Kiggavik Project

Final Environmental Impact Statement

Tier 3 Volume 5C:
Aquatics Baseline

September 2014

History of Revisions

Revision Number	Date	Details of Revisions
01	December 2011	Initial release Draft Environmental Impact Statement (DEIS)
02	September 2014	FINAL Environmental Impact Statement

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Abbreviations

Ba .... Barium
Ba-133 .... Barium-133 isotope
BIC .... Benthic Invertebrate Community
CCME .... Canadian Council of Ministers of the Environment's
CWQG .... Canadian water quality guidelines
ICP- MES .... Inductively coupled plasma atomic emission spectroscopy
ICP-MS .... Inductively coupled plasma mass spectroscopy
ISQG .... CCME Interim Sediment Quality Guidelines
LSA .... Local Study Area
Pb-210 .... Lead-210 isotope
Po-210 .... Polonium-210 isotope
PEL .... Probable Effects Levels
QA/QC .... Quality assurance/quality control
Rn .... Radon
Ra-226 .... Radium-226 isotope
SSWQO .... Saskatchewan Surface Water Quality Objectives
SRC .... Saskatchewan Research Council
Th-228 .... Thorium-228 isotope
Th-230 .... Thorium-230 isotope
Th-232 .... Thorium-232 isotope
TKN .... Total Kjeldahl nitrogen
TSS .... Total suspended solids
U .... Uranium

Units of Measure

Bq/L	Becquerel per litre
Bq/g dw	Becquerel per gram dry weight
ºC	degrees Celsius
cells/L	number of cells per litre of water
cm	centimetre
g/cm^2	grams per square centimetre
$g/m^2/y$	grams per square metre per year
km	kilometre
L	litre
m	metre
m^2	square metre
mg/m^3	milligrams per cubic metre
mg/g dw	milligrams per gram dry weight
$mgCaCO_3/L$	milligrams of calcium carbonate per litre
mg/L	milligrams per litre
mg N/L	milligrams of nitrogen per litre
mm	millimetre
mm^3/m^3	cubic millimetre per cubic metre
mm/y	millimetre per year
m/s	metres per second
µg/L	micrograms per litre
µg/g ww	micrograms per gram wet weight
µm	micrometre
µS/cm	microSiemens per centimetre
NTU	Nephalometric turbidity units
organisms/L	number of organisms per litre

organisms/m^3 .... number of organisms per cubic metre

pCi/L .... picoCurie per litre

pH .... pH units

1 Introduction

1.1 Overview

The objective of this baseline report is to provide information about the aquatic environment in the watersheds associated with the AREVA Resources Canada Inc. (AREVA) Kiggavik Project (the Project). This information will be used to assess potential effects of the proposed Project on the aquatic environment. The Project is a new uranium ore development, including open pits, underground mine, mill, and supporting infrastructure. The Project is located in the Kivalliq region of Nunavut about 80 kilometres (km) west of the community of Baker Lake (Figure 1.1-1).

This baseline report integrates information collected during various aquatic habitat investigations, including historical information from 1975, 1979 to 1980, 1986, and 1988 to 1991, and recent field studies undertaken from 2007 to 2010. In doing so, it presents the current understanding of the aquatic resources within the Project area.

This report is organized as follows:

- Section 2 describes the setting.
- Section 3 describes the study area.
- Section 4 presents methods and results for water quality.
- Section 5 presents methods and results for sediment quality.
- Section 6 presents methods and results for limnology.
- Section 7 presents methods and results for benthic invertebrate communities.
- Section 8 presents methods and results for the aquatic macrophyte chemistry.
- Section 9 presents methods and results for lower trophic communities (i.e., plankton).
- Section 10 presents methods and results for fish habitat.
- Section 11 presents the methods and results for fish distribution, fish health, and tissue chemistry.
- Section 12 presents a summary of the key baseline results.
- Section 13 presents references cited in this report.
- Section 14 presents a glossary of terms used in the report.

1.2 Purpose

The purpose of this baseline report is to describe the existing aquatic environment that may be affected directly or indirectly by the Project and to provide sufficient information to support the environmental impact statement. The scope of work for fish and fish habitat included field studies, literature review, and modelling. Field studies were conducted in fall 2007; spring, summer, and fall 2008; winter, spring, summer, and fall 2009; and spring and fall 2010. The objectives were to determine fish presence and use within the proposed Project area and to describe physical, chemical, and biological components of the aquatic environment in the watersheds of the proposed Project area.

1.3 Scope

This document provides a compilation of the available information for the aquatic environment in the Kiggavik Project area. The report integrates information collected during previous environmental assessments as well as the results of the sampling done for the current project.

The geographic extent of the Project covers three watersheds, including the Aniguq River, Thelon River, and Baker Lake (Figure 1.1-1). The majority of the proposed Project infrastructure is located in the Aniguq River watershed, with ancillary support facilities in the Thelon River watershed and Baker Lake watershed. Several of the watersheds have been separated into sub-basins as follows (Figure 1.3-1):

- The Aniguq River watershed, which includes the following sub-basins:
  - Judge Sissons Lake sub-basin, which has been further subdivided into Willow Lake, Lower Lake, Caribou Lake, and Boulder Lake sub-basins;
  - Siamese Lake sub-basin; and
  - Kavisilik Lake sub-basin, which has been further subdivided into Skinny Lake and the portion of the watershed extending from Kavisilik Lake to Long Lake.
- The Thelon River watershed, which includes the Squiggly Lake sub-basin.
- Baker Lake watershed, which for the purposes of the assessment, includes Baker Lake and the small tributary streams on the north side of the lake, which flow directly into the lake.

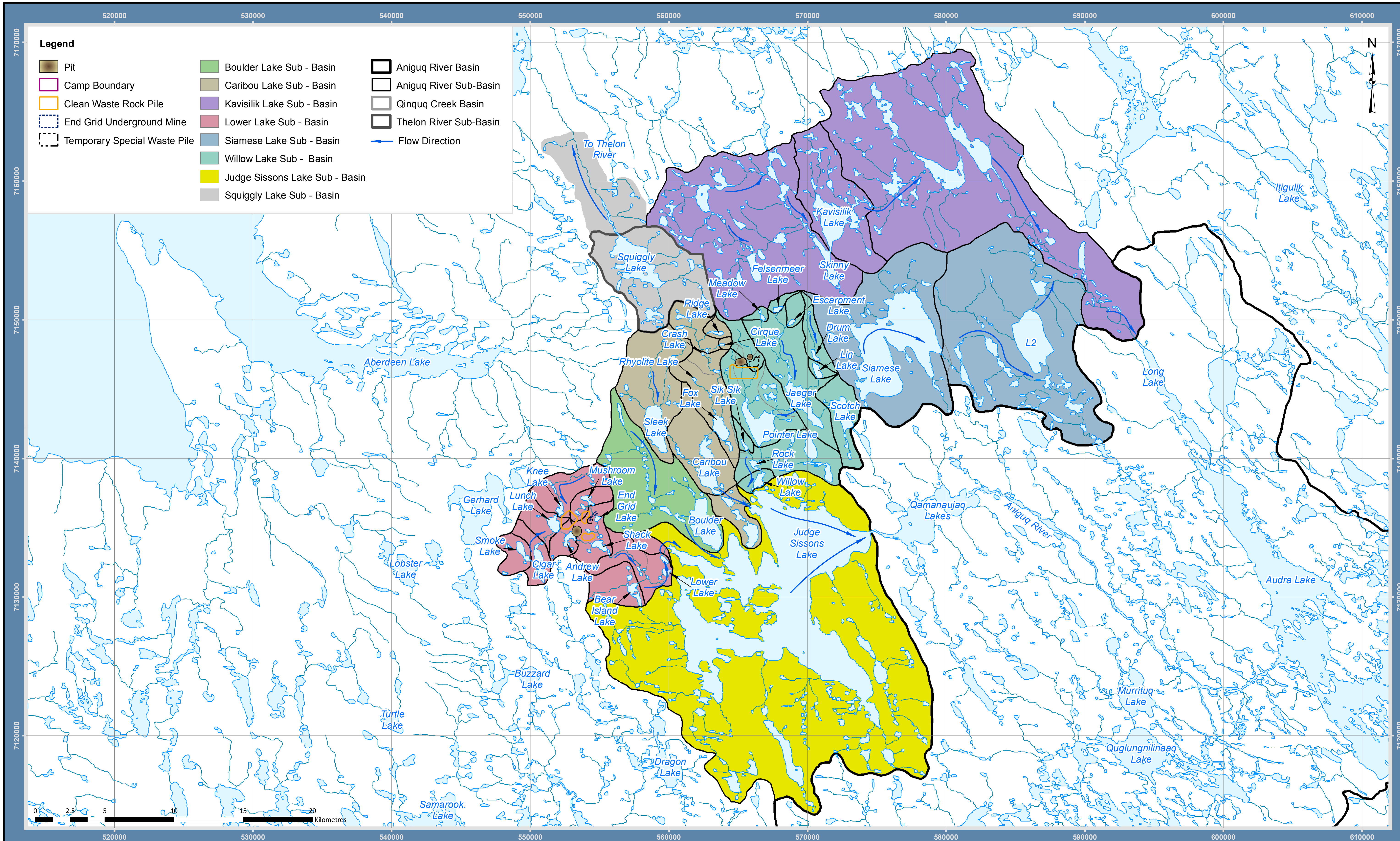
The aquatic sampling program evolved over time as the Project design and assessment basis developed. Field studies for the proposed Project development were carried out during the period of August 2007 to August 2010. The recent studies included assessments of the following components of the physical aquatic habitat and biological aquatic communities:

- physical aquatic habitat:
  - water chemistry in lakes and streams;
  - habitat assessment of lakes and streams;
  - dissolved oxygen, temperature, conductivity and pH measurements in lakes and streams; and
  - sediment chemistry and particle size in lakes;

- biological aquatic communities:
  - benthic invertebrate communities in lakes and streams;
  - macrophyte chemistry;
  - plankton communities including phytoplankton and zooplankton in lakes, and periphyton in streams;
  - fish community composition;
  - spring and fall spawning surveys;
  - fish movement patterns; and
  - fish tissue chemistry.

Various assessments of the aquatic environment have been undertaken over the history of the Project. The historical field studies were either carried out over a two year period (e.g., 1979 to 1980, 1988 to 1989, and 1990 to 1991) or in a single year (e.g., 1975 and 1986) (BEAK 1990, 1992a). A review of the available historical information was completed and to the extent possible, this information has been included in the aquatic baseline summary.

Golder Associates Limited (Golder) was retained by AREVA to undertake the aquatic baseline studies of lakes and streams in the local and regional study areas. Nunami Stantec was retained by AREVA to undertake baseline environmental studies related to the marine transportation route, which included Baker Lake. Therefore, to provide a comprehensive assessment of the freshwater aquatic environment, the information from both recent field studies has been compiled into this volume. This report presents the most current understanding of the aquatic environment in the Project area.



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Date: 19/02/2014 Scale: 1:250,000
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Data Sources: *NTS Mapsheet 56D, 66A, 66B*
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FIGURE 1.3-1
WATERSHED BOUNDARIES IN THE KIGGAVIK PROJECT STUDY AREA

KIGGAVIK PROJECT - EIS

Golder Associates
AREVA

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2 Setting

The Kiggavik Project is located within the physiographic region of the Canadian Shield and, as such, the land contains features formed by glaciation, including eskers and boulder moraines (Environment Canada 2009, internet site). The topography is gently undulating, and is filled with hummocks and patterned ground resulting from permafrost. Vertical drainage is impeded by the permafrost layer, and wetlands, small ponds, and lakes are common over the landscape. The Project is also located in the Southern Arctic terrestrial ecozone, which is characterized by continuous permafrost that may be present just a few centimetres below the surface (Environment Canada 2009, internet site). Low precipitation and extremely low winter temperatures prevent tree growth in this ecozone (National Resources Canada [NRCAN] 2004, internet site). Summers in the Southern Arctic Ecozone are cool and about four months in length. This ecozone is bounded to the south by the treeline and the Taiga Shield Ecozone and to the north by the Northern Arctic Ecozone, which includes most of the islands off the northern shores of Nunavut and the Northwest Territories, as well as the northern-most portion of the Ungava Peninsula. Common types of vegetation that may be found here include low-lying shrubs such as willow, shrub birch and Labrador tea, and lichens and mosses (EC 2009, internet site).

Climate and permafrost play an important role in the hydrological regime of this area. Peak stream flows in this region are a result of spring melt, which can account for the majority of the volume of total annual runoff. Throughout the summer and fall, the active layer of permafrost increases, thereby increasing the amount of storage available within the ground. Secondary peaks are common in the late summer or early fall of the annual hydrograph, due to precipitation later in the season. Smaller streams may freeze completely to their channel bottoms throughout the winter, and begin to flow again overtop the anchor ice as a result of spring melt. Lake ice thickens over winter reaching a depth of approximately two metres. Thus, many shallow lakes freeze completely and a substantial portion of the volume of larger lakes is frozen by late winter.

3 Study Areas

The aquatic environment was investigated in two local study areas (LSA); one that encompasses the Kiggavik-Sissons project areas and one that includes the proposed access road corridors (Figure's 3.0-1a and 3.0-1b). The study area for the Project was similar for all aquatic components (e.g., water and sediment chemistry, aquatic habitat, limnology, benthic invertebrate communities, macrophytes, plankton communities, and fish and fish habitat). The spatial boundaries of the Project study area were based on watershed boundaries, as fish can access all lakes within a watershed unless a permanent obstacle (e.g., fall or cascade) impedes the fish migration. The majority of the Project footprint is to be located in the Judge Sissons Lake watershed; while the access roads cross a number of watersheds.

3.1 Mine Site Local Study Area

The mine site LSA includes lakes and their tributary streams that may be potentially directly affected by project activities or infrastructure. The LSA includes the main basin of Judge Sissons Lake, several sub-basins of Judge Sissons Lake, and several watersheds that connect to the Aniguq River (Figure 3.0-1a and 3.0-1b). Brief descriptions of watersheds or sub-basins directly influenced by the proposed project infrastructure are provided in the following sections.

3.1.1 Willow Lake Sub-Basin

The Willow Lake[1] sub-basin includes lakes and streams from Pointer Lake downstream to Judge Sissons Lake, including two small streams that flow into the northwest arm of Pointer Lake (Table 3.1-1 and Table 3.1-2; Figure 1.3-1).

The Northeast Inflow of Pointer Lake is located in the area of the central zone pit and storage pile/waste rock storage (AREVA 2008). The Northwest Inflow of Pointer Lake is located to the west of the main zone pit, storage pile, water treatment plant, mill, and power house (AREVA 2008).

[1] The sub-basin names used in the aquatics baseline are the same as those used in the hydrology baseline report (refer to Volume VIII). Each of the sub-basins to Judge Sissons Lake have been designated by the name of the lake closest to Judge Sissons Lake. For example, Pointer Lake, Rock Lake and Willow Lake are all in the same sub-basin. As Willow Lake is the closet to Judge Sissons Lake, the sub-basin has been designated the Willow Lake sub-basin.

Seasonal discharge of treated mill effluent into Pointer Lake was an option being explored. In addition, the lake is located immediately downstream of the proposed Kiggavik Site infrastructure and a potential airstrip may be located between Sik Sik Lake and Pointer Lake (AREVA 2008). Therefore, Pointer Lake was included in the LSA.

Table 3.1-1 List of Lakes and Ponds Within the Mine Site and Access Local Study Areas

Watershed	Sub-Basin	Waterbody	Mine Site	Road
Aniguq River	Willow Lake	Meadow Lake	X	-
		Felsenmeer Lake	X	-
		Escarpment Lake	X	-
		Drum Lake	X	-
		Lin Lake	X	-
		Scotch Lake	X	-
		Jaeger Lake	X	-
		Pointer Pond	X	-
		Pointer Lake	X	-
		Sik Sik Lake	X	-
		Rock Lake	X	-
		Willow Lake	X	-
	Lower Lake	Mushroom Lake	X	-
		Pond 1 to Pond 8	X	-
		End Grid Lake	X	-
		Smoke Lake	X	-
		Cigar Lake	X	-
		Knee Lake	X	-
		Lunch Lake	X	-
		Andrew Lake	X	-
		Shack Lake	X	-
		Bear Island Lake	X	-
		Lower Lake	X	-
	Caribou Lake	Ridge Lake	X	-
		Cirque Lake	X	-

Table 3.1-1 List of Lakes and Ponds Within the Mine Site and Access Local Study Areas

Watershed	Sub-Basin	Waterbody	Mine Site	Road
		Crash Lake	X	-
		Rhyolite Lake	X	-
		Fox Lake	X	-
		Sleek Lake	X	-
		Caribou Lake	X	-
		Calf Lake	X	-
	Boulder Lake	Boulder Lake	X	-
	Judge Sissons Lake	Judge Sissons Lake	X	-
	Siamese Lake	Siamese Lake	X	X
	Skinny Lake	Skinny Lake	X	-
	Kavisilik Lake	Kavisilik Lake	X	-
Thelon River	Squiggly Lake	Squiggly Lake	-	X
Baker Lake	Baker Lake	Baker Lake	-	X

- = not applicable.

