middle to Upper Devonian sediments of quartz sandstone, limestone and siltstone, together with some Triassic quartz sandstone. Middle Devonian rocks consist mainly of limestones grading to shale, whereas the Upper Devonian is represented by a thick sequence of paralic and nonmarine quartz-rich clastic sediments. The northern sections of the island consist of sandstones and shales of Jurassic, and Upper and Lower Cretaceous age. Two large gypsum domes are located in the extreme northeastern portion of the island.

The physiography of Melville Island is similar to Bathurst Island and is influenced by the underlying geological structure. The region is generally of low relief but much of the topography is rugged with deeply incised streams and V-shaped valleys.

7.7.1 Study Areas on Melville Island

Two study areas have been designated for Melville Island because of distinct differences in geology. These are:

Study Area MWQ1 - Eastern Portion of Melville Island

Study Area MWQ2 - Northeastern Portion of Melville Island

Study Area MWQ1 - Eastern Portion of Melville Island

Analyses of samples taken during the period June to August, 1975 show that water quality in this study area is generally low in major ions and specific conductance, with pH values showing a slight acidic tendency. These water quality values reflect the dominance of siliceous material although relatively high values for sodium and chloride ions indicate a saline influence within the study area.

Nutrient values are generally low, although phosphorus tends to be high, recording a maximum of 0.028 mg/ℓ. Nitrogen levels are quite low. Several heavy metals record significantly high levels, especially aluminum, copper, manganese and zinc, and indicate considerable base metal mineralization within the study area. Iron mineralization has also been reported and its presence is somewhat confirmed by a maximum recorded value of 0.88 mg/ℓ.

Study Area MWQ2 - Northeastern Portion of Melville Island

Water quality in study area MWQ2 is significantly different from that reported in area MWQ1, and reflects, to a large extent, the variation in geology. Results from analyses of samples collected during the period from June to August, 1975, indicate that the water is significantly higher in specific conductivity, although pH remains the same. This study area is considerably higher in major ion content than area MWQ1, and records relatively high levels for calcium, potassium, sodium, chloride, fluoride, sulphate and reactive silica. A low alkalinity is also recorded, indicating a lack of bicarbonate ions and hence the relative absence of calcareous rocks.

Nutrient values within study area MWQ2 are low for inorganic nitrogen at 0.045 mg/ℓ but quite high for phosphorus, where a maximum of 0.28 mg/ℓ has been recorded. This is the highest phosphorous level recorded along the proposed pipeline route.

Heavy metal concentrations in study area MWQ2 are also the highest recorded in the various study areas along the proposed pipeline route. Significantly high levels have been recorded for aluminum, copper, iron, manganese, cobalt, chromium, nickel and lead. Although there are no known economic mineral deposits in this area of Melville Island, these values may indicate considerable local base metal mineralization.

8. CONCLUSIONS

The following conclusions are based on an analysis of available information. It should be recognized, however, that they are quite generalized as detailed site-specific information for most locations within the proposed pipeline corridor is lacking.

8.1 District of Keewatin

For the most part surface water within the District of Keewatin is of exceptional quality. Only in the Murchison lowland, in the northern part of the District, does some natural deterioration occur.

The geology of the District is mainly comprised of hard igneous shield rocks that characteristically produce surface and ground waters of high quality. The periodic natural deterioration in water quality that does occur, especially during the thaw season, is mainly induced by the weathering of glacial till which blankets much of the District. The natural deterioration in water quality in the Murchison lowland appears to result from the relatively rapid erosion of the thick non-calcareous to weakly calcareous marine silts and clays that are widespread in this area.

Major ion concentrations within the District are low except in the Murchison lowland. Also, nutrient levels are low except in the north in the Hayes River and Murchison River areas, where significantly high levels of phosphorus have been recorded.

Considerable sulphide mineralization has been reported in the southern section of the District, especially in the region stretching from Ennadai Lake in the southwest to Rankin Inlet on Hudson Bay and south to the Manitoba border. However, the degree of mineralization in this area is not reflected to any great extent in results of the heavy metal analyses. Iron mineralization is believed to be present in the northern section of the District as evidenced by the relatively high recorded level of 2.9 mg/ℓ in the Murchison River area.

The high quality natural waters in the District have a low buffering capacity and are therefore susceptible to wide pH fluctuations even with the introduction of relatively small amounts of pollutants.

