4 GROUNDWATER

4.1 Introduction

This section presents a summary of hydrogeological baseline information compiled from literature, air photograph interpretation and fieldwork conducted over 2001, 2002 and 2003.

Hydrogeology is the study of groundwater, i.e., subsurface water and its surface manifestations. In northern Canada groundwater lies close to the surface, generally because of the presence of permafrost.

In the North, hydrogeology is often seen to be a critical consideration in the successful completion of construction projects in Canada. In permafrost areas, groundwater has a profound effect on ground stability, because of the relationship between groundwater, permafrost, and the stability and bearing capacity of ground.

4.1.1 Baseline Study Objectives

The objective of the hydrogeology field studies was to identify areas of groundwater inflow to streams and other waterbodies. Particular attention was paid to areas of groundwater inflow that would maintain year-round baseflow in streams. Another objective was to map groundwater-related surface features and identify points of groundwater recharge or discharge. This information can be used to determine groundwater flow patterns and provide evidence of the presence of aquifers.

To meet these objectives, information on the location of perennial groundwater inflow to streams, e.g., perennial springs and seeps, was required. The occurrence of the following features might provide evidence of perennial groundwater inflow:

- open, flowing water in streams during winter
- polynyas, i.e., nonlinear patches of open water in lakes or streams, surrounded by ice
- icings, i.e., accumulations of ice formed by continuous freezing of slowly discharging water

4.1.2 Regional Overview

4.1.2.1 Physiography

The term physiography refers to the description, categorization and nomenclature applied to the physical structure of the land surface. Therefore, the physiography of a region includes the description of landforms and topography and how terrestrial processes such as mountain building, subsidence, erosion, mass transport and chemical change have affected these features. A physiographic region is a large area of the earth's surface that is characterized by a certain type of landform, which is expressed in the structure of the land surface. Physiography depends to a large extent on the study of geology, climatology and geochemistry as those fields contribute to the study of landforms. These branches of the earth sciences at the same time exert a profound influence on hydrogeology.

The project study area spans eight physiographic regions as shown in the following figures:

- Figure 4-1: Physiographic Regions – North
- Figure 4-2: Physiographic Regions – Central
- Figure 4-3: Physiographic Regions – South

The eight physiographic regions are:

- Mackenzie Delta
- Caribou Hills
- Pleistocene Coastal Plain
- Anderson Plain
- Mackenzie Plain
- Franklin Mountains
- Great Slave Plain
- Alberta Plateau

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Figure 4.3 has been removed for the purposes of reducing file size and can be viewed as a graphic separately. This document can be accessed through the link in the Table of Contents reference web page.

Mackenzie Delta

The Mackenzie Delta Physiographic Region is underlain by a thick, highly complex assemblage of fluviatile sediments, and overlain at surface by organic soils, thermokarst features, lakes and the numerous interlaced channels of the Mackenzie River. The delta region lies in the zone of intermediate discontinuous permafrost, because of the influence of the Mackenzie River as it flows through the delta. Major waterbodies, such as the main channels of the Mackenzie River, prevent the development of continuous permafrost beneath them or in their immediate vicinity. The great thickness of the deltaic sediments and the presence of coarse-grained unconsolidated sediments in the delta could indicate that groundwater is abundant in the deltaic sediments. Portions of the delta that are underlain by taliks are expected to have a shallow water table, and it is likely that saturated conditions prevail throughout the great thickness of the delta. Where permafrost is present, groundwater movement is restricted to the active layer. The movement of subpermafrost groundwater in the delta is not considered important to the pipeline right-of-way.

Caribou Hills

The Caribou Hills Physiographic Region consists of a series of minor uplands, including the Caribou Hills, which border the Mackenzie Delta on the west, the North Storm Hills on the north and the South Storm Hills in the south. The uplands achieve an elevation of 700 m in the North Storm Hills and are situated on thick morainal deposits. Because of the lack of major waterbodies, the region falls in the zone of continuous permafrost. A thin active layer controls the shallow hydrogeology of the region, and groundwater flow is restricted by the presence of permafrost and the low-permeability morainal deposits.

Pleistocene Coastal Plain

Along the pipeline corridor, the Pleistocene Coastal Plain extends from the shores of the Beaufort Sea southward as far as Sitidgi Lake. Although the surficial geology and permafrost conditions are similar to those described for the Caribou Hills, the Pleistocene Coastal Plain is low-lying and relatively flat. Groundwater flow is limited by the factors listed for the Caribou Hills.

Anderson Plain

The pipeline corridor traverses the Anderson Plain from Campbell Lake and the north tip of Sitidgi Lake, southward to a point about 10 km north of Chick Lake. The Anderson Plain is situated in the zone of continuous permafrost as far south as Travaillant Lake, and in the zone of extensive discontinuous permafrost between Travaillant Lake and the southern boundary of the physiographic region near Chick Lake. The Anderson Plain is underlain by morainal deposits. The portion of the region underlain by extensive continuous permafrost will be subject to similar groundwater flow restrictions as described for the Caribou Hills and the Pleistocene Coastal Plain. Although, regionally, the presence of intermediate discontinuous permafrost from near Travaillant Lake to near Chick Lake might be expected to allow for a thicker active layer and larger areas of discontinuous permafrost, the low permeability of the morainal sediments would still be expected to limit the rate of groundwater flow, even in unfrozen ground. Therefore, although permafrost controls could be removed to some extent, the basic surface geology is still a strong limiting factor.

Mackenzie Plain

The Mackenzie Plain Physiographic Region is defined principally in terms of topography. The region is underlain by a wide variety of surficial materials, including lacustrine, alluvial, morainal, glaciofluvial and others. Bedrock exerts an influence on the east flank of the Mackenzie Plain, where the Franklin Mountains rise. The Mackenzie Plain traverses the zone of intermediate discontinuous permafrost. Groundwater flow in this region remains under the control of permafrost, although significant groundwater could be found where unfrozen ground coincides with the presence of coarse-grained, saturated surficial materials, such as glaciofluvial sand.

Franklin Mountains

The Franklin Mountains Physiographic Region extends from Chick Lake in the north, to just south of Willowlake River in the south. Permafrost conditions are similar to those described for the Mackenzie Plain. However, the main features that control groundwater flow are bedrock geology and topography. In the Franklin Mountains, extensive karst terrain has developed in the soluble precipitates, i.e., carbonate rocks, and evaporites i.e., halite, and other minerals deposited through the evaporation of ancient seawater. This has enabled major groundwater flow systems to develop in the mountainous karst terrain (see Section 4.1.2.4, Bedrock Geology for an explanation of karst).

Groundwater flow in the Franklin Mountains has caused extensive spring development throughout the south half of the Sahtu Settlement Area and the northern half of the Deh Cho Region. Groundwater flow on the west flank of the Franklin Mountains affects hydrology in the Mackenzie Plain by maintaining all-year open flow in some streams.

Great Slave Plain

South of the Franklin Mountains, the pipeline corridor traverses the Great Slave Plain Physiographic Region between Willowlake River and Trout Lake in the Deh Cho Region. Except for the lacustrine and alluvial deposits in the Mackenzie Valley, the region is mantled by flat-lying, thick morainal deposits. As this region lies in the zone of sporadic discontinuous permafrost, the distribution of permafrost alone will not exert significant control on groundwater. However, the low permeability of the morainal deposits, i.e., glacial till, and the lack of topographic variation, cause shallow groundwater flow to be very slow. This is indicated by widespread conditions of poor drainage in the region, characterized by extensive peat and muskeg deposits.

Alberta Plateau

The pipeline corridor traverses the Alberta Plateau from Trout Lake, to the southern terminus of the pipeline in northwestern Alberta. The Alberta Plateau Region is mantled with morainal deposits, overlying flat-lying Mesozoic bedrock. Surficial deposits include extensive peat and muskeg deposits. Groundwater flow constraints are similar to those in the Great Slave Plain.

4.1.2.2 Permafrost

Permafrost is present in varying degrees over the entire project area (see Volume 3, Section 8, Soils, Landforms and Permafrost). The distribution of permafrost along the pipeline corridor was determined by the Geological Survey of Canada from engineering geology field mapping, and from maps of surficial geology and Quaternary features (Heginbottom 2000).

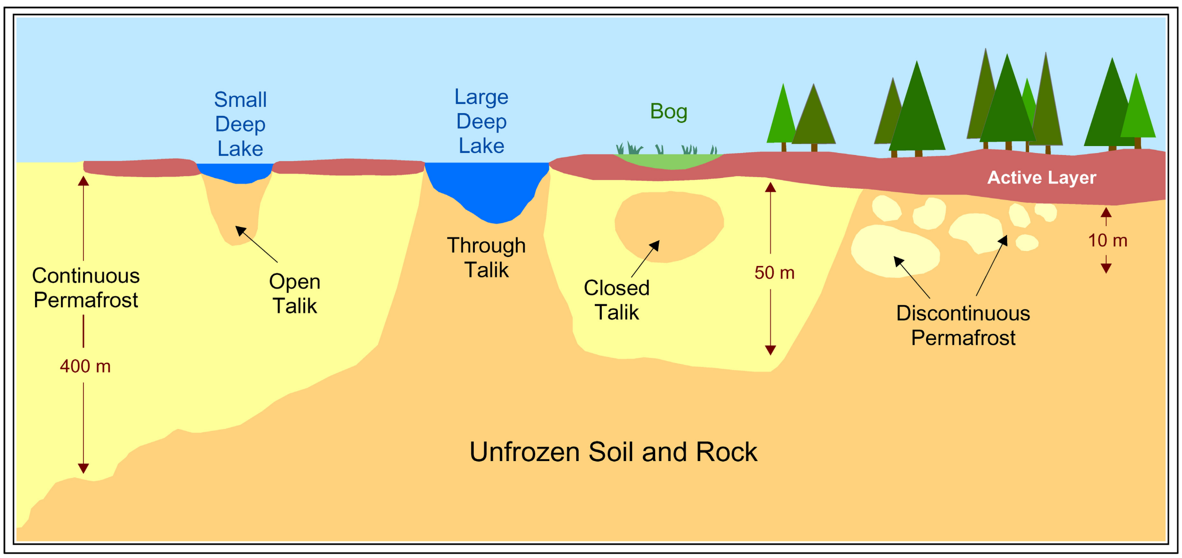
Permafrost zones are defined in van Everdingen (1998) as follows:

- continuous permafrost – permafrost occurring everywhere beneath the exposed land surface throughout a geographic region with the exception of widely scattered sites, such as newly deposited unconsolidated sediments, where the climate has just begun to impose its influence on the thermal regime of the ground, or beneath waterbodies that remain open all year
- discontinuous permafrost – permafrost that is present in some places, whereas other places are free of permafrost, in a given representative area. The zone of discontinuous permafrost lies between the continuous permafrost zone and the southern latitudinal limit of permafrost in lowlands. Near its northern boundary, discontinuous permafrost is extensive, whereas near its southern boundary it grades from sporadic discontinuous permafrost into sporadic permafrost. There is no sharp distinction, or boundary, between the continuous and discontinuous permafrost zones. The definition of discontinuous permafrost is further subdivided:
    - extensive discontinuous permafrost – permafrost underlying 65% to 90% of the area of exposed land surface
    - intermediate discontinuous permafrost – permafrost underlying 35% to 65% of the area of exposed land surface

- sporadic discontinuous permafrost – permafrost covers 10% to 35% of the exposed land surface
- isolated patches of permafrost – permafrost underlying less than 10% of the exposed land surface

The prevalence and depth of permafrost affects the distribution and movement of groundwater. Figure 4-4 illustrates the distribution of permafrost and the relationship between frozen and unfrozen ground, and various surface features. The distribution of permafrost is governed by complex thermal regimes, which include interrelated factors, such as:

- climate
- soil properties
- surficial and bedrock geology
- ground and vegetation cover
- surface waterbodies
- geographic location



SOURCE: Michael Pidwirny 2004, Department of Geography, Okanagan College, used with permission.