Table 3.1-2 List of Streams Within the Mine Site and Access Local Study Areas

Watershed	Sub-Basin	Watercourse	Mine Site	Access
Aniguq River	Willow Lake	Northeast Inflow of Pointer Lake	X	-
		Upper Tributary to the Northeast Inflow of Pointer Lake	X	-
		Upper Northwest Inflow of Pointer Lake	X	-
		Northwest Inflow of Pointer Lake	X	-
		Pointer/Rock Stream	X	-
		Sik Sik/Rock Stream	X	-
		Rock/Willow Stream	X	-
		Willow/Judge Sissons Stream	X	-
	Lower Lake	Mushroom/End Grid Lake	X	-
		End Grid/Shack Stream	X	-
		Cigar/Lunch Stream	X	-
		Knee/Lunch Stream	X	-
		Lunch/Andrew Stream	X	-
		Andrew/Shack Stream	X	-
		Shack/Lower Stream	X	-
		Lower/Judge Sissons Stream	X	-
	Caribou Lake	Ridge/Crash Stream	X	-
		Cirque/Crash Stream	X	-
		Crash/Fox Stream	X	-
		Fox/Caribou Stream	X	-
		Caribou/Calf Stream	X	-
		Calf/Judge Sissons Stream	X	-
	Aniguq River	Aniguq River	-	X
Thelon River	Thelon River	Thelon River	-	X

-= not applicable.

Sik Sik Lake was included in the LSA as the option for releasing treated effluent discharge into Sik Sik Lake was being explored (AREVA 2008). There may also be indirect effects and potential surface run-off from the proposed airstrip.

Connecting streams from Sik Sik Lake downstream to Judge Sissons Lake were also included in the LSA. From upstream to downstream, these include Sik Sik/Rock Stream[2], Rock/Willow Stream, and Willow/Judge Sissons Stream.

3.1.2 Lower Lake Sub-Basin

Several Lakes in the Lower Lake sub-basin have the potential to be affected by Project infrastructure or activities at the Sissons Site. Proposed infrastructure or activities in the Lower Lake sub-basin include:

- development of the Andrew Lake Pit may result in the partial dewatering of Andrew Lake and Pond 8;
- Mushroom Lake may be used as a source of freshwater for the End Grid mine;
- special waste and ore storage areas may be located near Shack Lake and two of its inlet streams;
- clean waste storage may be located near Knee, Lunch and Andrew lakes; and
- treated mine water from the End Grid mine may be discharged through the Lower Lake watershed (Tables 3.1-1 and 3.1-2; Figure 1.3-1).

Therefore, the LSA includes Mushroom, End Grid, Cigar, Knee, Lunch, Andrew, Shack and Lower lakes in the Lower Lake sub-basin. In addition, the connecting streams from Mushroom Lake downstream to Judge Sissons Lake have been included in the LSA.

3.1.3 Judge Sissons Lake Sub-Basin

The Caribou Lake sub-basin is located between Willow and Lower Lake sub-basins. At this time limited project infrastructure is planned for Caribou Lake sub-basin. The haul road to the Andrew Lake and End Grid mines may cross through the sub-basin. Therefore, lakes and streams in the Caribou Lake sub-basin have been included in the LSA.

Judge Sissons Lake is downstream of both the Kiggavik and Sissons sites. Options for discharge of treated mill effluent to the lake are being evaluated (Table 3.1-1; Figure 1.3-1). Therefore, the lake has been included in the LSA.

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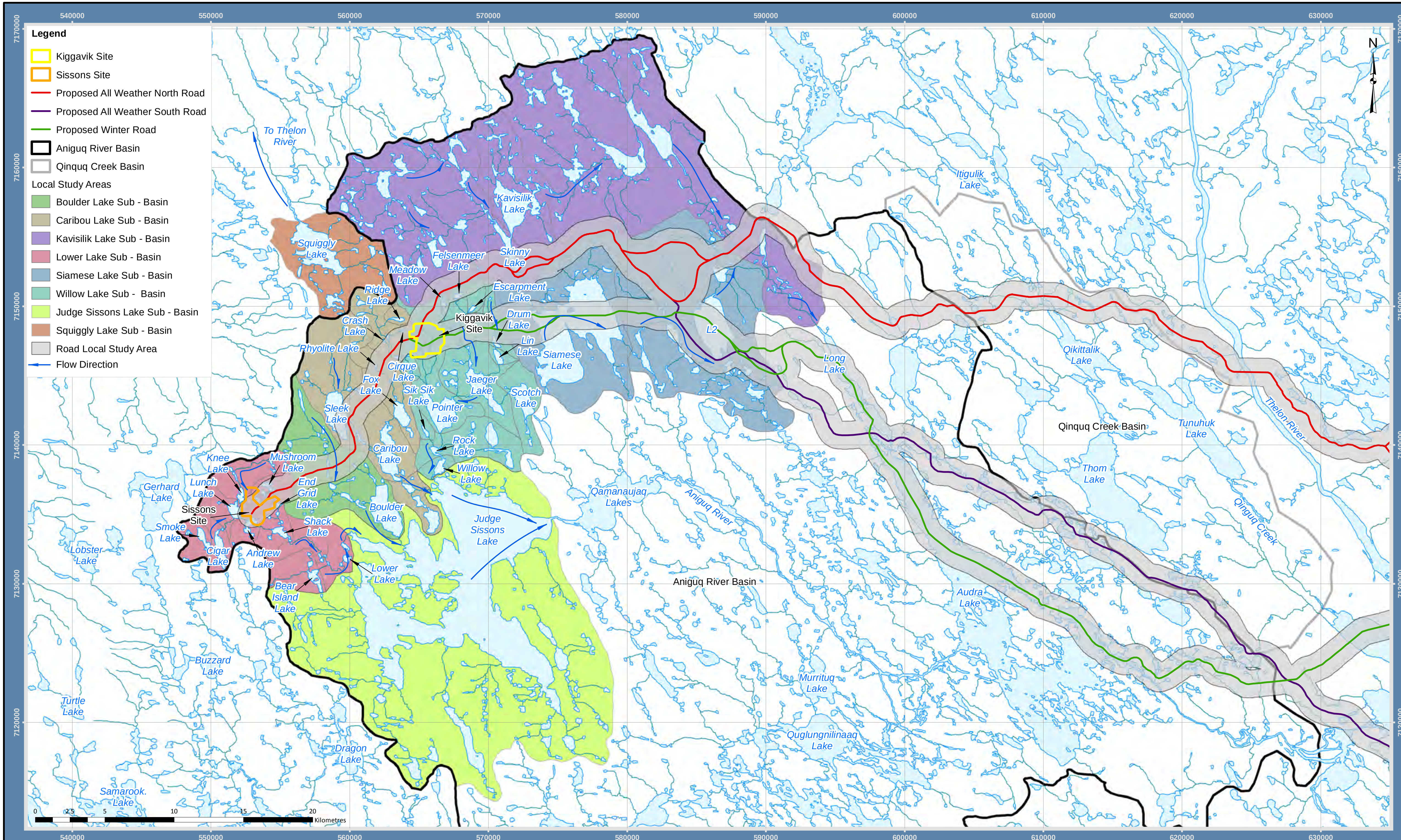
[2] Stream reaches have been designated by the names of the lakes that the reach connects. For example, the stream reach between Sik Sik and Rock lakes has been designated as Sik Sik/Rock stream.

3.2 Site Access Local Study Area

The site access LSA includes several optional corridors for winter and/or all-season roads extending from the community of Baker Lake, west to the mine site (Figures 3.0-1a and 3.0-1b). This LSA overlaps portions of Thelon and Aniquq River watersheds. Project infrastructure would include prepared transition areas or ramps between ice and overland portage areas of the winter road and bridge or culvert crossings of streams along the all-season road alignment.



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File: KI08C302
Data Sources: NTS Mapsheet 56D, 66A, 66B; AREVA Resources Canada Inc.

FIGURE 3.0-1a
LOCAL STUDY AREAS

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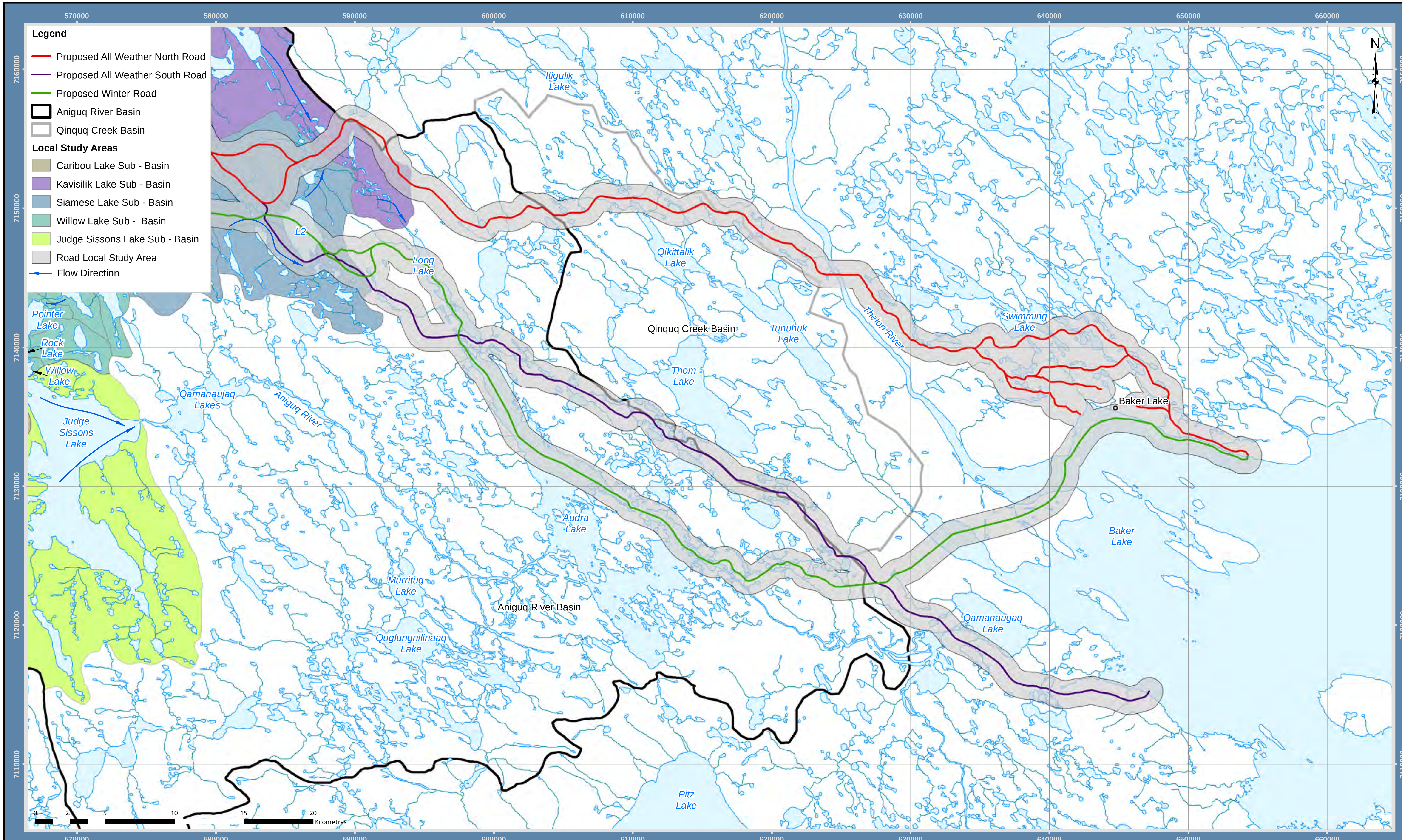

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File: KI08C316
Data Sources: NTS Mapsheet 56D, 66A, 66B; AREVA Resources Canada Inc.

FIGURE 3.0-1b
LOCAL STUDY AREAS

KIGGAVIK PROJECT - EIS

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4 Water Quality

Studies of water quality in the Kiggavik Project study area were carried out between 1979 and 1991 (BEAK 1987, 1990, 1992a). The objectives of the historical studies were to collect baseline information on major ions, nutrients, metals and metalloids, and radionuclides in the surface water of lakes of the study area. Recent studies were conducted between 2007 and 2009 to expand and complement the existing historical baseline information on water chemistry in lakes and streams of the study area. Appendix 4A, Table 4A-1 provides a summary of the lakes and streams sampled between 1979 and 2009.

4.1 Overview of Studies

4.1.1 Historical Summary 1974 to 1991

Field studies in the Project Area were carried at various times between 1974 and 1991. Studies related to the Kiggavik Project were done in 1979, 1980, 1986, 1988, and 1989 to document existing baseline concentrations of trace metals, radionuclides, nutrients and major ions in watersheds in the local study area. The 1979 and 1980 field studies were general in scope, as the Project had not advanced to the conceptual design stage at that time. The 1986 studies were carried out as part of a pre-feasibility study and were focused on assessing the existing environmental conditions relevant to the initial conceptual project design (BEAK 1987, 1990). Field surveys were carried out in 1988 and 1989 (BEAK 1990) to fill in data gaps that became apparent as a more detailed project design was developed. These studies also addressed concerns expressed by the Regional Environmental Committee on the Project Design Description document (BEAK 1987, 1990).

Aquatic environmental studies were started in the Lower Lake sub-basin in August 1990 to collect baseline data (BEAK 1990). Baseline studies were continued at the Sissons Site area in 1991 to gather additional data from the Lower Lake sub-basin and to gather data necessary to address Federal Environmental Assessment Review Office[3] requests for additional information (BEAK 1992b). The 1991 program included a winter survey, which was conducted in late February and early March, to document under-ice conditions in the late winter (BEAK 1992a).

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[3] The Federal Environmental Assessment Review Office has since been superseded by the *Canadian Environmental Assessment Agency*.

4.1.1.1 Sampling Period 1974 to 1982

Water quality sampling was carried out between 1974 and 1982 in Baker Lake (Baker Lake sub-basin; BEAK 1990). Water quality sampling was carried out in August 1979 on seven waterbodies in the mine site LSA (BEAK 1990), including:

- Lin, Scotch, Jaeger, and Sik Sik lakes of the Willow Lake sub-basin;
- Crash and Fox lakes (Caribou Lake sub-basin); and
- Judge Sissons Lake, including Judge Sissons Lake and inlet to the lake (Judge Sissons Lake sub-basin).

Water quality sampling was carried out in August 1980 on seven waterbodies in the mine site LSA (BEAK 1990), including:

- Scotch, Jaeger, and Pointer lakes (Willow Lake sub-basin);
- Crash Lake (Caribou Lake sub-basin);
- Judge Sissons Lake, including the inlet and outlet of Judge Sissons Lake (Judge Sissons Lake sub-basin);
- Kavisilik Lake (Kavisilik sub-basin of the Aniquq River); and
- Squiggly Lake (Squiggly Lake sub-basin of the Thelon River).

Sampling methods used in the 1979 and 1980 field studies could not be confirmed with the information available.

4.1.1.2 Sampling Period 1986 to 1989

Water quality sampling of 13 waterbodies and the drainages were completed in the study area in July 1986 (BEAK 1990); including:

- Meadow, Felsenmeer, Escarpment, Drum, Scotch, Pointer, and Sik Sik lakes (Willow Lake sub-basin);
- Ridge, Cirque, Crash, and Caribou lakes (Caribou Lake sub-basin);
- Judge Sissons Lake (Judge Sissons Lake sub-basin); and
- Skinny Lake (Skinny Lake sub-basin of the Aniguq River).

Water quality sampling was performed in June and July 1988 (BEAK 1990) on seven waterbodies and one watercourse, including:

- Pointer Lake tributary and Escarpment, Scotch, Jaeger, and Pointer lakes (Willow Lake sub-basin);
- Ridge Lake (Caribou Lake sub-basin);
- Judge Sissons Lake (Judge Sissons Lake sub-basin); and
- Skinny Lake (Skinny Lake sub-basin of the Aniguq River).

Additional sampling was completed in June and August 1989 (BEAK 1990) on eight waterbodies, including:

- Escarpment, Jaeger, and Pointer lakes (Willow Lake sub-basin);
- Ridge and Cirque lakes (Caribou Lake sub-basin);
- Judge Sissons Lake (Judge Sissons Lake sub-basin);
- Skinny Lake (Skinny Lake sub-basin of the Aniguq River); and
- Baker Lake (Baker Lake sub-basin).

All water samples collected in these surveys (1986 to 1989) were surface grab samples taken from the outlets of each waterbody or in the case of the Pointer Lake tributary, directly from the stream.

4.1.1.3 Sampling Period 1990 to 1991

Water samples were collected in the study area in 1990 and 1991 to augment existing baseline information. Parameters analyzed included nutrients, trace metals and radionuclides. Sulphate was included in the parameter list for the 1991 field study, as were dissolved oxygen readings under-ice (BEAK 1992a).

Surface water grab samples were collected from the following watercourses in the Lower Lake sub-basin in August 1990 including:

- Shack Lake inlet from Mushroom Lake;
- Lunch Lake inlet from Cigar Lake;
- Knee Lake outlet;
- Shack Lake inlet from Andrew Lake; and
- 2 km upstream from the mouth of the Lower Lake inlet.

Collected samples were intended to be representative of the outflow from each of the headwaters and sub-basins. Prior to collecting a sample, the sample bottles were triple-rinsed with ambient water. Samples for mercury, metals, nutrients, and radionuclides were appropriately preserved in the field. Samples were kept cool prior to delivery to the BEAK laboratory. Dissolved oxygen and temperature were determined using a calibrated YSI Model 54 dissolved oxygen meter (BEAK 1992a).