8.2 Boothia Peninsula

Water quality for the Boothia Peninsula differs considerably from that encountered in the District of Keewatin. Natural waters here are more alkaline, are harder, and have higher conductivities. This indicates that the geological conditions favour dissolution of rock minerals to a greater extent than occurs in the igneous bedrock in the District of Keewatin.

Water quality for the Boothia Peninsula is influenced by the dominance of limestone and dolomite. It is these calcareous rocks that produce natural waters with higher values in fundamental parameters such as pH. Consequently, major ion concentrations are generally high for the region, but low values are recorded for heavy metals and nutrients.

Natural waters of the Boothia Peninsula have a relatively high buffer capacity and are therefore considerably less susceptible to pH fluctuations by the additions of pollutants than natural waters of the District of Keewatin.

8.3 Somerset Island

The natural water quality of Somerset Island is reflected in the dichotomous geological nature of the island, with Precambrian granites predominating in the west and Palaeozoic limestones in the east. Water of characteristically high purity is found in the granitic region, while the water quality in the limestone region tends to be higher in pH, alkalinity, hardness and specific conductivity.

As a result of the geology, major ion concentrations tend to be low in the granitic region but characteristically higher in the calcareous region. In both regions, nutrient and heavy metal levels are low.

8.4 Prince of Wales Island

The predominance of carbonate rocks accounts for the relatively uniform quality of natural water systems throughout the island. However, there is a considerable variation in pH across the island that is difficult to explain.

Major ion concentrations are relatively high on Prince of Wales Island but nutrient and heavy metal levels are generally low.

8.5 Cornwallis Island

The geology of Cornwallis Island consists primarily of calcareous rocks, Middle Devonian and older in age. Shales are common in portions of the northern half of the island and Quaternary deposits are present in the northwestern area.

Water quality for the island is controlled by the calcareous nature of the bedrock so that relatively high values are recorded for the major water quality parameters. Major ion concentrations tend to be high, but nutrient and heavy metal levels are low. Distinctly high levels of chloride, sulphate and sodium, and, to a lesser extent other major ions, were recorded at Sophia Lake in the northeast of the island by Gummer and Dunn (1976). However, it is believed that this lake is an impoundment of marine waters.

8.6 Bathurst Island

The geology of the Bathurst Island group is complex but consists primarily of quartz sandstone, limestone and siltstone, of Devonian age. The geology consists of predominantly calcareous rocks in the southern section of the island and quartz sandstone in the central and northeastern sections. Triassic quartz sandstones predominate in the northwest.

In the southern section of the island, major ion concentrations are relatively high because of the calcareous nature of the bedrock; however, throughout the remaining greater portion of the island, major ions and other fundamental parameters record low levels because of the quartz sandstone bedrock.

In the southern section of the island, nutrient and heavy metal levels are low. However, in the quartz sandstone region that covers much of the island group, nutrient levels appear to be quite high, as recorded within the Snowbird Creek basin. Nitrogen and phosphorus levels are both high, recording 0.5 mg/ℓ and 0.12 mg/ℓ respectively. Heavy metals in this area are low apart from significant levels of aluminum and iron.

8.7 Melville Island

The geology of Melville Island is similar in many respects to Bathurst Island and consists of Devonian quartz sandstones, limestones and siltstones.

The northern sections of the island are mainly composed of Jurassic and Cretaceous sandstones and shales.

Throughout the central and southern sections of the island, the siliceous bedrock dominates natural water quality resulting in low levels for main parameters including major ions. However, for reasons not fully understood, sodium and chloride ion concentrations are relatively high in the region. Nutrient levels in the region are generally low, although phosphorus tends to be high recording 0.027 mg/ℓ. Significantly high levels of heavy metals are reported for the area, especially aluminum, copper, manganese, zinc and iron. Considerable heavy metal mineralization is believed to exist in the region.

In the northern section of the island, water quality is influenced by the sandstone and shale bedrock which produces slightly acidic natural waters that have relatively high major ion concentrations. Alkalinity is low, indicating an absence of calcareous bedrock. Nutrient levels are low for nitrogen but quite high for phosphorus, recording a maximum of 0.28 mg/ℓ. Heavy metal levels are quite high, even surpassing the levels in the central and southern portions of the island. Significantly high levels are recorded for aluminum, copper, iron, manganese, cobalt, chromium, nickel and lead, which may be indicative of local base metal mineralization.