Figure 4-4: Transition Zone between Continuous and Discontinuous Permafrost

Northern development activities and climate change could cause changes in the existing thermal conditions, which can further result in changes to groundwater conditions through changes in permafrost.

In permafrost regions, groundwater can be classified into three types, based on its relationship to permafrost (Church 1974; Tolstikhin and Tolstikhin 1976), as follows:

- suprapermafrost groundwater – occurs above the permafrost in the active layer. This zone is usually thin and freezes in winter. The active layer generally grows thinner with increased distance from waterbodies under which *through taliks* are found.
- intrapermafrost groundwater – occurs in closed taliks, i.e., unfrozen ground, surrounded on all sides by permafrost
- subpermafrost groundwater – occurs below the permafrost, and stays unfrozen because of heat flow from the earth, conducted upward by the geothermal gradient

The three types of talik are:

- open taliks characterized by unfrozen ground beneath a surface waterbody
- through taliks found beneath some waterbodies, and extending through the permafrost zone
- closed taliks surrounded in all directions by permafrost

Groundwater occupying through taliks can result in:

- continuous stream flow beneath winter ice in river channels
- continuous groundwater flow through permeable alluvium beneath surface water streams that have frozen to bottom

Where groundwater flow through riverbed gravels or permeable alluvium is blocked, e.g., by the presence of frozen ground, groundwater flow is dammed and can be forced to the surface. This would result in ice buildup at the discharge point. Ice buildup can also occur at spring discharge points.

From the Mackenzie Delta south through the Inuvialuit Settlement Region, the Gwich'in Settlement Area and into the Sahtu Settlement Area as far south as Chick Lake in the Sahtu K'ahsho Got'ine District, continuous and extensive discontinuous permafrost landscapes predominate (see Figure 4-5). Shallow groundwater flow, therefore, is minimal. Groundwater beneath the permafrost layer has little interaction with surface flow.

From Chick Lake, south through the Sahtu Tulita District, to Wrigley in the Deh Cho Region, the pipeline corridor crosses extensive and intermediate discontinuous permafrost (see Figure 4-6). South of Wrigley and into northwestern Alberta, sporadic discontinuous permafrost is predominant (see Figure 4-7).

Groundwater inflow to streams, as springs and seeps, provides the baseflow for streams. Baseflow is that part of stream flow that consists of groundwater input. However, groundwater movement is restricted by the presence of permafrost. In areas of continuous and extensive discontinuous permafrost, most streams freeze to the channel bottom in winter and have essentially no baseflow. In the continuous permafrost region, which extends along the pipeline corridor through the Inuvialuit Settlement Region and the Gwich'in Settlement Area, groundwater contributions to stream flow are seasonal, with negligible or no baseflow in winter. Similar conditions prevail from the northern boundary of the Sahtu Settlement Area, south to Chick Lake.

4.1.2.3 Surficial Geology

The Niglintgak and Taglu significant discovery licence areas are situated in the Mackenzie Delta, on fluvial sediments (see Figure 4-8). Throughout the Inuvialuit Settlement Region the gathering pipeline route and the pipeline right-of-way run principally over thick morainal sediments, deposited from melting Pleistocene glaciers, and minor glaciofluvial and lacustrine deposits. In the Sahtu Settlement Area, the surficial geology becomes more complex, and the pipeline corridor traverses morainal sediments and lacustrine deposits occupying the floor of the Mackenzie Valley (see Figure 4-9). In the Deh Cho Region, the pipeline corridor again traverses moraine, except for a broad belt of lacustrine sediments lying along the Mackenzie River and its confluence with the Liard River at Fort Simpson (see Figure 4-10).

Surficial geology is important in the hydrogeological context because of its influence on:

- distribution of permafrost
- stability of ground under freeze-thaw conditions
- distribution of aquifers

4.1.2.4 Bedrock Geology

In the Inuvialuit Settlement Region, from the Mackenzie Delta south to the northern boundary of the Gwich'in Settlement Area, bedrock consists of Cenozoic sedimentary rock of Tertiary age (see Figure 4-11). As thick morainal sediments of Quaternary Age cover the Cenozoic rocks, they are not generally considered important with respect to the groundwater of the project area.

From the northern boundary of the Gwich'in Settlement Area south, the pipeline corridor crosses a belt of Mesozoic sedimentary rocks and then crosses Paleozoic sedimentary rocks as far south as Chick Lake, which lie about 10 km north of the boundary between the Kahsho Got'ine and Tulita districts in the Sahtu Settlement Area (see Figure 4-12). From that point south, the pipeline corridor traverses the limestone and evaporite-rich terrain of the Mackenzie Plain and Franklin Mountain physiographic regions. The karst landscapes of the Franklin Mountains and associated lowlands make up an important hydrogeological region in the zone of extensive discontinuous and discontinuous permafrost.

The term karst refers to terrain made up of carbonate and other soluble rocks, characterized by sinkholes, and cavernous subsurface drainage channels that largely follow solution-widened joints, faults and bedding planes. Karst topography refers to a landscape where soluble rocks underlie surficial material, and where dissolution of the underlying rocks has caused sinkholes to develop. Continued dissolution of bedrock along fractures and joints creates channels for groundwater movement. Groundwater in karst areas moves through these solution channels before re-emerging at the surface as a spring.

In karst regions, groundwater is recharged from snowmelt and rainfall through various karst features, such as:

- sinkholes and swallow holes – areas of bedrock where solution channels and fractures have formed a pathway for the rapid infiltration of surface water and shallow groundwater, into the groundwater flow system
- disappearing streams – streams that lose water to karst-controlled groundwater flow systems, by gravity drainage into solution channels and fractures
- closed depressions – topographically low areas with no surface water outlet, from which accumulated water exits via ground infiltration to karst-controlled flow systems

Over the section of the project area extending from Chick Lake to Willowlake River, the discharge from perennial springs of karst origin maintains baseflow in streams, and could keep long stretches of streams open all winter.

Karst springs occur in other streams between Tulita and Willowlake River. It appears that no comprehensive study of karst features has yet been done in this southern area. Devonian and older carbonates and evaporites, i.e., salt and salt-rich deposits formed by the evaporation of ancient seawater, are the main rock types associated with karstification in this area. Freshwater springs and ice-free stretches of open water have been noted at some streams traversed by the pipeline corridor in this area, e.g., Steep Creek or Birch Island Creek, White Sand Creek and Hodgson Creek. A flow rate of 128 L/s was reported for one spring on Steep Creek (Michel 1977). This is a relatively high flow rate for groundwater issuing from a well-defined spring.

In the Deh Cho Region, soluble bedrock and karst features extend to within about 30 km of the Alberta boundary (see Figure 4-13). However, along the pipeline corridor, no soluble bedrock or karst features are evident south of Willowlake River. The pipeline corridor traverses the Great Slave Plain and Alberta Plateau physiographic regions, which are underlain by relatively flat-lying shale of Devonian and Cretaceous age. As thick morainal sediments overlie the bedrock in this region, bedrock is not generally considered important with respect to the groundwater in this area.

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4.2 Methods

Figure 4-14 shows the methods for this groundwater baseline study.

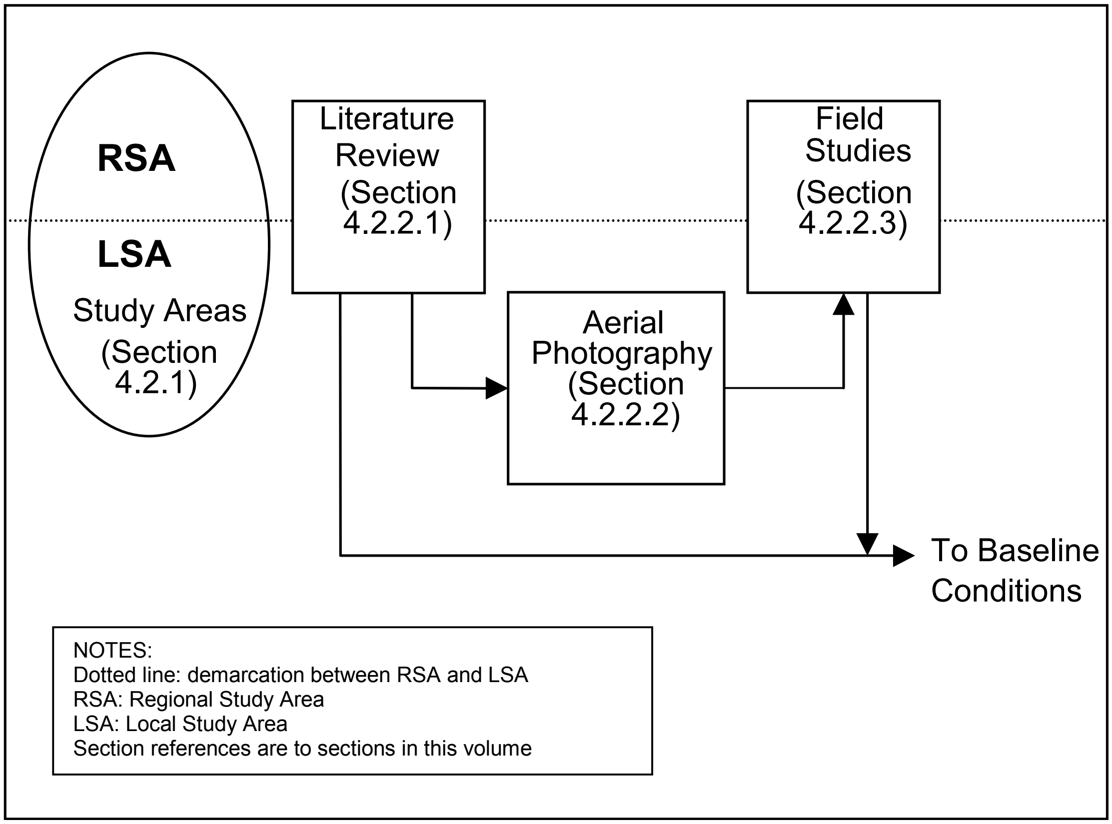

Figure 4-14: Methods for Groundwater Baseline Study

4.2.1 Study Areas

4.2.1.1 Local Study Area

The focus of the work was the production area and the pipeline corridor. With respect to the gathering pipeline and the NGL and gas pipelines, the local study area (LSA) extends 500 m on either side of the centre of the pipeline corridor. The total width of the LSA is therefore 1 km. Similarly, a 1-km-wide strip bordering the anchor fields and a 500-m strip bordering all local infrastructure sites is defined as LSA.