Under ice water quality samples were collected from in early March 1991. Five waterbodies in were sampled, including:

- Pointer Lake (Willow Lake sub-basin);
- Mushroom and Cigar lakes (Lower Lake sub-basin);
- Ridge Lake (Caribou Lake sub-basin); and
- Judge Sissons Lake (Judge Sissons Lake sub-basin).

At each sampling location, a hole was drilled through the ice with an auger. Judge Sissons, Pointer and Ridge lakes were sampled in the vicinity of their deepest basins. Water samples were collected from below the ice using a Teflon bailer, originally designed for the collection of water from piezometers.

A lake ice sample was also collected from Judge Sissons Lake for analysis. Snow samples were also collected near the Lone Gull camp, in the area upwind of the exploration camp.

Water samples were collected in the spring and summer 1991 (BEAK 1992a) from the outlets of four waterbodies, including:

- Mushroom and Cigar lakes and Andrew Lake at the outlet to Judge Sissons Lake (Lower Lake sub-basin); and
- the outlet of Judge Sissons Lake (Judge Sissons Lake sub-basin).

Oxygen-temperature profiles were not measured due to previous surveys clearly demonstrating an absence of thermal stratification in summer (BEAK 1992a).

4.1.2 Recent Sampling Period 2007 to 2009

Water samples were collected by Golder from a variety of lakes in the mine site LSA during the current sampling program. The purpose of the sampling was to provide a description of existing baseline conditions in waterbodies in the Project area.

4.1.2.1 Sampling Areas

Waterbodies sampled in each year varied depending upon access, weather, and time constraints. Sampling areas were broad in 2007 and 2008. As project plans were refined during the winter of 2008, a more focussed sampling program in 2009 concentrated on lakes that could potentially be affected by the Project. A summary of lakes and streams sampled and the geographic coordinates of the individual sampling stations has been provided in Attachment X.I.

Lakes

Water chemistry samples were collected from 12 lakes during the fall 2007 sampling session (Attachment X.I, Figure X.I-1 and Table X.I-1). Lakes sampled included:

- Pointer, Sik Sik, and Willow lakes (Willow Lake sub-basin);
- End Grid, Andrew, Shack and Lower lakes (Lower Lake sub-basin);
- Ridge, Cirque, Crash, and Fox lakes (Caribou Lake sub-basin); and
- Skinny Lake (Aniguq River).

There was one water quality station per lake with the exception of Pointer Lake, which had two stations.

Water chemistry samples were collected from six lakes in the summer of 2008 (Attachment X.I, Figure X.I-1 and Table X.I-1). Lakes sampled included:

- Pointer Lake (Willow Lake sub-basin);
- Mushroom and Lower lakes (Lower Lake sub-basin);
- Fox and Caribou lakes (Caribou Lake sub-basin); and
- Judge Sissons Lake (Judge Sissons Lake sub-basin).

There was one water quality station per lake with the exception of Judge Sissons Lake, which had five stations.

Water chemistry samples were collected from 23 lakes in the fall of 2008 (Attachment X.I, Figure X.I-1 and Table X.I-1). The following lakes were sampled:

- Pointer, Sik Sik, Rock, and Willow lakes (Willow Lake sub-basin);
- Mushroom, End Grid, Cigar, Knee, Lunch, Andrew, Shack and Lower lakes (Lower Lake sub-basin);
- Ridge, Cirque, Crash, Fox, Caribou, and Calf lakes (Caribou Lake sub-basin);
- Judge Sissons Lake (Judge Sissons Lake sub-basin);
- Siamese and Skinny lakes (Aniguq River sub-basin);
- Squiggly Lake (Thelon River sub-basin); and
- Baker Lake (Baker Lake sub-basin).

There was one water quality station per lake with the exceptions of Pointer Lake (two stations), Judge Sissons Lake (five stations), Siamese Lake (two stations), and five stations in Baker Lake.

Water chemistry samples were collected from five lakes in summer 2009 (Attachment X.I, Figure X.I-1 and Table X.I-1), including:

- Sik Sik, Rock, and Willow lakes (Willow Lake sub-basin);
- Judge Sissons Lake (Judge Sissons Lake sub-basin); and
- Baker Lake (Baker Lake sub-basin).

There was one water quality station per lake, except Baker Lake, which had two stations sampled.

Water chemistry samples were collected from five lakes in fall 2009 (Attachment X.I, Figure X.I-1). Lakes sampled included:

- Sik Sik, Rock, and Willow lakes (Willow Lake sub-basin);
- Andrew Lake (Lower Lake sub-basin); and
- Judge Sissons Lake (Judge Sissons Lake sub-basin).

There was one water quality station per lake with the exception of Judge Sissons Lake, which had five stations.

Streams from the Local Study Area

Water chemistry samples were collected from the following streams in fall 2007 (Attachment X.I, Figure X.I-2 and Table X.I-2):

- Pointer/Rock Stream (Willow Lake sub-basin);
- Shack/Lower Stream (Lower Lake sub-basin); and
- Crash/Fox and Fox/Caribou streams (Caribou Lake sub-basin).

In spring and fall 2008, the sampling area was expanded to include the following streams (Attachment X.I, Figure X.I-2 and Table X.I-2):

- Northeast and Northwest Inflows to Pointer Lake, Pointer/Rock, Sik Sik/Rock, Rock/Willow, and Willow/Judge Sissons streams (Willow Lake sub-basin);
- Mushroom/End Grid, End Grid/Shack, Cigar/Lunch, Knee/Lunch, Lunch/Andrew, Andrew/Shack, Shack/Lower, and Lower/Judge Sissons streams (Lower Lake sub-basin); and
- Ridge/Crash, Cirque/Crash, Crash/Fox, Fox/Caribou, Caribou/Calf, and Calf/Judge Sissons streams (Caribou Lake sub-basin).

Water chemistry samples were collected from the following streams in spring and fall 2009 (Attachment X.I, Figure X.I-2 and Table X.I-2):

- Northeast Inflow of Pointer Lake, Sik Sik/Rock, Rock/Willow, and Willow/Judge Sissons streams (Willow Lake sub-basin); and
- Aniguq River.

There was one water quality station per stream in the 2007, 2008, and 2009 studies with the exception of Aniguq River. The Aniguq River had two water quality sampling stations in fall 2009.

4.1.2.2 Sample Collection Methods

Water chemistry samples were collected according to methods and quality assurance/quality control (QA/QC) procedures outlined in Golder's *Technical Procedure 8.3-1: Surface Water Sampling Methods* (unpublished file information). Surface water grab samples were collected from shallow waterbodies (i.e., less than 3 metres [m] in depth), by taking a water sample at a depth of about 30 centimetres (cm) from the surface using a Kemmerer water sampler. For lakes deeper than 3 m, a composite water sample was taken at a station located in the deepest area of the lake. Composite samples combined water collected by a Kemmerer water sampler from three depths (i.e., approximately 30 cm below the surface, middle of the water column, and 1 m above the bottom) into a single sample.

In situ measurements of dissolved oxygen, water temperature, pH, and specific conductivity were obtained using a YSI 600QS meter. At stations with maximum water depths of less than 3 m, limnology measurements were recorded at the surface only. Stations with maximum water depths greater than 3 m had limnology profile measurements collected at 1 m increments within the water column. The final measurement was approximately 0.5 m from the bottom sediment.

Sampling in Baker Lake was done in accordance with the methods outlined in the *British Columbia Field Sampling Manual* (Clark 2003). Samples for analytical chemistry were collected using a van Dorn sampler. At sites 1, 2, and 3 in Baker Lake, samples were collected from two depths: one near surface (1 m) and one at mid-depth (i.e., one-half the depth of the total water column at each site). The remaining sites were shallow (i.e., less than 2m), so near surface (0.5 m) and bottom (1.5 m) samples were collected at Site 4 and only the near surface sample was collected at Site 5 (0.5 m).

Water samples were placed into the appropriate bottles supplied by Saskatchewan Research Council Analytical Laboratories (SRC) and applicable preservatives were added as required according to SRC Laboratories protocols. Samples for dissolved nutrients and dissolved metals require filtration prior to the addition of preservatives. Each sample was filtered, while in the field, through a 0.45 µm methyl-cellulose ester filter using a glass vacuum filtering tower. All samples were stored in coolers and kept cool (using ice packs) and in the dark. Most samples were shipped to the Golder office in Saskatoon prior to submission to SRC (Saskatoon, SK).

Samples collected in Baker Lake where shipped directly to SRC. Samples from Baker Lake sites 1, 2 and 3 were submitted to the laboratory within eight days of sampling and from sites 4 and 5 within five days, which ensured that samples met the applicable hold times for all parameters except ortho-phosphate, pH, alkalinity, and conductivity. Radionuclides were not analyzed at Baker Lake Site 5 due to an insufficient quantity of preservatives.

Laboratory Analysis

Water chemistry samples were analyzed by SRC for some or all of the following parameters:

- conventional parameters (i.e., pH, specific conductivity, total alkalinity, total hardness, total dissolved solids [TDS], total suspended solids [TSS], and turbidity);
- nutrients (i.e., total ammonia, nitrate, nitrite, total Kjeldahl nitrogen [TKN], total nitrogen, total and dissolved phosphorus, total carbon, total inorganic carbon [TIC], total organic carbon [TOC], and dissolved organic carbon [DOC]);
- major ions by inductively coupled plasma atomic emission spectroscopy (ICP-AES) scan (i.e., bicarbonate, calcium, carbonate, chloride, fluoride, hydroxide, magnesium, potassium, sodium, and sulphate);
- total and dissolved metals and metalloids by ICP-mass spectroscopy (ICP-MS) scan including aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, strontium, thallium, tin, titanium, uranium, vanadium, and zinc; and
- radionuclides including lead-210 (Pb-210), polonium-210 (Po-210), radium-226 (Ra-226), thorium-228 (Th-228), thorium-230 (Th-230), and thorium-232 (Th-232).

Water chemistry samples collected in 2007 were not analyzed for Th-228 or Th-230.

Data Analysis

As different contractors were involved in the data collection, data storage differed slightly. Water chemistry data received from SRC Laboratories for lakes and streams in the mine site LSA was imported into Golder's electronic database[4] (emLine™) along with all supporting data. Data for Baker Lake was stored in Excel spreadsheets. Historical and recent water chemistry results were compared among water sampling stations within year of sampling as well as to Canadian Council of Ministers of the Environment (CCME) Canadian Water Quality Guidelines (CWQG) for the protection of aquatic life - freshwater (CCME 2007) and to Saskatchewan Surface Water Quality Objectives (SSWQO; Saskatchewan Environment [SE] 2006). The focus of the comparison to CWQG and SSWQO guideline limits is on total metals as regulatory standards are based on concentration of total metals and not dissolved metals.

4.1.2.3 Quality Assurance/Quality Control

QA/QC programs in water quality studies are sampling and analytical procedures that are followed to limit the introduction of error into analytical data. Quality assurance (QA) procedures include appropriate training of sampling personnel, use of standard operating procedures when collecting the samples, appropriate sample handling and storage, submission of samples to accredited analytical laboratories, and use of data management systems. Quality control (QC) procedures are designed to assess data quality, including potential laboratory and field contamination, through the use of blanks, replicates, and spiked or reference materials.

Detailed specific work instructions were provided to Golder field personnel prior to the field programs to help ensure program and sampling success. As part of routine field operations for QA/QC, applicable equipment was frequently calibrated. Samples were collected by experienced personnel and were prepared, labelled, preserved, and shipped according to Golder's *Technical Procedure 8.3-1: Surface Water Sampling Methods* and *Technical Procedure 8.23-0: Basic Limnology and Bathymetric Procedures* (unpublished file information) and SRC Laboratory protocols. Duplicate samples, as well as field and trip blanks, were used for QA/QC purposes. Chain-of-Custody (COC) forms accompanied all samples from the field to the analytical laboratories.

Detailed field notes were recorded in pencil in waterproof field notebooks and on pre-printed waterproof field datasheets. Sample bottles were labelled in waterproof ink. Data collected during the field trip underwent a variety of thorough individual QA/QC checks. Field data sheets were verified at the end of each day for completeness and accuracy. COC forms were used to track sample shipment from the field to Golder's Saskatoon office. SRC request forms were submitted with the water chemistry samples. A QA/QC check was completed between the hard copy and the electronic

[4] emLine™ is a custom built relational database used by Golder to house chemistry, limnology, benthic invertebrate community and fish sampling data.

data received from SRC Laboratories to verify there were no transcription errors. All data sets and tables underwent an additional 100% QA/QC check.

The analysis of the travel blank in 2008 Baker Lake samples (Attachment X.II) indicates trace levels of some parameters (e.g., ammonia, nitrate, total phosphorus, manganese, strontium and zinc). Of these, zinc and nitrite+nitrate were greater than five times the detection limit, suggesting there may have been some contamination during sample collection, storage and shipping. Nitrate levels were notably higher in the blank (0.39 mg/L) than the lake samples (all less than 0.01 mg/L detection limit), implying contamination of the blank sample only and accuracy of the results for the lake sites. Zinc levels were similar and relatively low in both field blank and lake samples, suggesting there may be difficulty obtaining accurate zinc results (however, levels would be well below maximums set out in the guidelines).

4.2 Results

Table 4A-1 (Appendix A) provides a summary of all lakes and streams sampled between 1974 and 2009. The following discussion provides a brief summary of water chemistry for lakes and streams in the mine site LSA and the site access LSA. Detailed water chemistry results are presented in Attachment X.II.

4.2.1 Historical Summary

Detailed results of the historical water quality data are presented in Attachment X.II, Table X.II-1 and discussed below.

4.2.1.1 Sampling Period 1974 to 1982

Chemical Characteristics

Historical water chemistry results were compared with current water quality guidelines (i.e., SSWQO 2006 and CWGQ 2007). Five metals (cadmium, copper, lead, mercury, and zinc) exceeded both the SSWQO and the CWQG (SE, 2006; CCME 2007) in at least one sample (Attachment X.II, Table X.II-1); however, sample contamination was strongly suspected for copper (BEAK 1990).

Radionuclides

Radionuclides in waters samples collected during the 1979 and 1980 surveys were at or below analytical detection limits for unconcentrated samples (Attachment X.II, Table X.II-1). The radionuclide levels in the study area and Saqvaqjuac[5] lakes were generally similar, with overlapping concentration ranges. In the study area, detectable concentrations of Ra-226, Th-230, and uranium occurred, likely due to the mineralogy in the area (BEAK 1990).

4.2.1.2 Sampling Period 1986 to 1989

Chemical Characteristics

Overall, concentrations of nutrients (e.g., phosphorus and nitrogen) measured in 1986, 1988 and 1989 were low in the Project area lakes (Attachment X.II, Table X.II-1), falling within the range of concentrations that are expected for oligotrophic lakes (BEAK 1990).

Differences between winter and summer conditions were apparent in the mine site LSA lakes in 1988. Ions such as sodium, magnesium, potassium, and chloride had lower concentrations during the open water season, attributed to the effects of dilution by snowmelt and freeze-out during winter months (BEAK 1990). Freeze-out concentrates these elements in the unfrozen volume of the lake, and may account for some increase in nutrient concentrations under ice.

Chemical analysis of snow core samples in 1988 and 1989 showed that the snow was acidic and had low levels of conductivity, alkalinity, organic carbon, colour, calcium, magnesium, potassium, and barium relative to lake water (BEAK 1990). In addition, concentrations of some heavy metals in snow core samples were much greater than in the lake water samples. BEAK (1990) indicated that the lake chemistry is less acidic than the snow, suggesting that lakes sampled in the 1988 and 1989 surveys had considerable buffering capacities, which is particularly relevant with respect to controlling optimal conditions for aquatic life (BEAK 1990).

A small stream in the mineral exploration area that drains into Pointer Lake was sampled in 1986, 1988 and 1989. Results showed elevated concentrations of total dissolved solids, chloride, sulphate, calcium, sodium, potassium and several trace metals (e.g., iron, manganese, aluminum, barium) relative to other local surface waters (BEAK 1990). Elevated concentrations of ions in the tributary

[5] Saqvaqjuac lakes are located near the mouth of Chesterfield Inlet, where DFO ran a research camp in the 1980s and early 1990s.

were observed when active drilling was being performed in 1986, as opposed to 1988 when no drilling was carried out. Salt used at that time to keep drills and drill holes from freezing was identified as a major source of ions in the tributary (BEAK 1990). None of the parameters that had elevated concentrations in the mineral exploration drainage area were found in Pointer Lake at concentrations above typical background levels for lakes in the LSA.

Generally, it was found that mine site LSA waters were relatively low in both conductivity and concentrations of most dissolved substances. Low nutrient (e.g., phosphorous) concentrations suggest that local lakes were relatively unproductive (i.e., oligotrophic or ultra oligotrophic) (BEAK 1990). Aluminum, copper, iron, lead, mercury and silver exceeded both the SSWQO and CWQG in at least one sample collected during the 1986 to 1989 studies. Chromium concentrations exceeded the CWQG in six lake samples (Attachment X.II, Table X.II-1). In general, many of the water quality parameters measured in the LSA lakes were more dilute than Saqvaqjuac lakes (BEAK 1990).