9. POTENTIAL IMPACTS AND RECOMMENDATIONS

Pipeline construction invariably allows the local and usually short term release of sediment into nearby streams and lakes. This is particularly true of river and stream crossings where channel banks are composed of silt or similar fine grained, non-cohesive sediments. Such releases have the potential for adversely affecting the quality of the downstream aquatic environment. However, sediment addition to streams and lakes should not cause major problems provided that the amount of released sediment is not great, nutrients released from the soil are not increased to levels that cause excessive algal growth in lakes, and fish spawning grounds and migration areas are not disturbed.

In areas of nutrient-rich soils it is difficult to avoid nutrient release. On the other hand, construction activities can be scheduled to avoid excessive disturbances to fish populations and construction is best carried out before spring runoff when the sediment carrying capacity of the stream is greatest. Also, construction methods should be such that additional sediment loading will not occur beyond the period of construction. Obviously, sensitive areas of this kind are best avoided where possible.

Much of the proposed pipeline route crosses terrain that is underlain by hard, igneous bedrock of the Canadian Shield. Natural surface waters in these regions are characteristically very pure and have low buffering capacity, being susceptible to wide pH fluctuations with only small additions of pollutants. Particular care needs to be taken in these areas to avoid accidental spillages of potential pollutants since wide pH fluctuations are normally very harmful to aquatic organisms. In areas underlain by calcareous bedrock, the buffer capacity is usually high enough to minimize problems of this nature, but care should still be taken to avoid accidental spillages.

Much of the proposed pipeline will be buried beneath glacial till that frequently has a low liquid limit and limited plasticity. Such terrain can be very unstable during the thaw season and much of the till surface may be under significant hydrostatic pressure on slopes greater than a few degrees. The small range of plasticity allows till to pass from solid to liquid and back with only slight changes in moisture content. Soils such as these are inherently unstable and because of this may be introduced into fluvial systems more easily than those in areas where the ground surface is more stable. However, experience in pipeline construction under these conditions is very limited and the consequences largely unknown.

Problems relating to thermokarst, whereby the ground collapses and mass wasting and increased sedimentation can be induced by the melting of ground ice, are likely to be encountered in alluvial flats adjacent to streams and lakes where organic cover is thick and the terrain is poorly drained. Subsidence and the formation of tundra ponds can occur in these areas. Thermokarst problems can be best avoided by directing the proposed pipeline route away from such areas of high ground-ice content.

During pipeline construction, various hydrocarbons and potential toxicants to aquatic organisms will be used in the construction activity and will pose a threat to the aquatic environment unless strict measures are taken to enforce their use and careful storage. Also, the question of the disposal of sewage from construction sites will require consideration, as excess nutrients from sewage can cause considerable harm to smaller lakes along the pipeline route. Some type of sewage treatment facility will be needed and the effluent should flow into as large and deep a lake as available to minimize potential damage. The disposal of sewage effluent will be an on-going problem as the location of construction activity progresses along the pipeline route.

Tundra fires are estimated to burn off an average of 130 to 260 square kilometres of terrain per decade under natural conditions in the Keewatin District and this figure is believed to be increased several fold by the presence of humans (Rennie 1977). When these fires occur on till plains, erosion and slumping are likely to be increased locally as is the influx of nutrient-rich sediment into nearby lakes. Only by strict supervision of construction personnel will the possibility of tundra fires from human activity be minimized.

10. NEED FOR FURTHER STUDY

Existing data for the remote areas through which the proposed corridor passes has mainly been acquired on a "quick-look" basis because of the need to gather regional information rapidly. Consequently, the acquired information on water quality, geology and other physical characteristics can only be meaningfully related on a regional basis.

Site-specific spatial and temporal information on water quality and related parameters along the proposed pipeline corridor is scarce and a definite need exists to acquire localized data, particularly at sensitive localities such as river and stream crossings. Also, water quality of low buffering capacity or relatively high nutrient level is a problem in many areas, and the effect of the development on the vast number of lakes along the proposed corridor can only be evaluated after careful study.

The effects of terrain and river crossing disturbances on water quality need to be studied on a site-specific basis. Small scale pipeline development simulation studies conducted in sensitive northern areas should be implemented so that the effects of these disturbances on the quality of the aquatic environment in these remote regions can be assessed. Laboratory studies can also provide some insight into these concerns.

There is also a need to define the ambient quality of the existing aquatic environment so that impacts of development projects can be predicted with greater confidence and accuracy. In the event that the Arctic Islands Pipline is constructed, this baseline information can be used to assess the "actual" impacts.

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