4.2.1.2 Regional Study Area

A larger, regional study area (RSA) was defined to include groundwater-related features that could influence groundwater in the LSA, or that might contribute to winter baseflow of streams that cross the pipeline corridor. The RSA includes the proposed borrow sites, roads, barge landing sites and camps. Parts of the road network and barge traffic areas might extend beyond the limits of the RSA. The RSA boundary extends outward 30 km on either side of the pipeline corridor. The total width of the RSA is therefore 60 km. For the RSA boundary, see:

- Figure 4-15: Study Area and Project Components – North
- Figure 4-16: Study Area and Project Components – Central
- Figure 4-17: Study Area and Project Components – South

Groundwater features and influences are most pronounced in the Franklin Mountains and Mackenzie Plain physiographic regions, where soluble bedrock and karst features are common. Groundwater flow systems in this region that might affect, or be affected by, the project are expected to extend from the ridgeline or crest of the Franklin Mountains to the Mackenzie River. This area lies entirely within the RSA boundary. Groundwater effects in other regions are more localized and are well within the RSA boundary. Some groundwater influences might extend beyond the RSA boundary, but at that distance from the pipeline corridor, groundwater effects on the project and the project's effects on groundwater are expected to be negligible.

4.2.2 Data Sources

4.2.2.1 Literature Review

Peer-reviewed publications i.e., published in the open literature, and government agency reports were reviewed in detail. Unpublished data in reports submitted to regulatory agencies, in support of environmental assessment requirements or regulatory obligations, were also consulted. Other data sources included aerial photographs and geological maps.

Most of the historical information reviewed was from the 1970s and 1980s, when earlier proposals for a pipeline from the Mackenzie Delta to southern Canada were being considered, and oil and gas exploration in the delta was at its peak. Most information was collected for projects, such as the Canadian Arctic Gas Pipeline, and hydrocarbon development in the Beaufort Sea and Mackenzie Delta region. Data from these sources was supplemented by studies done over the same period by, or on behalf of, federal government agencies, such as:

- Fisheries and Oceans Canada (Freshwater Institute)
- Environment Canada
- Indian and Northern Affairs Canada

More recent information from the 1990s to the present is also available, but is more difficult to locate. In the 1970s and 1980s, more government-sponsored research was done, and this work tends to be cited in the open, i.e., in the public domain, literature. Much of the more recent information is not in the public domain.

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Figure 4.17 has been removed for the purposes of reducing file size and can be viewed as a graphic separately. This document can be accessed through the link in the Table of Contents reference web page.

Although few references exist on the hydrogeology of the Mackenzie Valley region, the available literature provided some background information. However, this information was rarely site-specific. Where site-specific information was available, it was seldom georeferenced, i.e., accurately referenced to existing survey systems, such as the UTM coordinate system, or described according to latitude and longitude, so historical information cannot always be easily mapped or linked to the proposed pipeline crossing locations.

4.2.2.2 Aerial Photography

Aerial photographs for the pipeline corridor were studied to identify and delineate groundwater-related features, such as:

- springs
- seeps
- karst features such as sinkholes
- permafrost features such as thaw-flow slides, active layer slides and pingos

4.2.2.3 Field Studies

The purpose of the field studies was to identify areas where groundwater inflow to streams would sustain winter stream flow. Table 4-1 shows a summary of the information collected at each location studied.

In 2001, fieldwork included a fixed-wing reconnaissance flight in early September.

In 2002, fieldwork included:

- a late March survey in northern Alberta, and a mid-April survey in the Inuvialuit Settlement Region, Gwich'in Settlement Area, Sahtu Settlement Area and the Deh Cho Region
- a mid-August survey in the Deh Cho Region
- a mid-September survey in the Inuvialuit Settlement Region, Gwich'in Settlement Area and Sahtu Settlement Area

In 2003, fieldwork included:

- a July survey in the Inuvialuit Settlement Region, Deh Cho Region and Gwich'in Settlement Area
- an October survey in the Sahtu Settlement Area

Table 4-1: Summary of Site Inspection Information

General Category	Parameters Recorded	Notes
Site identification	Unique site identifier number	–
	Descriptive name	A name was selected for the site that was descriptive of the location or some feature.
	Crossing number	Where applicable, the water crossing number was identified for the site.
	Settlement area	–
	Date	–
	UTM location	Determined using a handheld GPS unit.
Site information	Ground or aerial inspection	It was not possible to land at all sites of interest. Data recorded from aerial inspections is also of value. This information explains lack of field measurements.
	Photographs	Reference numbers were used for photographs recorded at the sites. The approach was typically to obtain both ground photos (as appropriate) and aerial photos, to provide an overview of the site setting.
	Type of feature	Could include the following: spring, open water (winter only), icing (winter only), slide and geological materials exposure.
	Observer	This was the field crew lead.
Site setting	Physical setting	Description given of physical setting of site, e.g., river crossing, slope, slumped ground.
	Geological setting	Observations made of local geology, both surficial and bedrock, visible or encountered near the site.
	Vegetation	Observations made of the vegetation types near the site. Might indicate groundwater geochemistry (where applicable).
	Depth to groundwater table or permafrost	Recorded if encountered.
	Weather	–
Groundwater discharge	Flow rate	Where practical, the rate of groundwater discharge was measured using either a flow meter, container fill or velocity measurement methods.
	Sample collected	Sample was collected to analyze major ions.
	Water temperature	–
	Ambient air temperature	–
	Field conductivity	–
	Field pH	–
	Field dissolved oxygen	–

NOTE:
– = no additional notes

Features that were mapped from the air, up to a few kilometres upstream and downstream of the proposed watercourse crossings, included:

- springs
- open water (in winter)
- icings

During the 2002 late March to mid-April survey, landings were made only at pipeline corridor watercourse crossings. The ice at the crossings was bored with an auger to determine thickness and stream flow conditions. The winter survey was done along the pipeline corridor and the gathering pipeline in the Inuvialuit Settlement Region. The 2002 mid-August to mid-September survey involved more detailed work in areas of:

- previously reported springs and other groundwater-related features
- potential groundwater inflow to streams determined during the winter survey

Landings were made where practical at spring locations and the area was examined and described. The rate of spring discharge was measured, where practical, or estimated. Temperature, conductivity, pH and dissolved oxygen content of the springs were measured in the field as close to the spring source as possible, and a water sample was collected for laboratory determination of the main chemical constituents. The samples were analyzed for:

- pH and specific conductivity, in the field and in the laboratory
- major ions
- dissolved oxygen
- calculated parameters, i.e., hardness, total alkalinity and total dissolved solids
- turbidity

The 2002 mid-August to mid-September survey included the gathering pipeline and anchor fields.

The 2002 field studies revealed that many of the mineralized springs had lower flow rates than larger, less mineralized springs, but they could be more easily seen from the air or on aerial photographs. Possible reasons for this include:

- vegetation upstream of the mineralized spring was conspicuously different from that downstream

- deposition of calcium carbonate as tufa or travertine, deposition of salts or the presence of iron precipitate along the mineralized spring outflow channels

- no vegetation along the highly mineralized outflow channels

- less mineralized, freshwater spring outflow tended to have vegetation along the channels that was indistinguishable from the normal vegetation types along a stream

- many of the large karst spring outflows originated at or near stream level along the stream channel

Major springs and areas where groundwater inflow was present were more visible during winter surveys.

Field studies in July 2003 included an aerial inspection of the rerouted sections of the pipeline. In addition to the aerial inspection, 26 sites were inspected on the ground to examine:

- seepage areas
- springs
- karst features
- exposures of geological materials
- areas of possible instability

Water samples were collected from eight locations. The 2003 water samples were analyzed for the main chemical constituents previously listed. Where applicable, spring discharge was estimated.

4.3 Baseline Conditions

4.3.1 Niglintgak and Taglu

Niglintgak and Taglu are in the Inuvialuit Settlement Region. Both anchor fields are in the Mackenzie Delta in the intermediate discontinuous permafrost region (Heginbottom 2000).

The surficial materials underlying Niglintgak are an assemblage of deltaic fluviatile (river deposited) silt, sand and gravel, covered in places with organic deposits. The geology is highly complex, because of the many changes in streambed alignment during evolution of the Mackenzie Delta.

Surficial sediments at Taglu, in the area west of Harry Channel, are similar to those at Niglintgak. Norris (1975) described the sediments mantling the area east of Harry Channel as mainly hummocky or ridged moraine and lacustrine deposits with extensive organic cover.

The terrain at Niglintgak and Taglu is low-lying and subject to annual flooding. Niglintgak straddles the wide expanse of the Middle Channel of the Mackenzie River and Taglu straddles Harry Channel (see Figure 4-18). The terrain southeast toward Parsons Lake is similar rising up toward the Storm Hills (see Figure 4-19). The active layer at Niglintgak ranges from 0.25 to 1.3 m thick and is expected to be a similar thickness at Taglu. The active layer is expected to become thinner away from the taliks that are generally associated with waterbodies such as the main channels of the Mackenzie River. Permafrost thickness below the active layer at Niglintgak ranges from 146 to 275 m and at Taglu from 500 to 670 m (Burgess et al. 1982; Taylor et al. 2000).

Extensive or through taliks, i.e., taliks that extend completely through the permafrost, are likely to occur beneath some lakes and the river channels in the Niglintgak and Taglu anchor fields and in the surrounding delta. Burn (2002) estimated that on Richards Island, which is the lake-dominated area between Harry and East channels of the Mackenzie River, 23% of the lakes and 10 to 15% of the surface area of the island are underlain by through taliks.

At Taglu, groundwater is present in the active layer and in intrapermafrost and subpermafrost taliks, i.e., zones of unfrozen water completely enclosed in permafrost (Bowerman and Coffman 1975). Taliks are also found beneath deep lakes and beneath channels of the Mackenzie River. Across part of Taglu, there is a laterally continuous, relatively shallow, unfrozen zone, 20 to 60 m thick, which forms a closed talik between the overlying 35- to 90-m thick permafrost cap and the underlying main permafrost body. A shallow well drilled into this talik produced water from a depth of 67 m.