Radionuclides

Results of radionuclide analysis of surface waters from the Project area for the periods of 1986 to 1989 are shown in Attachment X.II, Table X.II-1. Prior to 1988, levels of most radionuclides analyzed from mine site LSA lakes were at or below analytical detection limits for unconcentrated water samples. Detectable levels were reported for 1988 and 1989, owing to the analysis of samples pre-concentrated from large volume samples (BEAK 1990). Radium-226, analyzed only by Radon-emanation (Rn-emanation) due to the Ba-133 tracer and stable Ba carrier used in sample pre-concentration, was undetected in 1988. This lack of detection can in part be attributed to the relatively high detection limits of the Rn-emanation method used (BEAK 1990).

Uranium concentrations in 1988 and 1989 water samples were close to those reported in previous years from study area lakes, with the exception of Jaeger Lake in 1988. Concentrations of uranium in Jaeger Lake were below detection limits in 1979 to 1980 and 1.5 µg/L in the June 1998 sample; however, the concentration of uranium was 8 µg/L in the July 1988 sample (BEAK 1990). Total uranium concentrations were higher in the mine site LSA surface waters than those recorded in Saqvaqjuac surface waters.

The Pointer Lake tributary, draining an area of surface mineralization, had higher concentrations of most radionuclides than the lakes sampled in 1988. BEAK (1990) indicated that radionuclides were being mobilized from the mineralized area to the surface waters of the tributary stream (BEAK 1990).

4.2.1.3 Sampling Period 1990 to 1991

Chemical Characteristics

Water quality sampling during the spring and summer 1991 focused on collecting baseline data in the Lower Lake sub-basin and was completed in early June, under low flow conditions. The concentrations of most parameters collected during the 1990 and 1991 studies were within the reported background range previously noted for the mine site LSA lakes (Attachment X.II, Table X.II-1). Concentrations of total hardness, total dissolved solids, and zinc were above the background range in some waterbodies during the 1991 survey (BEAK 1992a). Samples from six lakes in 1990 to 1991 had pH values below the CWGQ range of 6.5 to 9.0, including Cigar Lake, Andrew Lake, Judge Sissons Lake, Cirque Lake, Ridge Lake. Concentrations of aluminum, cadmium, copper, iron, lead, mercury, selenium and silver exceeded both the SSWQO and CWQG in at least one sample.

In 1991, snow samples were collected from the snow drifts in the Lone Gull camp. The 1991 snow samples had similar pH values and mercury concentrations as the 1989 snow samples. Values were lower for most parameters in the snow and ice samples as compared to lake water samples.

During water quality sampling on Ridge and Judge Sissons lakes, water effervescing was observed, suggestive of gas supersaturation (BEAK 1992a), confirmed by oxygen saturation levels in excess of 150%. Some depletion of oxygen was evident in 1991 and was most apparent in shallower lakes such as Pointer and Cigar lakes. Pointer Lake oxygen levels were similar to those measured under-ice in June 1988 (BEAK 1992a).

Radionuclides

Radionuclides were below detection limits in most of the samples collected in 1990 and 1991, with the exception of Cigar Lake (BEAK 1992a). Radium-226 was detectable in the 1991 samples; however, concentration were at the analytical detection limits.

4.2.2 Recent Sampling Period 2007 to 2009

Sampling of lakes and streams in the mine site LSA were undertaken in 2007, 2008 and 2009. Recent water chemistry results were compared with current water quality guidelines (i.e., SSWQO 2006 and CWGQ 2007). Information on the location of sampling stations in each waterbody and watercourse has been provided in Attachment X.I, Tables X.I-1 and X.I-2, respectively.

4.2.2.1 Lake in the Mines Site Local Study Area

Willow Lake Sub-Basin

2007

Water chemistry samples were collected from Pointer, Sik Sik, and Willow lakes in fall 2007 (Attachment X.II, Table X.II-2). Field- and laboratory-measured pH values were variable among the lakes, ranging from pH 6.9 to 9.9. All pH values were within the current SSWQO and CWQG of 6.5 to 9, with the exception of Station 1 in Pointer Lake (pH 9.9). Sik Sik Lake had higher values for field-measured specific conductivity (54 microSiemens per centimetre [µS/cm]), total alkalinity (32 milligrams per litre [mg/L]), total hardness (28 mg/L), total suspended solids (TSS) (10 mg/L), and turbidity (4.6 nephelometric turbidity units [NTU]) than in the other lakes. Concentrations of these parameters in other lakes ranged from 13 to 19 µS/cm conductivity, 4 to 6 mg/L alkalinity, 6 to 8 mg/L hardness, 2 to 4 mg/L TSS, and 1.5 to 1.8 NTU turbidity.

Nutrient concentrations were similar among the lakes with the exception of TKN and total phosphorus. Concentrations of TKN were 0.84 mg N/L in Pointer Lake Station 1 and 0.69 mg N/L in Sik Sik Lake, compared to 0.40 to 0.42 mg N/L in the other lakes. Total phosphorus was not detected in any sample (detection limit was 0.01 mg/L) except from Sik Sik Lake (0.08 mg/L). In aquatic systems, nitrogen occurs in organic and inorganic forms (dissolved nitrite, nitrate, ammonium, and ammonia compounds). Total ammonia concentrations ranged from 0.07 to 0.23 mg/L and nitrate-nitrite concentrations ranged from less than 0.01 to 0.04 mg/L among the lakes.

Analytical detection limits for total metals were at or below the most conservative guideline (SSWQO 2006 or CWQG 2007) with the exception of cadmium and mercury. The detection limit for cadmium was 0.0001 mg/L, which is higher than the SSWQO and CWQG of 0.000017 mg/L). The detection limit for mercury was 0.05 µg/L, whereas the SSWQO and CWQG limits are 0.026 µg/L. Total metal concentrations were either below the detection limits or below applicable guidelines with two exceptions. The concentration of total iron in Sik Sik Lake was 0.43 mg/L, which was higher than the SSWQO and CWQG of 0.3 mg/L. Total lead concentration in Pointer Lake Station 2 was 0.0026 mg/L, which was higher than the CWQG and SSWQO of 0.001 mg/L.

Radionuclides were not detected in most lakes. Polonium-210 concentrations at Pointer Lake Station 2 and Pointer Lake outlet were measured at 0.007 and 0.005 Becquerel per litre (Bq/L), respectively. No SSWQO or CWQG exist for radionuclides.

2008

Water chemistry samples were collected in Pointer Lake in summer 2008 and in Pointer, Sik Sik, Rock, and Willow lakes in fall 2008 (Attachment X.II, Tables X.II-3 and X.II-4). In general, conventional water chemistry parameters were similar between the summer and fall sampling events in Pointer Lake. The following discussion of the Willow Lake sub-basin water chemistry focuses on the results of the fall sampling event.

In the fall, Pointer Lake had the lowest values for total alkalinity, specific conductivity, pH, and total hardness. Conversely, Sik Sik Lake had the highest values for the same parameters. Total alkalinity values in the lakes ranged from 1 to 28 mg/L. Specific conductivity ranged from 15 to 62 µS/cm. For a given site, field-measured pH values were similar to the laboratory-measured pH values. Field pH values ranged from 6.7 to 7.6, all pH values were within the CWQG of 6.5 to 9. Total hardness in the Willow Lake sub-basin ranged from 6 to 31 mg/L.

Nitrate and nitrate-nitrite as nitrogen concentrations were at or below the reported detection limits in all lake samples. None of the lake samples had concentrations that exceeded the CWQG for nitrate of 13 mg NO_3/L. Detectable concentrations of ammonia ranged from 0.02 to 0.08 mg N/L, and were below the pH and temperature dependent SSWQO and CWQG. Concentrations of TKN ranged from 0.28 to 0.83 mg N/L. Total phosphorus concentrations were below detection limit (0.01 mg/L) except in Pointer Lake (0.03 mg/L in fall). Dissolved organic carbon concentrations ranged from 4.1 mg/L (Pointer Lake) to 12 mg/L (Sik Sik Lake).

The concentrations of total metals were either below the detection limits or below the current SSWQO and CWQG.

The majority of radionuclides were below detection limits in the lake samples in 2008. Polonium-210 in Pointer Lake was measured at 0.007 Bq/L and Ra-226 in Willow Lake was measured at 0.006 Bq/L. No SSWQO or CWQG exist for radionuclides.

2009

Water chemistry samples were collected in Sik Sik, Rock, and Willow lakes in summer and fall 2009 (Attachment X.II, Table X.II-5). In general, water chemistry parameters were similar between the summer and fall sampling events in these lakes. An exception was total iron concentration in the summer sample from Sik Sik Lake; the total iron concentration in this sample was 0.30 mg/L, which was the same as the SSWQO and CWQG of 0.3 mg/L. In the fall, total iron concentration in the sample from Sik Sik Lake was 0.15 mg/L (Attachment X.II, Table X.II-5). Also, field-measured pH was generally higher in the fall (pH 8.1 to 8.2) than in the summer (pH 6.9 to 7.5). The rest of the discussion of the Willow Lake sub-basin water chemistry focuses on the results of the fall sampling event.

In the fall, Sik Sik Lake had higher values for total alkalinity, specific conductivity, pH, and total hardness than Rock and Willow lakes. Total alkalinity values in the lakes ranged from 3 to 28 mg/L. Specific conductivity ranged from 17 to 62 µS/cm. All field pH values were within the CWQG of 6.5 to 9. Total hardness in the Willow Lake sub-basin ranged from 6 to 29 mg/L.

Total ammonia concentrations ranged from less than 0.01 to 0.02 mg N/L, and were below the pH and temperature dependent SSWQO and CWQG. Concentrations of TKN ranged from less than 0.05 mg/L (Willow Lake) to 0.79 mg/L (Sik Sik Lake). Total phosphorus concentrations were below detection limit (0.01 mg/L) except in Willow Lake (0.02 mg/L) in fall. Dissolved organic carbon concentrations ranged from 3.9 mg/L (Willow Lake) to 11 mg/L (Sik Sik Lake).

The concentrations of total metals were either below the detection limits or below the SSWQO and CWQG during the fall sampling event.

The majority of radionuclides were below detection limits in the lake samples in 2009. Polonium-210 in Sik Sik Lake was measured at 0.02 Bq/L. Lead-210 and Ra-226 in Rock Lake were measured at 0.03 Bq/L and 0.009 Bq/L, respectively. No SSWQO or CWQG exist for radionuclides.

Lower Lake Sub-Basin

2007

Water chemistry samples were collected from End Grid, Andrew, Shack and Lower lakes in fall 2007 (Attachment X.II, Table X.II-2). Conventional parameters were similar among the lakes. Field-measured pH ranged from pH 7.5 to 7.9. Field-measured specific conductivity ranged from 25 to 34 µS/cm. Total alkalinity and total hardness both ranged from 13 to 18 mg/L.

Nutrient concentrations were similar among the lakes with the exception of total ammonia and TKN. Total ammonia concentration in Shack Lake was 0.35 mg N/L, which exceeded the pH and temperature dependent SSWQO and CWQG of 0.24 mg N/L. Total ammonia concentrations in the other lakes ranged from 0.03 to 0.1 mg N/L. The TKN concentration in Shack Lake was also higher at 1.3 mg N/L compared to 0.46 to 0.95 mg N/L in the other lakes sampled.

Total metal concentrations were either below the detection limits or below applicable current guidelines.

Lead-210, Ra-226 and Th-228 were not detected in any samples from lakes in the Lower Lake sub-basin. Polonium-210 was detected in all lakes at concentrations ranging from 0.005 Bq/L (Lower Lake) to 0.009 Bq/L (Andrew Lake). The detection limit for Po-210 was 0.005 Bq/L. No SSWQO or CWQG exist for radionuclides.

2008

Water chemistry samples were collected from Mushroom and Lower lakes in summer and fall 2008 and in End Grid, Cigar, Knee, Lunch, Andrew, and Shack lakes in fall 2008 (Attachment X.II, Tables X.II-3 and X.II-4). In general, water chemistry parameters were similar between the summer and fall sampling events in Mushroom and Lower lakes. An exception was total iron concentration in the summer sample from Lower Lake (0.32 mg/L), which exceeded the SSWQO and CWQG of 0.3 mg/L. In the fall, total iron concentration in the samples from Lower Lake was 0.18 mg/L (Attachment X.II, Table X.II-4). The concentration of iron in Mushroom Lake was 0.06 mg/L in the summer, but increased in the fall to 0.32 mg/L (also exceeding the SSWQO and CWQG of 0.3 mg/L).

In the fall, Cigar Lake had the lowest values for total alkalinity (4 mg/L), laboratory-measured specific conductivity (13 µS/cm), field-measured pH (6.4), total dissolved solids (13 mg/L), and total hardness (4 mg/L) (Attachment X.II, Table X.II-5). With the exception of Cigar Lake, total alkalinity values in the lakes in the fall ranged from 10 to 23 mg/L, laboratory-measured specific conductivity ranged from 25 to 48 µS/cm, field-measured pH ranged from pH 6.8 to 7.6, total dissolved solids ranged from 25 to 46 mg/L, and total hardness ranged from 12 to 22 mg/L. With the exception of Cigar Lake (pH 6.4), all pH values were within the CWQG of 6.5 to 9.0.

Nitrate and nitrate-nitrite concentrations were at or below the reported detection limits in all fall lake samples with the exception of the Lower Lake duplicate, which had a nitrate concentration of 0.02 mg N/L and a nitrate-nitrite concentration of 0.09 mg N/L. Detectable concentrations of total ammonia ranged from 0.02 mg N/L (Shack Lake) to 0.06 mg N/L (Lunch and End Grid lakes), which were below the pH and temperature dependent SSWQO and CWQG limits. Concentrations of TKN ranged from 0.27 mg N/L (Cigar Lake) to 0.79 mg N/L (Lower Lake duplicate). All samples in the Lower Lake sub-basin collected in the fall were at or below detection limit for total phosphorus, with the exception of Lower Lake (0.09 mg/L). Concentrations of DOC ranged from 3.4 to 10 mg/L, with Cigar Lake being the lowest and Lower Lake being the highest.

Detection limits for total metals were at or below the most conservative guideline (SSWQO or CWQG) with the exception of cadmium (detection limit was 0.0001 mg/L, higher than the SSWQO and CWQG of 0.000017 mg/L) and mercury (detection limit was 0.05 µg/L, higher than the SSWQO and CWQG of 0.026 µg/L). The concentrations of total metals were either below the detection limits or below the SSWQO and CWQG with the following exceptions. At 0.32 mg/L, total iron concentrations in Lower Lake (summer) and Knee Lake (fall) were higher than the SSWQO and CWQG of 0.3 mg/L. Total aluminum concentration in Cigar Lake (fall) was 0.018 mg/L, which was higher than the SSWQG and CWQG of 0.005 mg/L, based on a field-measured pH of 6.4. Total chromium concentration in Andrew Lake was 0.0021 mg/L, which was higher than the CWQG of 0.0010 mg/L for hexavalent chromium but lower than the CWQG of 0.0089 mg/L for trivalent chromium.

Lead-210 and Th-228 were not detected in any samples from lakes in the Lower Lake sub-basin. Polonium-210 was detected at concentrations ranging from 0.006 Bq/L (Knee and Shack Lakes) to 0.01 Bq/L (Lunch and Andrew lakes). The detection limit for Po-210 was 0.005 Bq/L. Radium-226 was reported above the detection limit of 0.005 Bq/L in one sample in the summer (Mushroom Lake) and three samples in the fall (Cigar, Knee, and Shack lakes), at concentrations ranging from 0.005 to 0.008 Bq/L. Thorium-230 and Th-232 were detected in Knee Lake at concentrations at or slightly above the detection limits (0.01 Bq/L). Thorium-230 was detected in Mushroom Lake at the detection limit of 0.01 Bq/L.

2009

Water chemistry samples were collected from Andrew Lake in fall 2009 (Attachment X.II, Table X.II-5). In general, water chemistry in 2009 was similar to that observed in previous years. Field-measured pH and specific conductivity values were pH 7.3 and 31 µS/cm, respectively. Total alkalinity and total hardness concentrations were 14 mg/L.

Total ammonia concentration was 0.03 mg N/L and TKN concentration was 0.43 mg/L. Total phosphorus was not detected (detection limit was 0.01 mg/L). Dissolved organic carbon concentration was 6.0 mg/L.

The concentrations of total metals were either below the detection limits or below the SSWQO and CWQG.

The majority of radionuclides were below detection limits. Polonium-210 and Ra-226 were measured at 0.007 Bq/L. No SSWQO or CWQG exist for radionuclides.

Caribou Lake Sub-Basin

2007

Water chemistry samples were collected in Ridge, Cirque, Crash, and Fox lakes in fall 2007 (Attachment X.II, Table X.II-2). Field-measured pH values ranged from 7.3 (Ridge and Cirque lakes) to 7.6 (Fox Lake); all pH values were within the SSWQO and CWQG range of pH 6.5 to 9. Concentrations of other conventional parameters were higher in Crash Lake compared to the other lakes. Field-measured specific conductivity was 25 µS/cm in Crash Lake compared to 11 to 16 µS/cm in the other lakes. Total alkalinity and hardness concentrations in Crash Lake were 9 mg/L and 13 mg/L, respectively; compared to 2 to 6 mg/L and 5 to 8 mg/L, respectively, in the other lakes.

Nutrient concentrations were variable among lakes, but no clear pattern was observed. Nitrate and nitrate-nitrite concentrations were at or below the reported detection limits in all but one lake sample

(Fox Lake). Total ammonia concentrations ranged from 0.03 mg N/L (Cirque Lake) to 0.08 mg N/L (Ridge and Crash lakes), all of which were below the pH and temperature dependent SSWQO and CWQG. Concentrations of TKN ranged from 0.22 mg N/L (Ridge Lake) to 0.62 mg N/L (Crash Lake). Detectable levels of total phosphorus ranged from 0.01 mg/L (Ridge Lake) to 0.03 mg/L (Cirque Lake).

Detection limits for total metals were at or below the most conservative guideline (SSWQO or CWQG) with the exception of cadmium (detection limit was 0.0001 mg/L, higher than the SSWQO and CWQG of 0.000017 mg/L) and mercury (detection limit was 0.05 µg/L, higher than the SSWQO and CWQG of 0.026 µg/L). Total metal concentrations were either below the detection limits or below applicable guidelines with the exception of aluminum. Total aluminum concentration in Crash Lake was 0.12 mg/L, higher than the SSWQG and CWQG of 0.1 mg/L, based on a field-measured pH of 7.0.

Lead-210, Po-210, Th-232 were not detected in any lake samples. Radium-226 was detected in samples from Crash and Fox lakes, with concentrations of 0.01 and 0.007 Bq/L, respectively. No SSWQO or CWQG exist for radionuclides.

2008

Water chemistry samples were collected in Fox and Caribou lakes in summer and fall 2008 and in Ridge, Cirque, Crash, and Calf lakes in fall 2008 (Attachment X.II, Tables X.II-3 and X.II-4). In general, conventional water chemistry parameters were similar between the summer and fall sampling events in Fox and Caribou lakes. Field-measured pH values in these lakes were higher in the summer (pH 7.2 to 7.5) than in the fall (pH 6.9 to 7.1). All pH values were within applicable guidelines.

In the fall, total alkalinity values in lakes in the Caribou Lake sub-basin ranged from 5 mg/L (Calf Lake) to 14 mg/L (Crash Lake). Specific conductivity ranged from 13 µS/cm (Cirque Lake) to 29 µS/cm (Crash Lake). Total hardness ranged from 6 mg/L to 14 mg/L, with Cirque Lake being the lowest and Crash Lake being the highest.

Nitrate and nitrate-nitrite concentrations were at or below the reported detection limits in all but one lake sample (Ridge Lake). Detectable concentrations of ammonia in the fall ranged from 0.02 mg N/L (Cirque and Caribou lakes) to 0.03 mg N/L (Calf Lake), which were below the pH and temperature dependent SSWQO and CWQG. Concentrations of TKN ranged from 0.21 mg N/L (Ridge Lake) to 0.45 mg N/L (Calf Lake). Half of the samples in the Caribou Lake sub-basin were at or below the detection limit for total phosphorus, with detectable levels ranging from 0.03 mg/L (Cirque Lake) to 0.05 mg/L (Ridge Lake). Summer concentrations of DOC ranged from 3.4 to 10 mg/L, with Cigar Lake being the lowest and Lower Lake being the highest. Fall concentrations of DOC ranged from 2.6 (Cirque Lake) to 4.7 mg/L (Crash and Calf lakes).

Total metal concentrations were either below the detection limits or below applicable guidelines with the following exceptions. Fall total aluminum concentration in Crash Lake was 0.12 mg/L, which was higher than the SSWQG and CWQG of 0.1 mg/L, based on a field-measured pH of 7.0. Fall total chromium concentrations in Ridge and Cirque lakes were 0.0022 and 0.0015 mg/L, respectively, which were higher than the most conservative CWQG of 0.0010 mg/L for hexavalent chromium.

Lead-210, Ra-226, and Th-232 were not detected in any lake samples. Polonium-210 was detected in one summer sample (0.008 Bq/L; Caribou Lake duplicate) and one fall sample (0.007 Bq/L; Calf Lake). Thorium-230 was reported at the detection limit in one summer sample (0.01 Bq/L; Fox Lake). Thorium-228 was reported at the detection limit in one fall sample (0.01 Bq/L; Crash Lake). No SSWQO or CWQG exist for radionuclides.

Judge Sissons Lake Sub-Basin

2008

Water chemistry samples were collected at five stations in Judge Sissons Lake in summer and fall 2008. The results of the chemical analysis illustrates that water chemistry is uniform throughout the lake. Chemistry parameters were also similar between the summer (late July) and fall (late August) sampling periods (Attachment X.II, Tables X.II-3, and X.II-4). The conventional water chemistry parameters were similar to the range observed in other lakes in the mine site LSA.

Nitrate and nitrate-nitrite concentrations were at or below the reported detection limits in all lake samples. Total ammonia concentrations ranged from less than detection limit at some stations to 0.09 mg N/L (Station 3) and were below the pH and temperature dependent SSWQO and CWQG. Concentrations of TKN ranged from 0.28 mg/L (Station 1) to 1.5 mg/L (Station 4). Total phosphorus concentrations ranged from less than 0.01 to 0.04 mg/L. Concentrations of DOC ranged from 2.5 to 2.9 mg/L.

Detection limits for total metals were at or below the most conservative guideline (SSWQO or CWQG) with the exception of cadmium (detection limit was 0.0001 mg/L, higher than the SSWQO and CWQG of 0.000017 mg/L) and mercury (detection limit was 0.05 µg/L, higher than the SSWQO and CWQG of 0.026 µg/L). Total metal concentrations were either below the detection limits or below applicable guidelines with one exception. Total chromium concentration was 0.0026 mg/L at Station 4 in Judge Sissons Lake in the summer, which was higher than the most conservative CWQG of 0.0010 mg/L for hexavalent chromium.

Lead-210, Po-210, Th-228, Th-230, and Th-232 were not detected in any lake samples. Radium-226 was detected in one summer sample (0.009 Bq/L; Station 1 in Judge Sissons Lake). No SSWQO or CWQG exist for radionuclides.

2009

Water chemistry samples were collected at one station in Judge Sissons Lake in summer 2009, due to weather and safety constraints. Five stations were sampled in the fall 2009 (Attachment X.II, Table X.II-5). As observed in 2008, the results indicate that water chemistry is uniform throughout the lake and similar between the summer and fall sampling periods.

Field-measured pH and specific conductivity values were pH 7.2 to 8.4 and 21 to 24 µS/cm, respectively. Total alkalinity and total hardness concentrations were 7 to 12 mg/L and 9 to 11 mg/L, respectively.

Total ammonia was not detected (detection limit was 0.01 mg N/L). Concentrations of TKN ranged from 0.21 to 0.35 mg/L. Total phosphorus concentrations ranged from less than 0.01 to 0.01 mg/L. Concentrations of DOC ranged from 2.8 to 4.3 mg/L.

The concentrations of total metals were either below the detection limits or below the SSWQO and CWQG.

Skinny Lake and Siamese Lake Sub-Basins

2007

A water chemistry sample was collected in Skinny Lake in fall 2007 (Attachment X.II, Table X.II-2). Field-measured pH was 7.1, which was within the range of applicable guidelines. Specific conductivity (field-measured), total alkalinity, and total hardness values were 16 µS/cm, less than 1 mg/L, and 7 mg/L, respectively. Total ammonia and total Kjeldahl nitrogen were detected in the sample at 0.08 mg N/L and 0.12 mg N/L, respectively.

Detection limits for total metals were at or below the most conservative guideline with the exception of cadmium (detection limit was 0.0001 mg/L, higher than the SSWQO and CWQG of 0.000017 mg/L) and mercury (detection limit was 0.05 µg/L, higher than the SSWQO and CWQG of 0.026 µg/L). Total metal concentrations were either below the detection limits or below applicable guidelines.

No radionuclides were detected, with the exception of Th-230 (0.01 Bq/L). No SSWQO or CWQG exist for radionuclides.

2008

Skinny Lake and both basins of Siamese Lake were sampled in the fall of 2008 (Attachment X.II, Table X.II-4). The water quality parameters were similar between the two lakes and the results were similar to other lakes samples in the mine site LSA. Total alkalinity values ranged from 6 mg/L (Siamese Lake) to 8 mg/L (Skinny Lake). Specific conductivity ranged from 13 µS/cm (Squiggly Lake) to 17 µS/cm (Skinny Lake). pH values ranged from pH 6.7 (Skinny Lake) to pH 7.03 (Siamese Lake) and were within the SSWQO and CWQG range (pH 6.5 to 9). Total hardness was 6 mg/L in both lakes.

Nitrate and nitrate-nitrite concentrations were at or below the reported detection limits in all lake samples. Total ammonia concentrations ranged from less than 0.01 mg N/L (Skinny Lake) to 0.07 mg N/L (Station 1 of Siamese Lake) and were below the pH and temperature dependent SSWQO and CWQG. Concentrations of TKN ranged from 0.10 mg N/L (Siamese Lake in the fall) to 0.19 mg N/L (Skinny Lake). Total phosphorus concentrations ranged from less than 0.01 to 0.02 mg/L. Concentrations of DOC ranged from 2.1 to 2.4 mg/L.

Detection limits for total metals were at or below the most conservative guideline (SSWQO or CWQG) with the exception of cadmium (detection limit was 0.0001 mg/L, higher than the SSWQO and CWQG of 0.000017 mg/L) and mercury (detection limit was 0.05 µg/L, higher than the SSWQO and CWQG of 0.026 µg/L). Total metal concentrations were either below the detection limits or below applicable guidelines.

Lead-210, Po-210, Th-228, Th-230, and Th-232 were not detected in any lake samples. Radium-226 was detected in both basins of Siamese Lake; ranging from 0.006 Bq/L (Station 1) to 0.09 Bq/L (Station 2). No SSWQO or CWQG exist for radionuclides.

4.2.2.2 Streams in the Mine Site Local Study Area

Willow Lake Sub-Basin

2007

A water chemistry sample was collected from Pointer/Rock Stream in fall 2007 (Attachment X.II, Table X.II-2). Field-measured pH was 7.4, which was within the range of applicable guidelines. Specific conductivity (field-measured), total alkalinity, and total hardness values were 12 µS/cm, 4 mg/L, and 6 mg/L, respectively. Total ammonia and TKN were detected in the sample at 0.09 mg N/L and 0.42 mg N/L, respectively. Nitrate-nitrite and total phosphorus were not detected.

Detection limits for total metals were at or below the most conservative guideline with the exception of cadmium (detection limit was 0.0001 mg/L, higher than the SSWQO and CWQG of 0.000017 mg/L) and mercury (detection limit was 0.05 µg/L, higher than the SSWQO and CWQG of 0.026 µg/L). Total metal concentrations were either below the detection limits or below applicable guidelines.

No radionuclides were detected, with the exception of Po-210 (0.005 Bq/L). No SSWQO or CWQG exist for radionuclides.

2008

Water chemistry samples were collected from six streams in spring and fall 2008 (Attachment X.II, Tables X.II-6 and X.II-7). In the spring, total alkalinity ranged from 4 mg/L (Northeast Inflow of Pointer Lake) to 9 mg/L (Pointer/Rock Stream). Alkalinity was generally slightly higher in the fall, and ranged from 5 mg/L (Northeast Inflow of Pointer Lake) to 20 mg/L (Sik Sik/Rock Stream). Specific conductivity ranged from 14 µS/cm (Sik Sik/Rock Stream) to 19 µS/cm (Northeast Inflow of Pointer Lake) in the spring, and was higher in the fall, ranging from 15 µS/cm (Pointer/Rock Stream) to 46 µS/cm (Sik Sik/Rock Stream). Field pH values were slightly higher in the spring than in the fall. In the spring, field pH ranged from 6.6 (Sik Sik/Rock Stream) to 7.3 (Northeast Inflow of Pointer Lake) compared to pH 6.3 to 7.1 in the fall. The stream sample from Rock/Willow Stream in the fall had a field pH value (6.3) below the lower limit of the SSWQO and CWQG range of 6.5 to 9. Total hardness values were slightly lower in the spring than in the fall. Hardness ranged from 6 to 9 mg/L in the spring and from 6 to 23 mg/L in the fall.

Nutrient concentrations were similar between spring and fall. Nitrate and nitrate-nitrite were at or just above the reporting detection limits of 0.04 mg N/L and 0.01 mg N/L in the spring, respectively, and below the reported detection limit in the fall. Detectable levels of ammonia ranged from 0.02 mg N/L (Sik Sik/Rock Stream in the fall and Northeast Inflow of Pointer Lake in both sessions) to 0.07 mg N/L (Rock/Willow Stream in the spring), which are below the pH and temperature dependent SSWQO and CWQG. Concentrations of TKN ranged from 0.34 mg/L (Pointer/Rock Stream in the spring) to 0.68 mg/L (Sik Sik/Rock Stream in the fall). Total phosphorus was only above detection limits in the spring sample from Willow/Judge Sissons Stream (0.02 mg/L). Concentrations of DOC ranged from 4.4 mg/L (Pointer/Rock Stream) to 18 mg/L (Sik Sik/Rock Stream), both measured during the fall study.

Detection limits for total metals were at or below the most conservative guideline with the exception of cadmium (detection limit was 0.0001 mg/L, higher than the SSWQO and CWQG of 0.000017 mg/L) and mercury (detection limit was 0.05 µg/L, higher than the SSWQO and CWQG of 0.026 µg/L). Most total metals concentrations were either below the detection limits or below the SSWQO and CWQG. In the fall, the total aluminum concentration at Rock/Willow Stream was 0.054 mg/L, which exceeded the SSWQO and CWQG pH-dependent guideline of 0.005 mg/L. In the spring, total cadmium concentration at stations in Northeast Inflow of Pointer Lake and Sik Sik/Rock Stream were reported at the detection limit of 0.0001 mg/L, which exceed the SSWQO and CWQG of 0.000017 mg/L. Total cadmium was not detected in any fall samples. Total iron concentration in the spring at both of these streams was 0.35 and 0.43 mg/L, respectively, which exceeded the SSWQO and CWQG of 0.3 mg/L. Total iron concentration in the fall at the station in Sik Sik/Rock Stream was 0.42 mg/L, which also exceeds the guidelines. Total copper concentration at the station in Northeast Inflow of Pointer Lake was 0.0031 mg/L, which exceeded the hardness-dependent SSWQO and CWQG of 0.002 mg/L.

Lead-210, Ra-226, Th-228, Th-230, and Th-232 were either not detected in any stream samples or detected at or slightly above the detection limits. Polonium-210 concentrations were higher in the spring than in the fall samples. In the fall, Po-210 ranged from less than 0.005 to 0.006 Bq/L. In the spring, Po-210 was detected in five out of six stream stations; detected concentrations ranged from 0.008 Bq/L (Northeast Inflow at Pointer Lake) to 0.030 Bq/L (Sik Sik/Rock Stream). No SSWQO or CWQG exist for radionuclides.

2009

Water chemistry samples were collected from four streams in spring and fall 2009 (Attachment X.II, Table X.II-5). Field-measured pH values were generally lower in the spring (pH 6.7 to 7.7) than in the fall (pH 7.7 to 8.0). All pH values were within applicable guidelines. Field-measured conductivity, total alkalinity, and total hardness were lower in the spring than in the fall for two of the streams: Northeast Inflow of Pointer Lake and Sik Sik/Rock Stream. Conversely, these parameters were similar between seasons for the two other streams: Rock/Willow and Willow/Judge Sissons streams. Field-measured conductivity ranged from 16 to 45 µS/cm, total alkalinity from 3 to 10 mg/L, and total hardness from 7 to 17 mg/L.

Total ammonia concentrations were higher in the spring (0.10 to 0.13 mg N/L) than in the fall (less than 0.01 to 0.02 mg N/L). Total phosphorus concentrations were similar between seasons and among streams, ranging from less than 0.01 to 0.02 mg/L. Concentrations of DOC ranged from 2.9 mg/L (Northeast Inflow of Pointer Lake in fall) to 6.7 mg/L (Sik Sik/Rock Stream in spring).

Detection limits for total metals were at or below the most conservative guideline. Most total metals concentrations were either below the detection limits or below the SSWQO and CWQG. In the fall, the total copper concentration at the station in the northeast inflow of Pointer Lake was 0.0035 mg/L, which exceeded the SSWQO and CWQG hardness-dependent guideline of 0.002 mg/L. In the spring and fall, total iron concentrations at the station in Sik Sik/Rock Stream ranged from 0.39 to 0.51 mg/L, which exceeded the SSWQO and CWQG of 0.3 mg/L. Total metal concentrations were generally similar between seasons.

Thorium-228 and Th-232 were not detected in any stream samples. Lead-210, Po-210, and Th-230 were detected in the spring sample from northeast inflow of Pointer Lake, but not in the fall sample. Concentrations ranged from 0.008 to 0.03 Bq/L. Radium-226 was detected in three fall samples from Northeast Inflow of Pointer Lake, Rock/Willow, and Willow/Judge Sissons streams, ranging from 0.005 to 0.007 Bq/L. No SSWQO or CWQG exist for radionuclides.

Lower Lake Sub-Basin

2007

A water chemistry sample was collected from Shack/Lower Stream in fall 2007 (Attachment X.II, Table X.II-2). Field-measured pH was 7.5, which was within the range of applicable guidelines. Specific conductivity (field-measured), total alkalinity, and total hardness values were 33 µS/cm, 14 mg/L, and 16 mg/L, respectively. Nitrate-nitrite and total phosphorus concentrations were at the reported detection limit. Ammonia and TKN concentrations were 0.09 mg N/L and 0.42 mg/L, respectively.