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Figure 4.19 has been removed for the purposes of reducing file size and can be viewed as a graphic separately. This document can be accessed through the link in the Table of Contents reference web page.

The base of the permafrost at Taglu is in the Miocene Beaufort Formation, which is made up of gravel, sand and sandy mud (Young and McNeil 1984). The coarse granular nature of this formation suggests that subpermafrost water might be abundant in the Taglu area. The interconnections among surface waterbodies, through taliks beneath waterbodies, and subpermafrost and intrapermafrost taliks are unknown.

Detailed background information regarding groundwater quality is not available for either lease area. However, formation water (water in the gas reservoir) at Niglintgak is characterized by a low degree of mineralization. This suggests that groundwater in shallower zones will also be fresh, and might indicate active groundwater recharge, with movement from surface sources into and through the groundwater flow system.

Because of the thin active zone and the comparative depth to intrapermafrost and subpermafrost taliks in the Niglintgak and Taglu areas, shallow groundwater flow systems are expected to be localized, falling well within the scale of the LSA.

4.3.2 Parsons Lake

The Parsons Lake anchor field is in the zone of continuous permafrost in the Pleistocene Coastal Plain. Figure 4-20 shows the outline of the field. Permafrost north and east of Parsons Lake is consistently about 350 to 380 m thick (Taylor et al. 2000). The active layer is less than 0.3 m thick in organic peat and silts and up to 1 m thick in the sparsely vegetated glaciofluvial gravels and sands that cover much of this area (Hardy and Associates 1976).

Geotechnical test holes were drilled east and southeast of Parsons Lake to depths of up to 11.3 m (Hardy and Associates 1976). All holes drilled encountered frozen earth materials, although some zones, most often at the base of the deeper holes, were logged as poorly bonded or friable frozen soil with nonvisible ice. Some of these zones could pass into unfrozen strata at depth, where groundwater movement might occur in taliks.

The drilling program included investigations for a proposed dock site on the north shore of Hans Bay on Husky Lakes, about 6 km southeast of Parsons Lake. Test drilling took place less than 70 m from shore. All test holes encountered permafrost. The depth to top of permafrost varied with the depth of water in the lake, with a maximum depth to top of permafrost of 19 m in two test holes. Any unfrozen material consisted predominantly of fine-grained sand. Although the test holes on Hans Bay encountered permafrost, it is likely that through taliks exist beneath the central parts of Husky Lakes and Parsons Lake.

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An unusual feature in the area is a small, unnamed lake that stays open, i.e., unfrozen in winter. This lake is located immediately southeast of Parsons Lake. Gas is reported to bubble up through the water. This lake had open water on June 5, 2002 when other lakes nearby were still frozen. (Parsons Lake is also reported to have patches of open water in winter.) The lake differs from nearby lakes of similar size because of patches of vegetation in it and a broad fringe of aquatic vegetation along its shoreline. A water sample was collected from this unnamed lake on July 25, 2003. Analysis of the sample showed that the water had low ionic strength, indicated by low specific conductivity and low total dissolved solids content.

There are few groundwater outflows to the land surface, and those observed are seasonal, consisting mainly of groundwater released in summer, during the formation of retrogressive thaw-flow slides and active layer detachment slides. Retrogressive thaw-flow slides form where the permafrost melts back from a headwall (a break in the land surface, generally found adjacent to a lake or watercourse) causing instability in the sloped surface. This instability results in a debris flow, formed from the mixture of thawed sediment and ice that moves, under the influence of gravity, down the failure surface to form a chaotic mass at the base of the slope. Retrogressive thaw-flow slides occur principally along the edges of lakes or thermokarst depressions.

An active layer detachment slide occurs when permafrost melting in the active layer, on a sloped surface, causes the active layer to detach from the permafrost below it, and to move downslope on the failure surface without much deformation. Active layer detachment slides occur mainly on hillsides and along streambanks.

Both types of slides will add relatively small amounts of water to lakes and streams and will add to seasonal stream flow, but are not expected to add to winter baseflow.

4.3.3 Gathering Pipeline

4.3.3.1 Groundwater-Related Surficial Features

In the northern part of the study area, the gathering pipeline runs on the Pleistocene Coastal Plain, with the exception of a section that runs through the Mackenzie Delta connecting the Niglintgak and Taglu anchor fields, and a section that crosses the East Channel of the Mackenzie River. In the southern part of the study area, as far as the northern boundary of the Gwich'in Settlement Area, the pipeline traverses the Caribou Hills. Both the Pleistocene Coastal Plain and the Caribou Hills lie in the zone of extensive continuous permafrost.

In the Caribou Hills, as in the Pleistocene Coastal Plain, few groundwater-related features occur, and these are related to thawing in the active layer. Groundwater outflows are related to earth flow activity at slide locations. The term slide, here, refers to retrogressive thaw-flow slides. Relict retrogressive thaw-flow slides that have stabilized are not indicated. These slides are associated with melting of the permafrost exposed by the sliding. Icings are likely to form at these slides, although flow is expected to be seasonal.

The features were observed during the 2002 mid-August to mid-September survey, which was confined to 1 to 2 km on either side of the proposed gathering pipeline. Features located at a greater distance from the gathering pipeline are not shown. The main features shown are pingos, retrogressive thaw-flow slides and other smaller slides.

Pingos are common in the area north of North Storm Hills. Pingos are ice-cored hills that form in drained or partially drained lake basins, where permafrost is actively aggrading from the surface down into what were originally closed lake taliks (van Everdingen 1990). High pore pressures develop in the shrinking taliks, resulting in artesian discharge of water to the surface that subsequently freezes to produce an ice-cored mound or pingo. Continued permafrost aggradation leads to continued growth of the pingo.

4.3.3.2 Watercourse Crossings

Seven watercourse crossings (RPR-008 and RPR-048 and sites 18, 23, 35, 41 and 43) along the gathering pipeline were investigated on the ground during the 2002 late March to mid-April survey. All are unnamed streams except for Holmes Creek (Site 23) and Hans Creek (Site 41). RPR-048 is an inlet stream to Jimmy Lake, which drains from Noell Lake.

The seven sites were bored using a hand auger. Results of the auger work were:

- three of the seven crossings, i.e., sites 23 and 41 and RPR-008, were frozen to the bottom of the watercourse
- at two other sites, sites 35 and 43, the channel could not be located under uniform snow cover
- ice and slush extended to the bottom at RPR-048
- a water depth of 1.09 m was measured beneath 1.72 m of ice cover at Site 18. The ice cover, however, was too thick to obtain a flow measurement. The water at Site 18 could have been derived from lake storage or a result of backflow from an unnamed channel of the Mackenzie River

In addition, during fieldwork in 2003, a water sample was collected from an unnamed stream east of the gathering pipeline route, about 14 km southeast of Noell Lake. The sample was characterized by low pH, and moderately low total dissolved solids content, with sulphate the dominant anion. The combination of relatively low pH and relatively high sulphate suggests that the chemistry of this water is affected to some degree by oxidation of reduced sulphide minerals. However, no further data exists to verify this.

Some watercourse crossings of various channels of the Mackenzie River are not influenced by local groundwater conditions. Therefore, they were not investigated during this survey. They include:

- Harry Channel
- East Channel at Swimming Point
- channel crossing sites at Niglintgak and Taglu

Open water and icings were observed at two locations during the 2002 winter survey. Both were upstream of RPR-048 and a few kilometres off the gathering pipeline route. Open water was observed at the outlet from Noell Lake and a 2-km-long icing was noted about midway between the Noell Lake outlet and RPR-048 (see Figure 4-21). Both these features are attributed to flow derived from lake storage rather than to groundwater inflow.

4.3.3.3 Observed Groundwater-Related Features

Groundwater-related features observed along the gathering pipeline route do not appear to contribute to the winter baseflow of streams.

Thurber Engineering Ltd. (1993) reported springs on Yaya Creek, and on Holmes Creek near Site 23. Both springs were observed in late May 1992. These locations were checked during the 2002 mid-August to mid-September survey. Landings were made near the sites and creek traverses to locate the reported springs, but no springs were found. It is possible that the springs were seasonal, resulting from thawing of the active layer in late May 1992. A sample collected from a seep on Yaya Creek during that survey had low specific conductivity and total dissolved solids. This suggests that the groundwater from this seep does not have a long travel pathway in the subsurface and does not contact soluble minerals. This would be expected in an area where permafrost restricts groundwater movement to the shallow subsurface.

Thurber Engineering Ltd. (1993) also reported icings in this general area in late May 1992. No icings were seen here during the winter survey, which indicates that the formation of icings at this location might not occur every winter. However, the relatively thick snow cover might have masked the icings and made them difficult to locate visually. Any icings in this area would be fed by water discharge from the active layer, and would stop growing in early winter, when groundwater inflow ceases as frost progresses downward.

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The North Storm Hills and the upland between Hans Creek, Stanley Creek and Bonnet Plume Lake are capped by alluvial gravels of the Beaufort Formation of Miocene or Pliocene age (Norris 1975). This formation consists of unconsolidated gravel comprising chert, quartzitic sandstone and siltstone (Norris 1975). Because of the unconsolidated nature of this coarse granular material, springs could occur in some locations at the contact between the Beaufort Formation and adjacent morainal or lacustrine deposits, as mapped by Norris (1975). These areas were checked from the air during the 2002 mid-August to mid-September survey and two landings were made. Patterned ground, i.e., topographic features formed during the melting of ground ice in the upper part of the permafrost, was present, suggesting that groundwater outflow had occurred in the past. No springs were located along the geological contact. However, groundwater seeps were observed at several locations in the area. All the seeps appeared to be related to earth flow or slide activity, brought about by melting of ground ice.

Graves and Den Beste (1976) observed a spring off the west shore of Big Lake in February 1976. Big Lake straddles the northern boundary of Taglu.

Winter flow is present in substantial amounts beneath ice cover in the various channels of the Mackenzie River (Brooks 2000; McCart 1973; Water Survey of Canada 1992). Winter flow maintains taliks below the main channels, some of which might extend through to the base of the permafrost (Smith and Hwang 1973). The lateral extent of taliks on either side of the channels is unknown. The presence of water beneath ice at Site 18 might be related to lateral warming by water from a side channel off the East Channel of the Mackenzie River. The role of taliks in maintaining or adding to the stream flow in the Site 18 area is not known.

4.3.4 Pipeline Corridor

4.3.4.1 Gwich'in Settlement Area

In the Gwich'in Settlement Area, the pipeline corridor crosses the Anderson Plain physiographic region. The northern part of the Anderson Plain has continuous permafrost, whereas the southern part has extensive discontinuous permafrost. As in the Pleistocene Coastal Plain, few seasonal groundwater-related features occur. All groundwater outflows in the area are related to earth flow activity at slide locations and the thawing of the active layer.