Detection limits for total metals were at or below the most conservative guideline with the exception of cadmium (detection limit was 0.0001 mg/L, higher than the SSWQO and CWQG of 0.000017 mg/L) and mercury (detection limit was 0.05 µg/L, higher than the SSWQO and CWQG of 0.026 µg/L). Total metal concentrations were either below the detection limits or below applicable guidelines.

Radionuclides were not detected, with the exception of Po-210 (0.006 Bq/L). No SSWQO or CWQG exist for radionuclides.

2008

Water chemistry samples were collected from eight streams in spring and fall 2008 (Attachment X.II, Table X.II-6 and X.II-7). Concentrations of conventional parameters were generally lower in the spring than in the fall. In the spring, total alkalinity values ranged from 4 mg/L (Shack/Lower Stream) to 10 mg/L (End Grid/Shack Stream) compared to 10 mg/L (Mushroom/End Grid Stream) to 22 mg/L (Knee/Lunch Stream) in the fall. Specific conductivity ranged from 14 µS/cm (Cigar/Lunch Stream) to 21 µS/cm (Knee/Lunch and End Grid/Shack Streams) in the spring and from 28 µS/cm (Mushroom/End Grid Stream) to 46 µS/cm (Knee/Lunch Stream) in the fall. Total hardness ranged from 6 mg/L (Cigar/Lunch Stream) to 10 mg/L (Knee/Lunch and End Grid/Shack Streams) in the spring and from 13 mg/L (Mushroom/End Grid Stream) to 22 mg/L (Knee/Lunch Stream) in the fall. Field-measured pH values were higher in the spring than in the fall. Field pH ranged from 7.2 (Lunch/Andrew Stream) to 7.5 (Shack/Lower Stream) in the spring and from 6.9 (Mushroom/End Grid Stream) to 7.3 (Cigar/Lunch Stream) in the fall. All field pH values were within SSWQO and CWQG range of 6.5 to 9.

Nutrient concentrations were similar between spring and fall. Nitrate and nitrate-nitrite concentrations were generally at or below the reported detection limits. Detectable levels of total ammonia ranged from 0.01 mg N/L (Mushroom/End Grid Stream duplicate) to 0.08 mg N/L (Lower/Judge Sissons Stream), which were below the pH and temperature dependent SSWQO and CWQG. Concentrations of TKN ranged from 0.34 mg/L (various streams) to 0.57 mg/L (Lower/Judge Sissons Stream). Total phosphorus concentrations ranged from less than 0.01 mg/L (various streams) to 0.03 mg/L (Lower/Judge Sissons Stream). Concentrations of DOC ranged from 5 mg/L (Cigar/Lunch Stream) to 13 mg/L (Lower/Judge Sissons Stream).

Detection limits for total metals were at or below the most conservative guideline with the exception of cadmium (detection limit was 0.0001 mg/L, higher than the SSWQO and CWQG of 0.000017 mg/L) and mercury (detection limit was 0.05 µg/L, higher than the SSWQO and CWQG of 0.026 µg/L). Most concentrations of total metals were either below the detection limits or below the SSWQO and CWQG. In the spring, total cadmium concentrations at stations in Shack/Lower and Lower/Judge Sissons Streams were reported at the detection limit of 0.0001 mg/L, which exceed the SSWQO and CWQG of 0.000017 mg/L. Total cadmium was not detected in any fall samples. Total chromium concentration at a station in Knee/Lunch Stream in the spring was 0.0046 mg/L, which is higher than the most conservative CWQG of 0.0010 mg/L for hexavalent chromium. Total iron concentration in the fall at stations in two streams (Knee/Lunch and Andrew/Shack streams) was 0.30 mg/L and 0.40 mg/L, respectively, which exceed the SSWQO and CWQG of 0.3 mg/L.

Isotopes of lead and thorium (i.e., Pb-210, Th-228, Th-230, and Th-232) were either not detected in any stream samples or detected at or slightly above the detection limits. Polonium-210 was detected in more samples in the spring than the fall, and concentrations were slightly higher in the spring. In the spring, Po-210 was detected at all but one stream station, and detected concentrations ranged from 0.007 Bq/L (Shack/Lower Stream) to 0.020 Bq/L (Cigar/Lunch Stream). In the fall, Po-210 was detected in three streams (Knee/Lunch, Lunch/Andrew, and Andrew/Shack) at concentration ranging from 0.006 to 0.010 Bq/L. Radium-266 was detected in two samples in the spring (ranging from 0.006 to 0.007 Bq/L) and in five samples in the fall (ranging from 0.005 to 0.010 Bq/L). No SSWQO or CWQG exist for radionuclides.

Caribou Lake Sub-Basin

2007

Water chemistry samples were collected from Crash/Fox and Fox/Caribou streams in fall 2007 (Attachment X.II, Table X.II-2). Field-measured pH values were similar between the streams (pH 7.1 in Crash/Fox Stream and pH 7.3 in Fox/Caribou Stream). Both field pH values were within the SSWQO and CWQG range of 6.5 to 9.

Crash/Fox Stream had higher specific conductivity, total alkalinity, and total hardness than Fox/Caribou Stream. Specific conductivity was 29 µS/cm in Crash/Fox Stream compared to 7 µS/cm in Fox/Caribou Stream. Total alkalinity and total hardness concentrations were higher in Crash/Fox Streams at 13 mg/L (both parameters), compared to Fox/Caribou Stream (alkalinity of 8 mg/L and total hardness of 7 mg/L).

Nutrient concentrations were similar between the streams. For example, total ammonia concentrations were 0.1 and 0.14 mg N/L and TKN concentrations were 0.25 and 0.32 mg N/L. Nitrate-nitrite and total phosphorus concentrations were below or close to the detection limits of 0.01 mg N/L and 0.01 mg/L, respectively.

Detection limits for total metals were at or below the most conservative guideline (SSWQO or CWQG) with the exception of cadmium (detection limit was 0.0001 mg/L, higher than the SSWQO and CWQG of 0.000017 mg/L) and mercury (detection limit was 0.05 µg/L, higher than the SSWQO and CWQG of 0.026 µg/L). Total metal concentrations were either below the detection limits or below applicable guidelines with the exception of aluminum. The concentration of aluminum in Crash/Fox Stream was 0.18 mg/L, higher than the pH dependent SSWQO and CWQG of 0.1 mg/L.

No radionuclides were detected in Crash/Fox Stream. Polonium-210 and Ra-226 were detected in Fox/Caribou Stream (0.006 Bq/L for both). No SSWQO or CWQG exist for radionuclides.

2008

Water chemistry samples were collected from six streams in spring and fall 2008 (Attachment X.II, Table X.II-6 and X.II-7), including:

- Ridge/Crash Stream;
- Cirque/Crash Stream;
- Crash/Fox Stream;
- Fox/Caribou Stream;
- Caribou/Calf Stream; and
- Calf/Judge Sissons Stream.

Concentrations of conventional parameters were generally lower in the spring than in the fall. Field-measured pH values were higher in the spring than in the fall. Field pH values ranged from 6.8 (Fox/Caribou Stream) to 7.6 (Caribou/Calf Stream) in spring and from 6.6 (Cirque/Crash Stream) to 6.9 (Fox/Caribou Stream) in the fall. All field pH values were within the SSWQO and CWQG range of 6.5 to 9. Total alkalinity values ranged from 3 mg/L (Crash/Fox Stream) to 7 mg/L (Fox/Caribou and Calf/Judge Sissons streams) in the spring and from 6 mg/L (Cirque/Crash Stream) to 16 mg/L (Crash/Fox Stream) in the fall. Specific conductivity ranged from 14 µS/cm (Cirque/Crash Stream) to 19 µS/cm (Calf/Judge Sissons Stream) in the spring and from 15 µS/cm (Cirque/Crash Stream) to 26 µS/cm (Crash/Fox Stream) in the fall. Total hardness in the Caribou Lake sub-basin ranged from 6 mg/L (Cirque/Crash Stream) to 9 mg/L (Fox/Caribou Stream) in the spring and from 7 mg/L (Cirque/Crash Stream) to 12 mg/L (Crash/Fox Stream) in the fall.

Nutrient concentrations were similar between spring and fall. Nitrate and nitrate-nitrite concentrations were generally at or below the reported detection limits. Detectable levels of ammonia ranged from 0.02 mg N/L (Crash/Fox Stream) to 0.1 mg N/L (Calf/Judge Sissons Stream), which were below the pH and temperature dependent SSWQO and CWQG. Concentrations of TKN ranged from 0.23 mg N/L (Ridge/Crash Stream) to 0.39 mg N/L (Caribou/Calf and Calf/Judge Sissons streams). Total phosphorus concentrations ranged from less than 0.01 mg/L (various streams) to 0.04 mg/L (Cirque/Crash Stream). Concentrations of DOC ranged from 2.7 mg/L (Fox/Caribou Stream) to 6.2 mg/L (Calf/Judge Sissons Stream).

Detection limits for total metals were at or below the most conservative guideline (SSWQO or CWQG) with the exception of cadmium (detection limit was 0.0001 mg/L, higher than the SSWQO and CWQG of 0.000017 mg/L) and mercury (detection limit was 0.05 µg/L, higher than the SSWQO and CWQG of 0.026 µg/L). Most concentrations of total metals were either below the detection limits or below the SSWQO and CWQG. In the fall, total aluminum concentration in Cirque/Cigar Stream was 0.19 mg/L, which exceeded the pH dependent SSWQO and CWQG of 0.1 mg/L. Total chromium concentration in Ridge/Crash Stream in the fall was 0.052 mg/L, which exceeded the most conservative CWQG of 0.0010 mg/L for hexavalent chromium.

Lead-210, Th-228, Th-230, and Th-232 were either not detected in any stream samples or detected at or slightly above the detection limits. Po-210 was detected in more samples from the spring than the fall, and concentrations were slightly higher in the spring. In the spring, Po-210 was detected at all but two stream stations, at concentrations ranging from 0.010 to 0.030 Bq/L. In the fall, Po-210 was detected in one stream (Crash/Fox Stream) at 0.006 Bq/L. Radium-226 was detected in more fall samples in the spring samples; detected concentrations in the fall ranged from 0.005 to 0.008 Bq/L, whereas Ra-226 was only detected at one stream in the spring (0.007 Bq/L). No SSWQO or CWQG exist for radionuclides.

Aniguq River Watershed

2009

Water chemistry samples were collected from two stations in the Aniguq River in fall 2009 (Attachment X.II, Table X.II-5). Field-measured pH values were pH 7.9 and 8.1, which were within applicable guidelines. Field-measured conductivity values were 28 and 30 µS/cm, total alkalinity concentration was 13 and 22 mg/L, and total hardness was 11 and 12 mg/L.

Total ammonia concentrations were variable at less than 0.01 and 0.04 mg N/L. Total phosphorus concentrations were also variable at less than 0.01 and 0.04 mg/L. Concentrations of DOC were 3.1 and 4 mg/L.

Detection limits for total metals were at or below the most conservative guideline limits. Total metals concentrations were either below the detection limits or below the SSWQO and CWQG.

Lead-210, Ra-226, Th-228, Th-230, and Th-232 were not detected in either sample. Polonium-210 was detected in one sample at 0.007 Bq/L. No SSWQO or CWQG exist for radionuclides.

4.2.2.3 Lakes in the Site Access Local Study Area

Baker Lake was the only lake sampled in the access local study area.

Baker Lake Sub-Basin

2008/2009

The five Baker Lake stations (Attachment X.I, Figure X.I-3) were established near shore to characterize conditions around potential shipping facilities. Stations 1, 2, and 3 were located on the north shore, in areas of typical bathymetry (relatively steep slopes, 5 to 13 m water depth); Station 4 was located in a shallow protected bay (less than 2 m deep) on the south shore into which several small tributaries entered. Station 5 was located on a shallow shelf on the lake (less than 2 m deep), on the west shore, All five stations were sampled in September 2008 and Stations 1 and 2 were sampled in August 2009.

Baker Lake water at the five sampling stations was generally characterized by low concentrations of nutrients (e.g., total organic carbon was less than 4 mg/L; nitrate and total phosphate were often below detection limits of 0.01 mg/L and ammonia ranged from 0.01 to 0.09 mg/L), low hardness and alkalinity, clear water conditions, and circum-neutral conditions (mean pH of 7.0; Attachment X.II, Table X.II-8). Previous studies support these results, suggesting that the lake is oligotrophic (AREVA 2008). Water was visibly turbid at Station 4, possibly due to freshwater inputs from nearby tributaries.

Baker Lake was well mixed when sampled in 2008 and 2009, as indicated by temperature and dissolved oxygen profiles (Section 6.2.3.5) and the similarity in chemistry of samples collected from near surface and deeper waters (Attachment X.II, Table X.II-8). Exceptions were noted in 2008: iron (higher at surface than mid-depth at Stations 1 and 2) and zinc (higher at surface than mid-depth at Stations 2 and 3). Both iron and zinc levels were relatively low in these samples (iron ranged from 0.0012 to 0.012 mg/L and zinc ranged from 0.0028 to 0.0074 mg/L at Stations 1, 2, and 3).

Spatial trends in several water chemistry parameters were identified in the 2008 samples, which were likely related to differences in tributary inputs and water depths at the five stations (Attachment X.II, Table X.II-8). Levels of general parameters (e.g., sodium, potassium, strontium, sulphate, chloride, total dissolved solids, and conductivity) were similar at Stations 1, 2, and 3, and lower at Stations 4 and 5. In contrast, levels of aluminum and iron were higher at Station 4 than the other stations, with the elevated aluminum and iron levels likely associated with the high turbidity observed in the tributary streams draining into that portion of the lake. These tributaries were not investigated during this sampling program.

Metals levels showed similar spatial trends to the general parameters, that is, similar concentrations at Stations 1, 2, and 3, higher concentrations at Station 4 and intermediate at Station 5 (trends for selected metals shown in Figure 4.2-1). While this trend was most distinctive for aluminum and iron, with levels 1.5 to 3 times higher, barium, manganese, titanium and zinc levels were also higher and boron and strontium levels lower at Station 4 than the other stations. Concentrations of antimony, beryllium, cadmium, chromium, silver, thallium, and uranium were lower than detection limits in all samples at the five sites (Attachment X.II, Table X.II-8). Concentrations of arsenic, cobalt, copper, lead, molybdenum, nickel, selenium, tin, vanadium, were close to or at the detection limits, with concentrations slightly higher at Station 4 than the other stations. Cadmium concentrations were below the detection limit of 0.0001 mg/L at all five stations; however, since this was higher than the CCME guideline (0.000017 mg/L), it was not possible to evaluate cadmium levels.

Total metals concentrations were compared with CCME guidelines for protection of aquatic life (CCME 2007). Concentrations were well below these guidelines for all metals except cadmium, which was not possible to evaluate as noted above and total aluminum, which exceeded the CCME guideline (0.10 mg/L) at Station 4 (0.11 mg/L). Results for several metals are shown in Figure 4.2-1, along with the corresponding CCME guideline.

The August 2009 program included samples from Stations 1 and 2 (Figure 4.2-1). Water chemistry was more dilute at these stations in 2009, as reflected in lower conductivity (120 to 166 µS/cm) compared to 2008 (630 µS/cm); however, ions (e.g., sodium, potassium, sulphate), hardness, and nitrate levels were higher in 2009 (0.09 mg/L) than 2008 (less than 0.01 mg/L). These differences may have been related to seasonal trends (i.e., more dilute water related to freshet, more nutrients available earlier in the growing season). Metal concentrations remained very low in 2009. Concentrations of dissolved and total metals were similar for most metals, indicating that metals were present mainly in dissolved form. The lower proportion of dissolved to total levels for aluminum, iron and manganese reflected the presence of particulate matter (suspended solids), which was especially notable at Station 4 in 2008, which was influenced by the high turbidity of inflowing tributaries. Aluminum and iron are major constituents of silt.

The ratio of dissolved to total metals can be used as a quality check for filtration of samples in the field or laboratory; when dissolved levels are higher than total, potential contamination sources are considered. Levels of dissolved metals were typically lower than total levels (Attachment X.II, summary of laboratory results), which supports the accuracy of these results. There were a few cases where levels of dissolved metals were higher than total metals, and both measurements were more than ten times the analytical detection limit (i.e., high enough to be reliably measured), indicating potential contamination during filtration of samples in the field. These included:

- zinc in four samples (Station 1 surface [2008], Station 2 mid-depth [2009], Station 3 mid-depth, Station 5 surface);
- tin in one sample (Station 5 surface); and
- aluminum and iron in one sample (Station 2 mid-depth).

The potential contamination would not affect results in relation to water quality guidelines, given that levels of zinc, tin, and aluminum at these stations were considerably lower than guidelines.

Radionuclides were below detection limits at all sites (Attachment X.II, Table X.II-8) in both 2008 and 2009.

Thelon River Watershed

Squiggly Lake was the only waterbody in the Thelon River watershed sampled in 2008. Water chemistry characteristics were similar to that reported for lakes in the mine site LSA (Attachment X.II; Table X.II-4). There were no exceedances of the SSWQO and CWQG guideline limits. Radionuclides were below detection limits.