In September 2001, a fixed-wing overflight of the area was conducted, but no ground investigations. Work in 2002 and 2003 was primarily at a reconnaissance level. In the 2002 mid-March to mid-April survey, nine watercourse crossings, between sites 80 and 188, were checked.

Six of the watercourses were frozen to the bottom. One stream had an ice thickness of more than 1.95 m and was considered frozen to the bottom. The remaining two watercourses had some standing water below an ice cover.

Two small icings on the Travaillant River indicated that a groundwater seep was active in the river for at least part of the preceding winter.

During a groundwater survey in the Gwich'in Settlement Area in September 2002, particular attention was focused on possible seepages from granular areas and areas where springs, open water in winter or icings had been previously seen or reported. No evidence of discrete spring flow could be seen from the air. Two landings were made to check on reported spring areas at Thunder River and about 400 m upstream of Site 194. About 270 m along the stream were traversed on foot at Site 194. No springs were found at either location.

In July 2003 a groundwater sample was collected from a hand boring in a fen near the pipeline corridor, about 25 km north of North Caribou Lake (see Figure 4-22). This sample had low specific conductivity and low total dissolved solids, suggesting that the groundwater had not travelled a great distance from its input point, nor had it been in contact with soluble mineral materials.

Groundwater outflow was recognized at a few locations. All of these were related to earth flow activity at locations where slides were observed. The types of slide associated with groundwater outflow are retrogressive thaw-flow slides and active layer detachment slides (Aylsworth et al. 2000).

Thurber Engineering Ltd. (1993) reported some springs in the Gwich'in Settlement Area. However, in this study they are considered to be seasonal springs, related to melting of the active layer at active layer detachment slides and thaw-flow slides, and not perennial springs that would maintain winter stream flow.

In April 1973, Aquatic Environments Ltd. (1973) observed an open hole, 3 to 5 m in diameter, near the centre of Travaillant Lake in which water was bubbling and upwelling, suggesting a groundwater source (see Figure 4-23). They also reported an open-water discharge of 2.64 m3/s at the lake outlet. The substrate comprised mud and fine gravel, about 40% of which was covered with long, green algae. This suggests a possible substantial groundwater contribution to the lake, potentially from subpermafrost groundwater welling up through a talik underlying the lake.

Hydrogeological features in the southern part of the Gwitch'in Settlement area are illustrated for the Thunder River area (see Figure 4-24) and Little Chicago area (see Figure 4-25).

Based on literature surveys and project-specific field studies, groundwater contributions to winter flow in streams in the Gwich'in Settlement Area, including streams flowing into Travaillant Lake, appear to be slight to negligible.

4.3.4.2 Sahtu Settlement Area

In the northern half of the Sahtu Settlement Area, the pipeline corridor crosses the Anderson Plain. In the southern half, the pipeline traverses both the Mackenzie Plain and the Franklin Mountains physiographic regions. In the Anderson Plain, in the zone of extensive discontinuous permafrost, groundwater occurrence is similar to that described previously for the Gwich'in Settlement Area. Permafrost varies from extensive discontinuous to intermediate discontinuous and largely controls groundwater movement in the Mackenzie Plain. However, karst processes are dominant in the Franklin Mountains, and these also influence the adjacent Mackenzie Plain, by maintaining all-year flow in spring-fed rivers and streams. Karst features include sinkholes and perennial springs, some with high discharge rates.

Spring flow rates were rarely provided in previous studies, but some reported flow rates were lower than 1 L/min (Michel 1977). During the 2002 mid-August to mid-September survey, the larger springs in the area, and springs that were considered perennial, were examined. The location of winter icings and open water provided some evidence of spring locations and whether the springs were perennial.

During the 2002 mid-March to mid-April survey, 20 watercourse crossings were checked between Payne Creek, RPR-215, and Steep Creek, Site 464. Four watercourse crossings north of Chick Lake were bored with an auger. No water was located at RPR-221 at Tieda River (see Figure 4-26). Two other streams, Payne Creek, RPR-215 and Snafu Creek, RPR-258, had some water beneath ice, though no flow could be detected. Flow of 0.4 m^3/s beneath an ice cover of 0.43 m was detected at Loon River, RPR-232. All four of these stream channels, including Loon River, were snow-covered during the fieldwork. No open water was observed and one small icing on Snafu Creek was detected. In addition, no icings or open-water areas were observed on any other streams between Payne Creek and Chick Lake.

Two spring areas in the pipeline corridor were examined on the ground in early October 2003. Flights over a large area of forested terrain between Chick Lake and Norman Wells showed evidence of thawing of the shallow permafrost in response to a forest fire in July 2003. Evidence of permafrost degradation included disturbed vegetation, and active layer detachment slides, along the edges of lakes, ponds and streams.

From Chick Lake south, evidence of perennial groundwater inflow to streams was reflected in areas of open flowing water, polynya and many ice buildups along the streams. Of 20 crossings examined, 16 were bored with an ice auger. Flow rates ranged from 1 m^3/s at Donnelly River, Site 320, which drains Chick Lake, to 0.16 m^3/s at Vermilion Creek, Site 392. A flow rate of 0.47 m^3/s was measured at Steep Creek, Site 464, and 0.41 m^3/s was measured at Gibson Gap Creek, Site 326. These streams are discussed in more detail later in this section.

Massive ice buildups, which were more than 1.58 m thick and too thick for the auger equipment to penetrate, were encountered at three crossings:

- Hanna River, Site 336
- Canyon Creek, Site 380
- Helava Creek, Site 384

At the remaining nine crossings examined, the following observations were made:

- six streams were frozen to the bottom of the watercourse at the crossing locations
- one stream had an open space beneath ice with no water, suggesting that groundwater flow to the stream at the point of measurement is negligible
- one stream had standing water beneath ice
- one stream had water beneath ice, with slight to negligible flow

From about midway between the Snafu Creek crossing, RPR-258, and Chick Lake, south to the southern end of the Sahtu Settlement Area, the pipeline corridor crosses streams with either short drainage systems originating in the nearby Franklin Mountains, or with longer drainage systems in carbonate karst terrain. The carbonate strata of the Franklin Mountains and associated ridges are susceptible to karstification, and many karst features, such as sinkholes and perennial springs, are found in this area. Carbonate strata and karst features are also common in the area east of the Franklin Mountain belt.

North of Gibson Gap – Loon River and Donnelly River

North of Gibson Gap, winter stream flow was observed in the Loon and Donnelly rivers. The Donnelly River flows through Chick Lake from the Franklin Mountains and into the Mackenzie River.

The Loon River watercourse crossing, RPR-232 (see Figure 4-27), was snow-covered in early April 2002 and no icings were observed. There has been no investigation of karst features and there are no reported springs in this area. The stream valley is underlain by shale of the Middle Devonian Hare Indian Formation, with a small area of the underlying Hume Formation limestones at Rond Lake. The drainage system incorporates several lakes. These include Loon Lake, leading upstream on one branch to Manuel Lake and to Rorey Lake, Rond Lake and Carcajou Lake on the other branch. Loon Lake is about 10 km upstream of the crossing. The absence of observed springs or icings in the Loon River watercourse suggests that winter flow might result from lake storage.

A thick carbonate sequence of the Hume and Bear Rock formations and older carbonates is present at relatively shallow depth along the Loon River valley. The Cambrian Saline River Formation is present at greater depth, and is about 150 to 350 m thick (Pugh 1993). Halite and other evaporites in the Saline River Formation and evaporites in the Bear Rock Formation are readily dissolved by groundwater, which infiltrates down through fractures, enlarged by dissolution, in the overlying carbonates. Dissolution of underlying salt and evaporites can then lead to karst collapse structures developing in the overlying carbonates. Groundwater flow through karst terrain could constitute a major source of inflow to lakes in the area, such as Chick Lake, and could in turn contribute to lake outflow.

Duk-Rodkin and Hughes (1995) suggested preglacial drainage occurred along the Loon River. If preglacial sands and gravels occur along the valley in substantial thickness, they could provide an avenue for subsurface drainage along the valley.

The Donnelly River crossing (Site 320) is near where the river drains from Chick Lake (see Figure 4-28). Chick Lake is near the northern end of the Franklin Mountains in a synclinal trough of Cretaceous sediments. Ridges of carbonate terrain occur to the north, at Mount Effie and its westward extension, and to the south at Gibson Ridge. This area lies partly within the limit of karst investigations done by van Everdingen (1981), who identified several springs and sinkholes in the area. It is likely that the lake receives inflow of karst groundwater that would contribute to lake outflow.

Gibson Gap Creek, Hanna River and White Sulphur Springs

Figure 4-29 illustrates the section of pipeline corridor that passes through Gibson Gap. Figure 4-30 is a more detailed map, illustrating some of the groundwater features in the Gibson Gap Creek and Hanna River area. Springs are abundant. Sinkholes, mapped by van Everdingen (1981), occur in a small area west of Gibson Gap that is characterized by many small lakes, some of which display the round outline characteristic of sinkholes. Figure 4-31 is an aerial photograph of the Hanna River and White Sulphur Springs area. The Gibson Gap Creek area is shown in more detail in Figure 4-32.

Springs were observed emerging from:

- bedding planes, directly
- fractures in limestone and dolomite
- the base of talus slopes

Spring water varied from fresh in Talus Spring, A10, with total dissolved solids content of 364 mg/L, to saline, in the Hanna tributary spring, A02-11, with total dissolved solids content of 10,412 mg/L.

Gibson Gap Creek had open flowing water when examined in early April 2002. This creek is fed by many springs and seeps, originating from carbonate rock in the gap. One of these, Spring A9 near Gibson Creek crossing, was examined on the ground. The spring had a measured discharge of 0.41 m^3/s. A sample collected from this spring returned a total dissolved solids concentration of 1,124 mg/L and a sulphate concentration of 606 mg/L indicating sulphate-type water. Springs on the east side of the gap feed into ponds and boggy ground, whereas springs farther upstream occur in heavily wooded areas. No large discrete spring outflows are apparent in this area, but many smaller springs and seeps appear to contribute to the flow of the creek.

In mid-April 2002, a small area of open water was observed on Hanna River, about a 3-km straight-line distance upstream of the proposed pipeline-crossing site. Extensive stream icings extended beyond the watercourse crossing. Ice at the crossing was too thick to penetrate with the auger. No discrete spring inflow could be seen from the air at the open-water area in April or September 2002, and no landings or foot traverses were made at the site. It is likely that small springs and seeps from one or both sides of the open-water area maintained the winter flow. The highly mineralized saline spring, A02-11, mentioned previously is located near the mouth of a small tributary to Hanna River, about 1 km from the watercourse crossing, RPR-285. However, in mid-September 2002, this spring had a discharge rate of about 0.5 L/s and would not have a substantial influence on total stream water chemistry.