4.3 Summary

The water chemistry results indicate that the lakes of the mine site LSA were similar to each other. Lakes were characterized by low ionic strength and neutral to alkaline pH. The range of total alkalinity values during open water conditions indicated that the lake waters had low to high sensitivity to acid (Saffran and Trew 1996). Total hardness concentrations indicated that the waters had very soft to soft water hardness (McNeely et al. 1979). Concentrations of major ions were higher under ice conditions, likely as a result of ice formation, which concentrated the ions in the remaining water column. Measured nutrient concentrations (particularly nitrogen and phosphorus) were typical of oligotrophic waterbodies in subarctic regions. Baseline water quality parameters were less than SSWQO and CWQG with the exception of some parameters (i.e., aluminum, ammonia, chromium, iron, lead). Radionuclides were generally not detected or were detected near the analytical detection limits.

Streams of the study area were characterized by low ionic strength and neutral to alkaline pH. In general, pH values were higher in the spring than in the fall. Total alkalinity, total hardness, and specific conductivity were generally lower in the spring than in the fall. Total hardness concentrations indicated that the stream waters had very soft water hardness (McNeely et al. 1979). Measured nutrient concentrations were typical of oligotrophic waterbodies in subarctic regions. Baseline water quality parameters were less than SSWQO and CWQG with the exception of some parameters (i.e., aluminum, cadmium, chromium, copper, and lead). Radionuclides were generally not detected or were detected near the analytical detection limits.

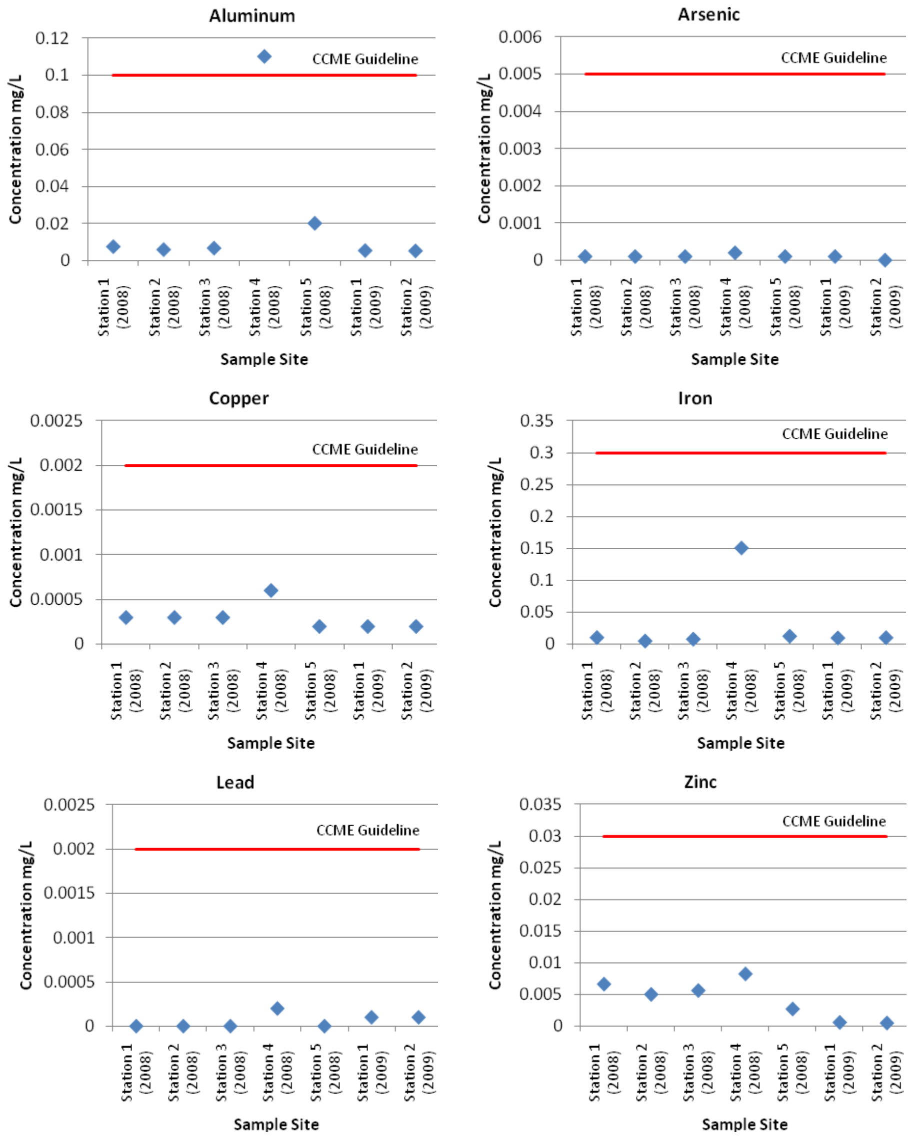


Figure 4.2-1 Mean Concentration of Total Metals in Baker Lake Water Samples, September 2008 and August 2009

5 Sediment Quality

Lake sediments consist of organic and inorganic matter introduced through erosion of soils and other geologic materials in the watershed, and through the deposition of particulate mineral matter and organic material produced in the lake (BEAK 1990). Studies of sediment quality in the Kiggavik study area were carried out between 1979 and 1991. These historical studies broadly covered the study area. The objectives were to collect baseline information on sediment particle size characteristics, sediment chemistry, and sedimentation rates. Recent studies were conducted between 2007 and 2009 to expand and complement the existing baseline information on sediment chemistry and sediment particle size characteristics. An overall summary of lakes sampled and year of collection is presented in Table 5.0-1.

5.1 Overview of Studies

Available historical sediment quality information includes particle size characterization, physical properties, chemistry analysis (i.e., nutrients, major ions, metals, and radionuclides), and sedimentation rates. Sediment sampled for particle size characterization was collected from Willow and Judge Sissons Lake sub-basins in 1988. Sediment chemistry samples were collected in 1979, 1986, 1988, 1990, and 1991 from Skinny, Willow, Caribou, Boulder, Judge Sissons, and Lower Lake sub-basins. Sedimentation rate samples were collected from Pointer Lake and Judge Sissons Lake sometime before 1990 (the exact year of collection was not provided in BEAK (1990).

The sampling methods, intensity, and areas tended to differ between surveys, which affects the ability to compare results between data sets. Based on similarities in sampling methods and intensity, the field studies and results have been grouped into sampling periods for the purposes of this report. The sampling periods that have been identified are:

- 1979: Willow Lake and Judge Sissons Lake sub-basins;
- 1986: Willow, Caribou, Boulder and Judge Sissons Lake sub-basins;
- 1988: Willow, Caribou, and Judge Sissons Lake sub-basins; and
- 1990 to 1991: Willow, and Lower, and Judge Sissons Lake sub-basins.

Table 5.0-1 Summary of Lake Sediment Sampling in the Kiggavik Project Area, 1979-2009

			BEAK 1990			BEAK 1992a	Golder				Nunami Stantec	
Watershed	**Sub-Basin**	**Waterbody**	**1979**	**1986**	**1988**	**1990**	**1991**	**2007**	**2008**	**2009**	**2008**	**2009**
Aniguq River	Willow Lake	Felsenmeer Lake	-	X	-	-	-	-	-	-	-	-
		Escarpment Lake	-	X	-	-	-	-	-	-	-	-
		Lin Lake	-	X	-	-	-	-	-	-	-	-
		Scotch Lake	X	-	X	-	-	-	-	-	-	-
		Jaeger Lake	X	-	X	-	-	-	-	-	-	-
		Pointer Lake	X	-	X	-	X	X	X		-	-
		Sik Sik Lake	-	-	-	-	-	X	X	X	-	-
		Rock Lake	-	-	-	-	-		X	X	-	-
		Willow Lake	-	X	-	-	-	X	X	X	-	-
	Lower Lake	Mushroom Lake	-	-	-	-	-		X		-	-
		End Grid Lake	-	-	-	-	-	X	X		-	-
		Cigar Lake	-	-	-	-	-	-	X		-	-
		Lunch Lake	-	-	-	X	-	-	X		-	-
		Andrew Lake	-	-	-	-	-	X	X	X	-	-
		Shack Lake	-	-	-	X	X	X	X	-	-	-
		Lower Lake[(a)]	-	-	-	X	-	-	-	-	-	-
		Lower Lake	-	-	-	-	-	X	X	-	-	-
	Caribou Lake	Ridge Lake	-	X	-	-	-	X	X	-	-	-
		Cirque Lake	-	X	-	-	-	X	X	-	-	-
		Crash Lake	-	-	X	-	-	X	X	-	-	-
		Fox Lake	-	-	-	-	-	X	X	-	-	-
		Caribou Lake	-	X	-	-	-	-	X	-	-	-
		Calf Lake	-	-	-	-	-	-	X	-	-	-
	Boulder Lake	Boulder Lake	-	X	-	-	-	-	-	-	-	-
Aniguq River	Judge Sissons Lake	Judge Sissons Lake	X	X	X	-	X	-	X	X	-	-
	Siamese Lake	Siamese Lake	-	-	-	-	-	-	X	-	-	-
	Skinny Lake	Skinny Lake	-	X	-	-	-	X	X	-	-	-
Thelon River	Squiggly Lake	Squiggly Lake	-	-	-	-	-	-	X	-	-	-
Baker Lake	Baker Lake	Baker Lake	-	-	-	-	-	-	-	-	X	X

Source: BEAK 1990, 1992a.
(a) Sampling location was 2 km upstream of Lower Lake.
-= not collected.

5.1.1 Historical Summary 1979 to 1991

5.1.1.1 Sampling Period 1979

In 1979, sediments were collected in Scotch Lake, Jaeger Lake, Pointer Lake, and Judge Sissons Lake using a Kajak Brinkhurst (KB) corer (BEAK 1990). The number of samples collected at individual stations varied from one to 14 and were divided into surface (top 3 centimetres [cm]) and subsurface samples (10 to 13 cm depth). Station depths or methods of sample collection and handling were not provided. Each surface and subsurface sample was analyzed for metals (i.e., arsenic, cadmium, chromium, copper, lead, mercury, selenium, and tellurium) for all the lakes. In addition, uranium, lead-210 (Pb-210), radium-226 (Ra-226), thorium-228 (Th-228), thorium-230 (Th-230), and thorium-232 (Th-232) were analyzed in all the lake samples, except for Jaeger Lake (BEAK 1990).

5.1.1.2 Sampling Period 1986

In 1986, sediment samples were collected from 10 lakes in five sub-basins in the mine site LSA (BEAK 1990), including:

1. Felsenmeer, Escarpment, Lin, and Willow lakes (Willow Lake sub-basin);
2. Ridge, Cirque, Caribou lakes (Caribou Lake sub-basin);
3. Boulder Lake (Boulder Lake sub-basin);
4. Judge Sissons Lake (Judge Sissons Lake sub-basin); and
5. Skinny Lake (Skinny Lake sub-basin).

Limited information was available on the objectives of the 1986 program and the methods used. The Judge Sissons Lake sample was collected from a depth of about 5 metres (m) offshore from the inlet of the Willow Lake sub-basin. Samples were collected from areas near the deepest parts of the remaining smaller lakes. BEAK (1990) reported that it was difficult to locate zones of soft sediment accumulation in the shallow and relatively large lakes, such as Pointer, Caribou and Boulder and that repeated attempts were necessary to recover sufficient material for analysis. Whole sediment samples were analyzed for the following:

- physical properties (i.e., loss on ignition, chemical oxygen demand);
- nutrients (i.e., total Kjeldahl nitrogen [TKN], total phosphorus);
- major ions (i.e., calcium, magnesium, potassium, sodium);
- metals and metalloids (i.e., aluminum, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, strontium, uranium, vanadium, and zinc); and
- radionuclides (i.e., Pb-210, Ra-226, Th-230, and Th-232).

5.1.1.3 Sampling Period 1988

Three sub-basins were sampled in the mine site LSA in 1988 (BEAK 1990). Sediment samples were collected from five lakes, including:

- Scotch Lake, Jaeger Lake, and two stations on Pointer Lake (Willow Lake sub-basin);
- Crash Lake (Caribou Lake sub-basin); and
- Judge Sissons Lake (Judge Sissons Lake sub-basin).

Limited information was available on the objectives of the 1988 program and the methods used. Sediment samples were collected from the deep parts of each lake with the exception of Pointer Lake. In Pointer Lake, samples were collected from two stations; Station 1 was located in mid-lake, about 800 m south of the northern end of the lake, and Station 2 was located 800 m south of Station 1. The bottom material of the main basin of Pointer Lake consisted of sticky clay, sand, and rock, and did not appear to be indicative of depositional conditions (BEAK 1990). Whole sediment samples from all lakes were analyzed for uranium, Pb-210, polonium-220 (Po-220), Ra-226, radium-228 (Ra-228), Th-228, Th-230, and Th-232 (BEAK 1990).

Samples from Pointer Lake and Jaeger Lake were split in two to analyze for fine and whole fractions (BEAK 1990). Fine samples were sieved using a 63 micrometres (µm) sieve. Fine samples were analyzed only for major ions (i.e., calcium and magnesium) and select metals (i.e., aluminum, barium, lead, manganese, nickel, selenium, strontium, and zinc). Whole sediment samples were analyzed for the following:

- physical properties (i.e., loss on ignition, cation exchange capacity, chemical oxygen demand; particle size [percent clay, silt, sand]);
- nutrients (i.e., TKN, total phosphorus);
- major ions (i.e., calcium and magnesium); and
- metals and metalloids (i.e., aluminum, arsenic, barium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, selenium, strontium, uranium, and zinc).

5.1.1.4 Sedimentation Rates 1988

Sedimentation rates were measured in Pointer Lake and Judge Sissons Lake using the Pb-210 method (BEAK 1990). Sediment chronologies can be determined from the Pb-210 method when the supply of Pb-210 occurs at a constant (or proportional) rate to the sedimentation rate (McKee et al. 1987). This method has been used to estimate sedimentation rates in other Arctic lakes (BEAK 1990).

Duplicate sediment cores were collected in 1988, using a KB corer equipped with 4.7 cm (inside diameter) polycarbonate core tubes. Cores were collected from two depths (11 and 13 m) in Judge Sissons Lake, and one depth (approximately 1.8 m) in Pointer Lake. Attempts to collect cores from depths of 2 to 2.3 m in the main body of Pointer Lake and from depths greater than 10 m in the eastern basin of Judge Sissons Lake were unsuccessful, apparently due to the presence of rock, coarse sand or dense clay on the sediment surface, which prevented the corer from penetrating the lake sediments. Core samples were sliced into 0.5 to 2 cm sections in a plastic collar. Detailed analytical methods and calculation methods for sedimentation rates can be found in BEAK (1990).

5.1.1.5 Sampling Period 1990 to 1991

Field studies were carried out in August 1990 and July 1991 to collect additional baseline data from the Sissons and Kiggavik site development areas and to address the Federal Environmental Assessment Review Office requests for additional information (BEAK 1992b). In August 1990, sediment samples were collected from five stations within Lunch Lake, Shack Lake, and a waterbody located 2 kilometres (km) upstream of Lower Lake (BEAK 1992a). Each of the five samples were comprised of five pooled subsamples collected in each embayment. Samples were collected from the surficial layer (0 to 5 cm) with an Ekman or Ponar grab and transferred to a labeled plastic bag with a plastic spoon. Samples were kept cool with ice prior to delivery to the analytical laboratory. The samples (less than 500 µm size fraction) were analyzed for the following parameters:

- nutrients (i.e., total organic carbon);
- major ions (i.e., calcium, magnesium, potassium, and sodium);
- metals and metalloids (i.e., aluminum, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, strontium, titanium, uranium, vanadium, and zinc); and
- radionuclides (i.e., Pb-210, polonium-210 [Po-210], Ra-226, and Th-230).

Samples were collected from three waterbodies in July 1991, including Pointer Lake, Shack Lake, and Judge Sissons Lake. Sediment cores were collected in triplicate from the deep basins of Pointer Lake and Shack Lake using a KB corer. Only one sample was collected in Judge Sissons Lake despite several attempts using both a KB corer and a Ponar grab. The collected cores were sectioned in the field into three depth strata corresponding to 0 to 5 cm, 5 to 10 cm, and 10 to 15 cm. The 0 to 5 cm (surficial) samples were analyzed using the less than 63 µm size fraction for the following parameters:

- physical properties (i.e., loss on ignition);
- nutrients (i.e., TKN and total phosphorus);
- major ions (i.e., calcium, magnesium, potassium, and sodium);

- metals and metalloids (i.e., aluminum, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, strontium, titanium, uranium, vanadium, and zinc); and
- radionuclides (i.e., Po-210 and Ra-226).

The remaining core sections were not analyzed at that time and were archived for future analysis if required (BEAK 1992a).

5.1.2 Recent Sampling Period 2007 to 2009

5.1.2.1 Lakes in the Mine Site Local Areas

A summary of lakes and streams sampled and the geographic coordinates of the individual sampling stations has been provided Attachment X.I, Figure X.I-1, Table X.I-3). Twelve lakes from four different sub-basins were sampled by Golder in the 2007 sediment sampling program:

- Pointer, Sik Sik, and Willow lakes (Willow Lake sub-basin);
- End Grid, Andrew, Shack, and Lower lakes (Lower Lake sub-basin);
- Ridge, Cirque, Crash, and Fox lakes (Caribou Lake sub-basin); and
- Skinny Lake (Skinny Lake sub-basin).

In 2007, sampling was conducted at two stations in each lake; one at the deepest location in the lake station and one shallow station (1 m deep). Exceptions included Willow Lake, where only one sample was taken due to an absence of soft sediment at the deepest station, and Skinny Lake, due to time constraints.