The White Sulphur Springs area consists of at least six discrete spring outflows with adjoining seepage areas, located in a gap through a low ridge of the Bear Rock Formation. Several prominent sinkholes occur on higher land, 2 to 3 km east. These sinkholes might provide some of the infeed to the springs. The springs have highly mineralized, sulphate and chloride water, and feed into channels with visible yellowish-white saline mud flats on the edges.

Two samples, A03-24 and A03-24b, were collected from this area, in early October 2003. Water sample A03-24A was collected from the spring and was highly mineralized with a conductivity of 7.27 mS/cm. Sample A03-24B was collected from a stream downstream from the spring, and had a conductivity of 3.22 mS/cm. This sample was not as highly mineralized as the spring sample because of the contribution of muskeg outflow water to the stream.

Gibson Gap to Bosworth Creek

Figure 4-33 illustrates the stretch of pipeline corridor between Gibson Gap and Bosworth Creek. Springs investigated along this stretch originate at or near the base of ridges of the Norman Range of the Franklin Mountains. Examples of this type of spring can be found at the base of Brokenoff Mountain, Paige Mountain, Mount Thomas and Mount Morrow. Most springs feed into small lakes, ponds and bogs, which are part of the drainage systems of Gibson Gap Creek (Site 326), Hanna River (Site 336), Elliot Creek and Oscar Creek (Site 351).

Billy Creek and several small, unnamed crossing streams flow directly to the Mackenzie River. These streams are fed by many springs issuing from the Norman Range to the north. In the 13 springs examined, i.e., springs A9 to A21, measured or estimated discharge rates varied from 0.5 L/s to 27 L/s in September 2002. Winter flow rates are likely to be less, because of icings and freezing, and most outflow from springs in winter will not reach the receiving streams. The importance of these spring outflows depends on their total contribution to receiving lakes or streams. For example, the springs in Gibson Gap provide sufficient volume to keep Gibson Gap Creek open in winter. However, the springs at the base of Brokenoff Mountain are sufficiently far from the eventual receiving stream, Hanna River, that most of their outflow is not expected to reach the river.

In early October 2003, Sample A03-29 was collected from a small discrete outflow from a mounded spring, near Gibson Gap Spring. The mounded spring is part of a large mound-like seepage area, quaking in places. Quaking ground refers to a condition where the pore pressure of discharging groundwater in a waterlogged soil causes soil particles to become partially suspended. This condition is referred to as quicking. Over time, soil development and vegetal growth might stabilize the surface of the quick ground. Once this has occurred, any disturbance of the surface, e.g., walking on it causes the ground surface to shake and ripple (quake) outward from the disturbance.

Some light yellowish-tan, fine-grained carbonate was observed along the channel. The sample was only moderately mineralized, with a specific conductivity of 1.8 mS/cm and total dissolved solids content of 1,630 mg/L. This site showed evidence of precipitation of calcium carbonate from solution, possibly from the loss of dissolved carbon dioxide as the groundwater issued from the spring. Dominant ions in the water were calcium and, to a lesser degree, magnesium and carbonate. Streams issuing from these springs were characterized by green, filamentous algal growth near the discharge point.

Gypsum Canyon Spring (A12) was sampled in mid-September 2002. Groundwater from this spring is calcium sulphate type, and is moderately mineralized with a total dissolved solids content of 1,724 mg/L. Boggy Springs (A13) and Boggy Sulphur Springs (A14), about 6 km southeast, likewise yielded calcium sulphate-type groundwater, moderately mineralized with a total dissolved solids content of 1,640 mg/L and 1,256 mg/L. Groundwater from Tufa Cone Springs (A15) is calcium sulphate type, with a total dissolved solids content of 2,024 mg/L. Four additional springs, Iron Sinter Springs (A16), an unnamed spring (A17), Oscar Creek spring (A18) and Bosworth Creek spring (A22), also yielded calcium sulphate water, although with a lower level of mineralization than Tufa Cone Springs.

The two Billy Creek springs, A19 and A20, and the Tufa Mound Spring, A21, yielded groundwater of calcium carbonate type, with a lower level of mineralization than that seen in the four calcium sulphate springs, noted previously.

Bosworth Creek

Although Bosworth Creek, Site 371 (Figure 4-34) was frozen to the bottom at the crossing when bored with an auger in early April 2002, there was about 800 m of upstream open water, followed downstream by polynyas that extended almost to the proposed pipeline crossing site. The stream was snow-covered downstream of the crossing and no icings were seen. One hole was bored at the 15-m wide proposed channel crossing. The boring encountered water and it was considered likely that there was flow along the streambed. Many sinkholes occur in the headwaters area of the stream.

Bosworth Creek was sampled in mid-September 2002, and analysis showed that the surface water was calcium carbonate type, with a lower degree of mineralization than Bosworth Creek Springs, A22 and A22b. This indicates that the stream flow is partially derived from shallow groundwater and possibly some surface water input, in addition to the Bosworth Creek Springs contribution.

Canyon Creek to Vermilion Creek

For 35 km southeast of Norman Wells, the pipeline corridor crosses six streams with headwaters in the Norman Range. The creeks are (see Figure 4-35):

- Canyon Creek (Site 380)
- Francis Creek (Site 382)
- Helava Creek (Site 384)
- Christina Creek (Site 385)
- Prohibition Creek (no crossing number assigned)
- Vermilion Creek (Site 392)

Figure 4-36 shows Vermilion Creek in more detail. The crossings of all these streams, except Prohibition Creek, were bored with an auger in early April 2002. Stream conditions were as follows:

- Christina Creek was frozen to the bottom

- Francis Creek had standing water below a thin ice cover

- ice on Canyon and Helava creeks was more than 1.58 m thick and could not be penetrated by the auger

Springs from the base of the Norman Range have been reported in upstream sections of Canyon, Francis and Prohibition creeks at distances of 4 to 6 km from the pipeline corridor (Michel 1977). One of the two springs upstream of Prohibition Creek was reported by Michel (1977) to have a discharge rate of 4 L/s. This spring, A28, was visited in mid-September 2002, when a discharge rate of 2.2 L/s was measured. The spring was sampled, and the water found to be calcium sulphate type, with total dissolved solids content of 1,712 mg/L. Previously reported upstream springs on Canyon and Francis creeks could not be located from the air during the survey, and because of the distance from the pipeline corridor, no ground traverse was attempted. As a result, discharge rates for these reported springs are not available.

Icings were noted in early April 2002 at the crossings at Canyon, Francis and Helava creeks. Extensive upstream icings were noted the same day on Francis, Helava and Christina creeks, indicating spring discharge into these watercourses.

Christina Creek Spring and Helava Creek Spring were both sampled in mid-September 2002. The water quality of these springs is similar. Both springs yield calcium carbonate-type groundwater with total dissolved solids content of 292 mg/L and 315 mg/L.

Prohibition Creek was snow covered at the crossing and as far as could be detected upstream and downstream. Consequently, no flight was made along the creek. The ice levels at the Canyon Creek crossing were estimated to be 1.5- to 2-m higher than downstream of the Enbridge pipeline. Wet slush and some water lay on the surface of the ice in places, upstream and downstream of the crossing. The ice buildup at the Enbridge pipeline corridor most likely occurred because of stream flow blockage at the crossing. The thick ice buildups suggest that there is some winter flow at these watercourse crossings.

Vermilion Creek

Vermilion Creek has a relatively small surface drainage area, smaller than 150 km^2. It originates in the nearby Franklin Mountains, in Devonian and older carbonate sediments. Numerous sinkholes occur in the upper reaches of Vermilion Creek and were mapped by van Everdingen (1981). Four sinkholes are located along the creek near the head of winter open water.

Sinkholes and large perennial freshwater springs occur at Vermilion Creek. The springs along this creek keep it ice free all year. The combined discharge rate of springs on Vermilion Creek has been reported to probably exceed 180 L/s (van Everdingen 1973b). Other streams along this stretch of the pipeline corridor also have karst spring inflow and maintain ice-free stretches of open water. In early April 2002, Vermilion Creek had about 2 km of winter open water, with polynyas extending downstream from the proposed pipeline crossing. Large perennial springs near creek level feed the open-water areas.

The main springs at Vermilion Creek, identified as A27 and A27b, were sampled in mid-September 2002. The groundwater was moderately mineralized, with total dissolved solids content of 2,324 mg/L and with calcium the dominant cation and sulphate the dominant anion. The water of Vermilion Creek is expected to possess a lower degree of mineralization in the spring than in the fall, because of the inflow of relatively pure water from spring snowmelt.

The upstream parts of Vermilion Creek drain carbonate terrain, but the springs exit from the shale of the Upper Devonian Canol Formation. Groundwater flow originating in sinkholes in the upper reaches of Vermilion Creek would pass through carbonate rocks initially, then through the overlying shale of the Middle Devonian Hare Indian Formation, and finally through the Canol shale before exiting at the surface. Dissolution at depth of evaporites from the Cambrian Saline River Formation is possible, and would add to the total dissolved solids and sulphate content of the water. The Vermilion Creek springs display a higher than normal water temperature, suggesting that the groundwater discharging from the springs has followed a relatively long, deep flow path before making its way to the surface. Michel (1977) suggested a possible penetration depth of at least 200 m.

Nota Creek to South Boundary of Sahtu Settlement Area

Nota Creek (Site 393) and Jungle Ridge Creek (Site 396) were both snow-covered in mid-April 2002 when they were bored with an auger, and no icings were seen. The unnamed creek at Site 409 (see Figure 4-37) between Jungle Ridge Creek and Big Smith Creek was bored with an ice auger and was frozen to the bottom.

Michel (1977) recorded two upstream springs labelled as M and M58 in Figure 4-38, within 1.5 and 2.5 km of the Big Smith Creek crossing, but discharge rates were not recorded. Icing was observed at the Big Smith Creek crossing (A03-23), but the site was not inspected on the ground.

Little Smith Creek and Saline River, 10 km southeast of Little Smith Creek crossing were snow-covered at the crossings and no icings were seen. Michel (1977) reported a large spring (M57) flowing at 93 L/s upstream of the Little Smith Creek crossing (Figure 4-39). This spring was nine to 10 km northeast of the crossing, and had low mineralization, with total dissolved solids of 365 to 476 mg/L.

A small tributary stream flows into Little Smith Creek from the northwest about 1.5 km north of the crossing. This stream runs parallel to the Enbridge pipeline for about 2 km, about 500 to 600 m east of the pipeline. This stream had open flowing water in early April 2002. Examination of the banks in mid-

September 2002 revealed the presence of many small springs in the upper part of the heavily wooded west bank. One of these springs was examined and sampled. Its flow rate was 0.25 L/s and total dissolved solids content was 276 mg/L. This spring appeared to be representative of other springs along the bank. Its high location on the bank suggested possible flow from the active layer. However, winter flow in the stream might indicate that flow was from unfrozen layers in the bank, possibly from granular materials that could have a hydraulic connection to an unnamed linear lake about 2.5 km northwest of the nearest point on the stream.

Steep Creek

Steep Creek (Site 464) has a surface drainage area of less than 150 km^2. It originates in the nearby Franklin Mountains, in Devonian and older carbonate sediments. To date, no karst features have been mapped near Steep Creek, but the topography suggests that sinkholes might exist in the headwaters area (see Figure 4-40).

During the 2002 mid-March to mid-April survey, Steep Creek had about 2 km of open water, with polynya extending downstream from the pipeline crossing. Large perennial springs near creek-level feed the open-water areas, and Steep Creek was observed to have a considerable perennial water flow of 0.47 m^3/sec.

The Steep Creek springs, A24, A24b and A24c, were sampled September 17, 2002. Water from the springs has a moderate to low level of mineralization, with total dissolved solids content of 452 to 472 mg/L and is primarily calcium carbonate type, with sulphate being the secondary anion.

The differences in water quality and temperature between Steep Creek and Vermilion Creek, discussed previously, are believed to result largely from the rock type through which the water flows before emerging at the spring, and possibly the length and depth of the groundwater flow path. The springs at Steep Creek exit from carbonate rocks. The entire drainage basin is underlain by carbonate rocks, chiefly dolomitic, of the Ordovician–Silurian Mount Kindle Formation and the Middle and Lower Devonian Bear Rock Formation.

4.3.4.3 Deh Cho Region

In the Deh Cho Region, as far south as Willowlake River, the pipeline corridor runs through the Franklin Mountains and the Mackenzie Plain Physiographic Region. South of Willowlake River, the pipeline traverses the Great Slave Plain as far south as Trout Lake. From Trout Lake to the southern terminus of the pipeline in Alberta, the pipeline corridor passes through the Alberta Plateau. As noted in the discussion of the Sahtu Settlement Area, karstic features are an important controller of groundwater flow in the Franklin Mountains, and these features also influence stream flow in the adjacent Mackenzie Plain, by maintaining all-year flow in spring-fed rivers and streams. Karstic features include sinkholes and perennial springs, some with high discharge rates.

As noted previously, permafrost in the Franklin Mountains is not an important determinant of groundwater flow. In the Mackenzie Plain, permafrost varies from extensive discontinuous to intermediate discontinuous and largely controls groundwater movement, with the possible exception of places where the adjacent karst terrain to the east affects groundwater discharge. In the Great Slave Plain and the Alberta Plateau, both of which fall in the zone of sporadic discontinuous permafrost, groundwater recharge and lateral flow is expected to be generally very slow because of the low permeability of the thick morainal deposits (glacial till) that overlie bedrock in the area. The land surface in both these physiographic regions is flat and is characterized by poor drainage. Peat and muskeg deposits are common.

Twenty-seven springs were examined on the ground in the Sahtu Settlement Area during the summer to fall survey of 2002. Samples were taken at 23 of these 27 springs, i.e., A9 through A30. Three additional samples were collected in 2003.

During the 2002 mid-March to mid-April survey, 20 watercourse crossings between Dam Creek (RPR-381) and Kakisa River (Site 644) were assessed. All these watercourse crossings, except at Willowlake River (Site 544) were inspected on the ground, bored with an auger if frozen and sampled. Because of difficulty in access, the Willowlake River crossing (Site 544) was inspected from the air only. All 20 watercourses and many other streams were assessed from the air upstream and downstream of the proposed pipeline crossings. Areas of open water, springs and icings were mapped. Most streams inspected were frozen to the bottom.

The streams between the northern boundary of the Deh Cho Region and Willowlake River originate in the Franklin Mountains, which are immediately east of the pipeline corridor. Carbonate rocks predominate in the mountain belt, and karst features are common. Perennial springs related to karstification would be expected upstream of, and along this part of the pipeline corridor.

In the White Sand Creek area, and between the Ochre River and Smith Creek, the pipeline corridor is parallel to, and immediately west of, the McConnell Range of the Franklin Mountains. Collapse features caused by dissolution of halite and evaporites at depth in the Saline River and Bear Rock formations are expected along this stretch of the pipeline corridor. Precipitation on the McConnell Range will enter fractures and sinkholes caused by collapse and will cause additional dissolution of the carbonate rocks. This will increase the ability of these rocks to transmit water. Water will percolate downward and move preferentially through these rocks until it discharges from springs at the base of the mountains. These springs are mainly perennial, so icings might extend substantial distances along the stream channels. Icings were observed on crossings between Smith Creek and

River Between Two Mountains, even though the pipeline corridor is about 5 km away from the base of the Franklin Mountains in this area. Where the pipeline corridor is closer to the base of the range between White Sand Creek and Smith Creek, open water might be observed in some streams close to the outlet of the source spring.

South from Smith Creek, the pipeline corridor veers away from the Franklin Mountain front. Although icings were common in this stretch of the pipeline corridor, only one spring was identified. This spring, A62, was inspected and sampled. Located immediately downstream of the pipeline corridor, it appears to drain a large area of glaciofluvial sand and gravel. Icings were observed.

From Willowlake River south to the Alberta boundary, the terrain is relatively flat. Bedrock beneath the drift cover is mostly Devonian to Cretaceous shale. Carbonates occur only over a short stretch between Jean-Marie Creek (RPR-475) and Trout River (RPR-479). Karst features and springs are not numerous in the southern part of the Deh Cho Region, except possibly between Jean-Marie Creek and Trout River. This southern part is in the region of discontinuous permafrost so that groundwater additions to stream flow from unfrozen surficial materials or buried granular sediments in the drift might be expected.

The 2002 mid-March to mid-April survey was followed by additional fieldwork in mid-August 2002, which checked previously reported spring locations and evidence of groundwater inflow in areas of winter open water and icings. Most of the 13 springs visible from the air were field-inspected during this survey. The rate of spring discharge was estimated or measured, dissolved oxygen was measured and a sample was collected for major ion analysis. A few additional springs were observed, but it was not possible to land nearby.

The pipeline corridor in the Deh Cho Region does not pass near any of the main landslide areas along the Mackenzie Valley mapped by Aylsworth and Traynor (2001). However, smaller, unmapped slides are locally present near some of the proposed watercourse crossings. These remain largely unclassified.

Blackwater River

Blackwater River crossing (see Figure 4-41) was not inspected during the winter survey. Local residents report that icings are common along the river in the winter. Michel (1977) reported many springs, e.g., springs M50 to M53, along the Blackwater River and a northern tributary. Several springs along the northern tributary were observed from the air.

In mid-August 2002, two springs, A51 and A52, on the Blackwater River were inspected. Both springs originate over a wide low-lying area at the base of a low cliff. Flow collects in several small creeks and then discharges into the Blackwater River. Carbonates of the Nahanni Formation and carbonates and evaporites of the Bear Rock Formation are exposed. The location of springs in this area is probably structurally controlled, because many are adjacent to south-plunging anticlines or west-dipping thrust faults. Two samples were collected from these springs. The water quality of the two samples differed. The sample from A52 had about twice the total dissolved solids content of the sample from A51. The sample from A51 is essentially calcium-magnesium bicarbonate water, whereas the sample from A52 is sodium chloride and sodium sulphate type.

Flow rates were measured at these two springs in mid-August 2002. Spring A51 had a measured discharge of about 0.1 m^3/s and spring A52 had a measured discharge of about 0.1 m^3/s. These measured flow rates are probably underestimates, as the flow could not be measured at all creek outlets. Previously measured flow rates from springs on the northern tributary totalled 0.26 m^3/s (Michel 1977). Groundwater quality reported by Michel (1977) was variable in these springs, with total dissolved solids ranging from 634 to 2,133 mg/L, dissolved oxygen from 3.1 to 4.2 mg/L, and temperatures ranging from 1.5 to 3°C.

Blackwater River to Willowlake River

Six watercourse crossings were investigated in the Blackwater River to Willowlake River area in mid-April 2002. The following three northernmost crossings inspected were frozen to the bottom:

- Dam Creek (RPR-381)
- White Sand Creek (Site 488)
- a southern tributary of White Sand Creek (Site 491)

At the White Sand Creek crossing and a tributary crossing about 7 km south (sites 488 and 491) (see Figure 4-42) icings were evident and there was substantial water on the ice surface. On White Sand Creek, the icing extended upstream and downstream for about 1 km from the crossing. Farther upstream, stretches of open water originated at several seeps in the banks. Springs on White Sand Creek are located along an east-dipping fault in the Bear Rock Formation and are probably structurally controlled. During the 2002 mid-August to mid-September survey, no seeps upstream of White Sand Creek or tributary crossings were identified. Michel (1977) inspected two springs, M40 and M42 along White Sand Creek. Total dissolved solids content of 340 to 425 mg/L and temperatures from 1.5 to 4°C were reported. Based on winter observations, groundwater flow could provide local areas of winter open water along White Sand Creek.

Another spring, A54, is located on a small lake upstream of the pipeline corridor. This spring was designated Spring 41 by Michel (1977) who reported a discharge of 0.020 m^3/s.

Icing was observed on the Ochre River (Site 495) during the 2002 mid-March to mid-April survey, extending 0.5 km upstream to 1 km downstream of the crossing. Stretches of open water associated with seeps in the banks were identified upstream of the crossing. Substantial flowing water was seen beneath the ice. No springs were identified from the air along the Ochre River during this survey. Upstream from the site on the Ochre River, Spring M39 was inspected by Michel (1977). It was saline with a temperature of 18ºC. No discharge rate was given.

Hodgson Creek (RPR-399) had open water above the crossing and a measured flow rate of 0.2 m^3/s. Spring M31 was identified and inspected upstream of this crossing during the 2002 mid-March to mid-April survey. Its flow rate was estimated as 0.003 m^3/s. Michel (1977) previously measured it at 0.02 m^3/s. Michel (1977) also reported total dissolved solids concentrations of 421 to 466 mg/L and temperatures from 2 to 4.8°C. A dissolved oxygen content of 2.2 mg/L was measured in mid-August 2002. A sample collected at that time had a total dissolved solids content of 320 mg/L. The difference between this value and the value determined by Michel (1977) indicates that water quality in the spring is seasonably variable. Groundwater is expected to provide substantial winter flow into Hodgson Creek.

During the winter survey, many icings, some stretches of open water and several flowing springs were observed on the creeks along the pipeline corridor between Hodgson and Smith creeks. Several of these small creeks are expected to be primarily groundwater fed and might be open during winter. Other streams probably have groundwater recharge, which will cause winter icings. These creeks flow into Hodgson Creek downstream of the crossing. Because of the small size and low flow of these creeks, they are unlikely to remain open over winter.

Four water samples, A02-55 through A02-58, were collected in mid-August 2002 from springs feeding Hodgson Creek and one of its tributaries. These groundwater samples are all similar chemically, having moderately low total dissolved solids content, with calcium the dominant cation and bicarbonate the dominant anion.

An icing was observed downstream of the crossing on Smith Creek during the 2002 mid-March to mid-April survey (see Figure 4-43). During the mid-August to mid-September survey, springs M25 and M26, reported by Michel (1977), were inspected. Flow rates from these springs were low and the chemistry was variable. Three samples were collected in mid-August 2002 from Spring A59, which feeds a northern tributary of Smith Creek, Spring A60 (same as M26) and A61, near M27. The samples had a low to moderate degree of mineralization, based on the specific conductivity and total dissolved solids data. However, the sample from A61 had a considerably higher sodium concentration than the other two samples. This indicates that considerable variation in chemistry can occur in springs located a short distance from one another. The low flow rate of these springs results in icings along Smith Creek.

In mid-July 2003, a further sample, A03-8, was collected from a spring feeding Smith Creek near the crossing. This sample was taken from a wet area at the base of a sloping bank. The area was a broad, boggy area with standing shallow ponds, and water bubbled from the ground into pools in many places. Some of the seeps at this location were characterized by iron staining. The sample was moderately mineralized, with a specific conductivity of 3.4 mS/cm, and a total dissolved solids content of 2,200 mg/L. The iron concentration was 0.61 mg/L, which is high enough to result in some iron staining when the spring water becomes oxygenated at the surface.

River Between Two Mountains, Site 534, had a flow rate of 3.3 m^3/s. One spring, M, was reported by Michel (1977), but was not inspected in 2002, because it was located about 8 km upstream of the crossing.

In mid-July 2003, a sample was collected from a small, deep, circular lake, possibly a sinkhole, a short distance north of the River Between Two Mountains crossing (sample location A03-10). Analysis of the sample revealed a low degree of mineralization, with a specific conductance of 0.237 mS/cm and a total dissolved solids concentration of 136 mg/L. The dominant dissolved ions were calcium and bicarbonate. This low degree of mineralization could be because this small circular lake is a point of groundwater recharge, where the standing water in the lake has not been in contact with soluble minerals for a long time, and the water has not had time to dissolve the mineral material before it infiltrates into the ground.

An unnamed spring, A62, about 5.5 km south of the River Between Two Mountains crossing was sampled in mid-August 2002. This was calcium carbonate-type groundwater, with a low to moderate degree of mineralization. Farther south, Spring A63 was also sampled in mid-August 2002 (Figure 4-44). This spring, which is about 4 km north of Willowlake River (Site 544), was more mineralized, with a specific conductivity of 1.02 mS/cm. This spring also had a considerably higher sodium concentration than Spring A62, and a higher sulphate concentration, which placed this water in the calcium sulphate category.

Only one community, Wrigley, near the pipeline corridor actively uses groundwater as an all-year water source. Wrigley has relied on water supplied from a well for over 20 years. The well extracts water from a subpermafrost source beneath a permafrost thickness of 40 to 50 m (Smith et al. 2001). A deeper well was drilled for the community in about 1970, but the water was found to be saline, with a chloride concentration of 539 to 573 mg/L chloride, and unsuitable for community use (Mollard 1972; Michel 1977). The well was 48.8 m deep and was capable of producing at a rate of 0.92 L/sec. This indicates that groundwater quality can vary a great deal with depth at any given location, depending on the distance it has travelled from its point of recharge, and the type of geological material it has contacted. Generally, groundwater that has recharged the subpermafrost zone by way of a through talik in the area, perhaps beneath a river or lake, can be expected to be of higher quality than groundwater derived from discharge from a deeper aquifer.

Willowlake River

Springs upstream of the Willowlake River crossing, Site 544, e.g., Spring A64, and near Site 543, Spring A63, north of Willowlake River, illustrate the structural control on some of the springs in the northern part of the Deh Cho Region. Both spring areas are located on the crests of anticlines. A thrust fault was mapped at Spring A63 (Douglas and Norris 1961). A fault might also exist at the Spring A64 location (Michel 1977). These south-plunging anticlinal ridges mark the southern limit of the Franklin Mountains. Bell Ridge is just north of Spring A63 and Willow Ridge is north of Spring A64. Limestones of the Middle Devonian Nahanni Formation, Hume Formation equivalent, cap the south end of these ridges. Slightly farther north, the Lower Devonian Bear Rock Formation is exposed along the anticlinal folds. The Bear Rock Formation in this area consists of brecciated (broken) limestone and dolomite.

Topographic maps show many closed depressions in the Bear Rock Formation along Bell Ridge, which are interpreted as karst solution sinkholes. These depressions do not appear to retain surface water. It is likely that the depression bottoms are highly porous and would readily absorb rainfall and snowmelt water. This water would then flow through fractures in the formation to exit at some point, possibly feeding into nearby lakes and ponds. Most flow might follow a longer, deeper path to exit at locations such as Spring A63.

The Bear Rock Formation has long been recognized as being extremely porous. Aitken et al. (1982) described this porosity and the sinkholes in this formation:

> *"Outcrops of the Bear Rock Formation have been affected profoundly by solution. The widespread occurrence of active sinkholes along the trace of the Bear Rock and in places the overlying Hume Formation testifies to the presence of evaporites undergoing solution beneath the surface."*

Near Spring A63 there are a group of springs, seeps and ponds (see Figure 4-45). Flow is perennial, confirmed by open water in mid-April 2002. In mid-August 2002, outflow measurements were made from three component springs as follows:

- A63a – 0.15 m^3/s
- A63b – 0.04 m^3/s
- A63c – 0.02 m^3/s

The water was not highly mineralized, with total dissolved solids content of 756 mg/L. This data can be compared with a total outflow estimated to exceed 0.166 m^3/s in 1973 and 1975 (Michel 1977) and variable water chemistry at the various spring flow outlets, where total dissolved solids ranged from 675 to 6,945 mg/L. The variability of water chemistry from different springs in this area is striking. It probably indicates varying flow path lengths and depths, and varying degrees of water freshening from the active layer.

The Spring A64 area along Willowlake River, about 5 km upstream of Crossing 544, was documented by van Everdingen (1973a) and Michel (1977) and was visited during this study in mid-August 2002. Michel (1977) reported that the springs are expressed as a row of small ponds 50 m apart. Individual discharge rates ranging from about 0.015 to 0.075 m^3/s were reported by van Everdingen (1973a). Michel (1977) cited a total discharge for the entire group of springs of 0.002 m^3/s. This might have been a misprint, as the total outflow reported by van Everdingen (1973a) would have been close to 0.1 m^3/s.

Discharge at the outlet of one small pond with water bubbling up from the bottom was measured in mid-August 2002 at about 3.4 L/s. Adjacent marshy areas might represent the other ponds reported by Michel (1977). The water had total dissolved solids content of 2,320 mg/L and sulphate concentration of 1,400 mg/L.

Spring A64 was sampled in mid-August 2002. The water was calcium sulphate type, with a moderate degree of mineralization indicated by a specific conductivity of 2.38 mS/cm and total dissolved solids content of 2,320 mg/L.

According to Michel (1977), water temperatures ranged from 9.5 to 12°C at the Spring A64 area and from 1.5 to 11.8°C at the Spring A63 area. These temperatures and the degree of water mineralization suggest a relatively deep flow system feeding the springs. Michel (1977) calculated a minimum depth of penetration of the spring waters of about 400 m, assuming a subsurface temperature of 0°C and a geothermal gradient of 3°C per 100 m.

South of Willowlake River

Four crossings were inspected between Willowlake River and Trail River, Site 585, and all were found to have negligible winter flow. Crossing RPR-430, an unnamed stream, was snow-covered and frozen to bottom. The other two crossings, 567 (see Figure 4-46) and 585 (see Figure 4-47) were frozen to the bottom, or dry beneath the ice. In the area between the Harris River (Site 594) (see Figure 4-48) near Fort Simpson, and the Kakisa River (Site 644) near the Alberta boundary, four of the 10 crossings inspected had measurable flow below the ice cover as follows:

- Harris River (Site 594) – 0.02 m^3/s

- Manners Creek (Site 601) – 0.16 m^3/s
- Jean-Marie Creek (RPR-475) (see Figure 4-49) – 0.16 m^3/s
- Site 614 (see Figure 4-50) – standing water below ice
- Trout River (RPR-479) – flow not measured as water flowing over the ice made conditions unsafe
- RPR-483 – standing water below ice
- RPR-487 – standing water below ice
- Site 636 (see Figure 4-51) – standing water below ice
- Kakisa River (Site 644) (see Figure 4-52) – 0.54 m^3/s

Areas of open water were also observed on the Kakisa River.

The Trout River spring (A66) was sampled in mid-August 2002. Groundwater from this spring is calcium bicarbonate type, with a moderately low degree of mineralization indicated by specific conductivity of 0.403 mg/L and total dissolved solids content of 312 mg/L.

Winter flow south of Willowlake River was largely attributed to drainage of unfrozen surficial materials. Karst features could provide groundwater flow to Jean-Marie Creek and Trout River where carbonate strata occur. A limestone canyon immediately upgradient of Site 612 was inspected. However, no springs could be located from the air because of the narrowness of the canyon. No other areas of limestone outcrop were noted. The topography is low and the ground is covered by extensive vegetation. No springs or seeps are reported in this area.

4.3.4.4 Northwestern Alberta

In March 2002, 12 crossings between sites 701 and 744 were inspected. Seven were checked on the ground, bored with an auger and sampled. Five of the streams were inspected from the air only. No channel could be identified in these five streams because of the thick snow cover, low topography and narrow channel width. Four of the seven streams inspected on the ground had water present below the ice but no flow. Site 702 is shown in Figure 4-52 and site 737 is shown in Figure 4-53. The Kakisa River (Site 702) had a flow rate of 0.5 m^3/s. The Petitot River (Site 737) had a flow rate of 5.3 m^3/s. The unnamed stream at Site 744 had barely detectable flow. Patches of overflow ice were detected on the Kakisa and Petitot rivers. Polynyas were noted on the Kakisa River.

Borneuf and Pretula (1980) observed that in this area the water table was usually high and that upward groundwater flow gradients were expected near rivers and streams. Winter flow in the Kakisa and Petitot rivers is attributed to upward groundwater discharge from unfrozen surficial materials in these drainage systems. Drainage area and winter flow rates appear to have an excellent correlation, as exemplified by the Petitot and Kakisa rivers and watercourse Site 744.

Only one spring has been noted in this area. It is downstream of the crossing on the Kakisa River (Borneuf and Pretula 1980). No additional Hydrogeological investigations were completed in this area during the 2002 mid-August to mid-September survey.

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