In 2008, the sediment sampling program was expanded to include 50 stations in 22 lakes from the eight different sub-basins:

- Pointer, Sik Sik, Rock, and Willow lakes (Willow Lake sub-basin);
- Mushroom, End Grid, Cigar, Lunch, Andrew, Shack, and Lower lakes (Lower Lake sub-basin);
- Ridge, Cirque, Crash, Fox, Caribou, and Calf lakes (Caribou Lake sub-basin);
- Judge Sissons Lake (Judge Sissons Lake sub-basin);
- Siamese Lake (Siamese Lake sub-basin);
- Skinny Lake (Skinny Lake sub-basin);
- Squiggly Lake (Thelon River); and
- Baker Lake (Baker Lake sub-basin).

The 2009 sediment sampling program included five lakes in four sub-basins:

- Sik Sik, Rock, and Willow lakes (Willow Lake sub-basin);
- Andrew Lake (Lower Lake sub-basin);
- Judge Sissons Lake (Judge Sissons Lake sub-basin); and
- Baker Lake (Baker Lake sub-basin).

During the 2009 program, there was one station per lake, with the exception of Judge Sissons Lake, which had five stations located in the northern section of the lake. Only stations 1 and 2 were sampled in Baker Lake.

Surface sediment samples (approximately 2 litres [L]) were collected at each station using a standard Ekman grab sampler. Prior to sampling, the Ekman was rinsed twice with ambient water to remove any attached sediment or other material. If necessary, more than one grab was collected to obtain the required amount for analysis. Each sediment sample was placed into an individual polyethylene bag. The sample was double bagged and a waterproof paper label was inserted between the bags. The outer bag was labelled with waterproof marker with the appropriate information. Samples were frozen and shipped in sealed coolers to Golder's Saskatoon office prior to submission to Saskatchewan Research Council (SRC) Analytical Laboratories for analysis.

Two replicate sediment samples were taken at each of the five stations on Baker Lake in 2008 and again at stations 1 and 2 in 2009 (Attachment X.I, Figure X.I-3, Table X.I-3). Due to the abundance of rocks and boulders at Station 5, the samples were collect approximately 225 m from shore. Grab samples were collected from a boat using a petite ponar. Samples were taken from the entire grab using a stainless steel spoon and stored in plastic bags. General notes on sample colour and odour were recorded. Sampling methods were compatible with those described in the British Columbia Field Sampling Manual (Clark 2003).

5.1.2.2 Laboratory Analysis

Sediment chemistry samples were analyzed for some or all of the following parameters:

- physical properties (i.e., particle size, moisture content, loss on ignition);
- nutrients (i.e., nitrite+nitrate as nitrogen, ammonia as nitrogen, , total phosphorus, total organic carbon [TOC]);
- major ions (i.e., calcium, magnesium, potassium, sodium, and sulphate);
- metals and metalloids (i.e., aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, strontium, thallium, tin, titanium, uranium, vanadium, and zinc); and
- radionuclides (i.e., Pb-210, Po-210, Ra-226, Th-228, Th-230, Th-232).

Note that particle size and TOC are supporting environmental parameters required for the benthic invertebrate studies (refer to Section 7.0). Therefore, these parameters were only analyzed in lakes that were also sampled for benthic invertebrates.

Baker Lake sediment chemistry samples were analyzed for some or all of the following parameters in 2008 and 2009:

- physical properties (i.e., particle size);
- nutrients (i.e., total nitrogen [2008 only], total phosphorus [2008 only], TOC);
- major ions (i.e., calcium, magnesium, potassium, sodium, and sulphate [2008 only]);
- metals and metalloids (i.e., aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, manganese, molybdenum, nickel, selenium, silver, strontium, thallium, tin, titanium, uranium, vanadium, and zinc);
- polycyclic aromatic hydrocarbons (PAHs) (acenaphthene, acenaphthylene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(e)pyrene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenzo(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-c,d)pyrene, naphthalene, perylene, phenanthrene, pyrene [2008 only]); and
- radionuclides (i.e., Pb-210, Po-210, Ra-226, Th-230).

5.1.2.3 Data Analysis

Electronic sediment chemistry data received from SRC Laboratories were imported into Golder Saskatoon's electronic database (emLine™) or an Excel spreadsheet along with all supporting information from the lab. Following the protocols commonly used in analyzing data from environmental effects monitoring studies at uranium mines, sediment chemistry results were compared among sediment sampling stations as well as to the Canadian Council of Ministers of the Environment (CCME) Freshwater Interim Sediment Quality Guidelines (ISQG) and probable effects levels (PEL) (CCME 2002). Radionuclide results were compared with lowest effect levels (LEL) and severe effect levels (SEL) reference values reported in Thompson et al. (2004).

5.1.2.4 Quality Assurance/Quality Control

Detailed specific work instructions outlining each field task were provided to field personnel prior to the field program to support program and sampling success. Samples were collected by experienced personnel, and were collected, labelled, preserved, and shipped according to Golder's *Technical Procedure 8.2-3: Sediment Sampling* (unpublished file information) and laboratory protocols. Detailed field notes were recorded in waterproof field notebooks and on pre-printed waterproof field data sheets. All double-bagged sediment samples were labelled with waterproof ink and a waterproof label was inserted between the two bags.

Data collected during the field program underwent a variety of individual quality assurance/quality control (QA/QC) checks. Field data sheets were checked at the end of each day for completeness and accuracy. Chain of Custody forms were used to track sample shipment from the field to Golder's Saskatoon office. SRC Laboratories Analytical Request Forms were submitted with the sediment samples. A visual QA/QC check for obvious errors was conducted on the electronic chemistry data. Any data entered into emLine™ underwent a 100% transcription check by a second person not involved in the initial data entry process. All datasets generated by the database and all summary tables underwent an additional QA/QC screening.

5.2 Results

A number of lakes were sampled in the period of 1979 to 1991 (BEAK 1990, 1992a). More widespread sampling was carried out between 2007 and 2009 by Golder. Sampling in 2009 was focussed on lakes potentially affected by the Project (Table 5.0-1). The following sections provide a summary of the sediment chemistry results. Detailed data are provided in Attachment X.III.

5.2.1 Historical Summary

A summary of historical sediment chemistry data, collected between 1979 and 1991, is provided in Attachment X.III, Tables X.III-1 to X.III-2.

5.2.1.1 Sediment Composition

Kiggavik area lake bottom substrates varied from rock, boulder, and sand in shallow areas to organic-rich (soft light to dark brown) sediments in deeper depositional areas. The surficial light to dark brown sediments are typically 2 to 10 cm deep, and usually had an underlying layer of tan or grey deposits (BEAK 1987).

BEAK (1990) reported the results of quantitative assessment of sediment particle size that was conducted in 1988. Silt was the dominant particle size category in all lakes sampled except in Pointer Lake and Judge Sissons Lake. Surface sediment in the main body of Pointer Lake was dominated by dense clay, sand, and rock. Judge Sissons Lake sediment samples had nearly equal amounts of fine sand, very fine sand, silt and clay. BEAK (1990) presented quantitative results of particle size for only two lakes: Pointer Lake and Jaeger Lake (Table 5.2-1).

Table 5.2-1 Particle Size of Surficial Lake Sediments in Pointer and Jaeger Lakes in the Kiggavik Project Area, July 1988

Category	Size Range (mm)	Pointer Lake 1 (%)	Pointer Lake 2A[(a)] (%)	Pointer Lake 2B (%)	Pointer Lake 2C (%)	Jaeger Lake (%)
Coarse sand	0.5 - 1.0	0	0	0	0	1.01
Medium sand	0.25 - 0.5	0.62	1.28	1.08	7.66	2.54
Fine sand	0.088 - 0.025	3.71	3.2	3.54	12.31	16.71
Very fine sand	0.0625 - 0.088	49.41	13.15	13.67	26.29	39.49
Silt	0.0039 - 0.0625	37.69	71.53	70.18	42.96	27.69
Clay	<0.0039	8.59	10.82	11.54	10.77	12.47

Source: BEAK 1990.
(a) Pointer Lake samples 2A, 2B, and 2C are field replicates.
% = percent; mm = millimetres; < = less than.

The core sample collected in Judge Sissons Lake in 1991 consisted of sticky glacial clay and no soft organic sediments (BEAK 1990, 1992a). The 1991 result suggests that sediment deposition occurs sporadically in Judge Sissons Lake (BEAK 1992a). Differences in sediment texture between smaller lakes and Judge Sissons Lake can be attributed to the much greater depth of Judge Sissons Lake and the varying depositional environment provided in deep lakes (BEAK 1990).

5.2.1.2 Sedimentation Rates

Sedimentation rates were measured in Judge Sissons Lake and Pointer Lake, to assess the rate at which material in the water column settles out of suspension (BEAK 1990). The lakes were found to have low but variable sedimentation rates, reflecting the oligotrophic conditions of the aquatic ecosystem and possibly the frequent wind-driven sediment re-suspension (BEAK 1990). Given the small volume of many of the lakes, it is also possible that there is a short water retention time in the lakes, which would also influence sedimentation rates.

Sedimentation rates in the mine site LSA cores were 1.6 millimetres per year (mm/y) in Pointer Lake and between 0.11 mm/y and 0.26 mm/y in Judge Sissons Lake (Table 5.2-2). The average annual depth of accumulation (mm/y) is based on mass accumulation rates and on the dry bulk densities for the four surface core slices collected from the top 2 to 2.5 cm (BEAK 1990).

Table 5.2-2 Sedimentation Rates in the Kiggavik Project Area Measured Before 1990

Unit	Pointer Lake	Judge Sissons Lake	
		11 m depth	**13 m depth**
Grams per square metre per year ($g/m^2/y$)	300	11	20
Millimetre per year (mm/y)	1.6	0.11	0.26

Source: BEAK 1990.
m = metre; $g/m^2/y$ = grams per square metre per year; mm/y = millimetres per year.

Within the Judge Sissons Lake cores taken at a depth of 22 m, a sticky grey clay was encountered below 18.4 cm. This is likely a layer deposited during deglaciation, which occurred in the area about 6,000 to 8,000 years before present (BEAK 1990). The total mass accumulated above this layer was 5.3 grams per square centimetre (g/cm^2), which is equivalent to an overall average annual rate of 7.6 grams per square metre per year ($g/m^2/y$) over 7,000 years. This is about 70% of the 11 $g/m^2/y$ measured in recent sediments by Pb-210 method, probably reflecting an increase in sedimentation rate in recent history relative to the post-glacial period. These changes can be attributed to various factors, including glacial rebound, changes in erosion rates, climatic vegetation changes, and changes in the lake basin itself (BEAK 1990).

5.2.1.3 Sediment Chemistry

Comparisons of chemistry results among sampling years are difficult as little information on the sampling method is available for most of the historical sampling years. This is compounded by the fact that sampling methods can affect sediment chemistry results. All available historical sediment chemistry data are presented in Attachment X.III (Tables X.III-1 and X.III-2).

Where it was possible to obtain sediment samples, the soft sediments in the mine site LSA lakes typically have organic contents (based on loss on ignition measurements) of 9 to 28 percent (%) by weight. Nutrient (e.g., TKN and total phosphorus) and major ions concentrations were generally similar among stations, with few exceptions. Based on the 1979 results, differences in metal concentrations between surface and subsurface layers were not apparent, with the exception of chromium (Table 5.2-3). The surface sediments showed a slight enrichment in chromium relative to the subsurface layer (BEAK 1990). As there are no local contamination sources that would explain this enrichment, it is likely a natural phenomenon resulting from the variation in the reduction-oxidation potential with depth in the sediment (BEAK 1990).

Table 5.2-3 Average Quality of Surficial and Subsurficial Sediments Collected in Lakes in the Kiggavik Project Area, 1979

Analyte	Unit	Pointer Lake		Scotch Lake		Jaeger Lake(a)	Judge Sissons Lake	
		Surface(b)	Subsurface(c)	Surface(b)	Subsurface(c)	Surface(b)	Surface(b)	Subsurface(c)
		n = 10	n = 7	n = 2	n = 2	n = 1	n = 14	n = 14
Arsenic	µg/g ww	1.5	1.98	0.86	1.39	2.32	4.48	2.32
Cadmium	µg/g dw	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Chromium	µg/g dw	85.5	60.7	85.0	60.0	100.0	82.5	73.2
Copper	µg/g dw	18.0	15.0	22.5	15.0	15.0	14.4	15.0
Lead	µg/g dw	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
Mercury	µg/g dw	0.0141	0.0073	0.0265	0.0125	0.0060	0.0174	0.0170
Selenium	µg/g ww	0.052	0.059	0.090	0.130	0.020	0.034	0.043
Tellerium	µg/g ww	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Source: BEAK 1990.
(a) no subsurface samples were collected from Jaeger Lake.
(b) surface = top 3 cm.
(c) subsurface = 10 to13 cm.
n =sample size; µg/g ww = micrograms per gram wet weight; µg/g dw = micrograms per gram dry weight; cm = centimetres; < = less than.

In general, sediment metal and radionuclide concentrations in the mine site LSA were similar among lakes. Arsenic concentrations in samples from Escarpment Lake (30 and 34 micrograms per gram dry weight [µg/g dw]), Willow Lake (6 µg/g dw), and Ridge Lake (60 µg/g dw) from the 1986 program, and Judge Sissons Lake (12 µg/g dw) and Shack Lake (7 µg/g dw) in the 1991 program were above the ISQG of 5.9 µg/g dw. The reported concentrations for Escarpment Lake and Ridge Lake were also above the PEL of 17.0 µg/g dw. Chromium concentrations in sediment samples collected from 12 lakes of the mine site LSA between 1979 and 1991 were above the ISQG of 37.3 µg/g dw. Only one sediment sample collected from Jaeger Lake in 1979 (100.0 µg/g dw) had a chromium concentration above the PEL (90.0 µg/g dw). Concentrations of copper in sediment collected in 1986 from Escarpment Lake (34 and 36 µg/g dw), Lin Lake (63 µg/g dw), Ridge Lake (39 µg/g dw), and Cirque Lake (59 µg/g dw) were above the ISQG of 35.7 µg/g dw but below the PEL of 197 µg/g dw. Mercury concentrations in Shack Lake in 1990 (1 to 3 µg/g dw) were above the ISQG of 0.17 µg/g dw and the PEL of 0.486 µg/g dw. Other sediment concentrations were below ISQG and PEL when values were available.

5.2.2 Recent Sampling Period 2007 to 2009

5.2.2.1 Lakes of the Mine Site Local Study Area

Lake sediments were sampled for particle size and sediment chemistry during the 2007 to 2009 sampling sessions. Results of the sediment chemistry analysis are found in Attachment X.III; Tables X.III-3 to X.III-5.

Willow Lake Sub-Basin

Particle size distribution in sediment samples collected from lakes in the Willow Lake sub-basin was variable among lakes. Sediments from Sik Sik Lake and Rock Lake consisted of silt and clay, whereas sediments from Willow Lake consisted of either silt and clay (four samples in 2009) or silt and fine sand (three samples collected in 2007, 2008, and 2009). Sediments from Pointer Lake were most variable and generally consisted of silt or silt-sand. One station in Pointer Lake that was sampled in 2007 had 27% gravel and 46% silt, whereas no other station in Pointer Lake had more than 10% gravel.

Moisture content was generally similar among lakes and between years of collection. Moisture content ranged from 35 to 83% and was lowest in the samples with more sand content. Total organic carbon was variable among the lakes: lower in Willow Lake (1.2 to 5.5%) compared to Sik Sik and Rock lakes (4.3 to 7.3%). Sediments from Pointer Lake were most variable, as expected given the variability in particle size, with TOC ranging from 1.5 to 6.8%.

In general, total metal concentrations were similar among lakes and stations. Arsenic concentrations frequently exceeded the ISQG of 5.9 µg/g dw, with concentrations ranging from 3.5 to 12 µg/g dw. Chromium concentrations exceeded the ISQG of 37.3 µg/g dw in one or two samples from all lakes. Chromium concentrations ranged from 11 to 59 µg/g dw. Copper concentration in one 2007 sediment sample from Sik Sik Lake (44 µg/g dw) exceeded the ISQG of 35.7 µg/g dw; all other concentrations ranged from 7.3 to 33 µg/g dw. No other guideline exceedances were observed.

Radionuclides were detected in sediments at most stations sampled. Concentrations of all radionuclides were less than 0.25 Becquerels per gram dry weight (Bq/g dw) in all samples.

Lower Lake Sub-Basin

Particle size distribution in sediment samples collected from lakes in the Lower Lake sub-basin varied among lakes. Sediments from Mushroom, End Grid, Andrew, and Shack lakes consisted primarily of sand. Sediments from Cigar and Lunch lakes consisted primarily of silt and fine sand and sediments from Lower Lake consisted of silt-clay. One station in Mushroom Lake sampled in 2008 was primarily silty with about equal percentages of fine sand and clay. One station in Andrew Lake sampled in 2009 was primarily sand (77%) with some gravel (4%) and silt (18%).

Moisture content and TOC were variable among lakes and years. The 2008 sample from Cigar Lake had the highest values for moisture content (about 81%) and TOC (9.1%) compared to other lakes. Most samples from Andrew Lake (in particular those collected in 2007 and 2009) had the lowest values of moisture content (25 to 49%) and TOC (less than 0.01 and 1.1%). In the other samples, moisture content and TOC ranged from 24 to 75% and 0.7 to 5.5%, respectively.

Total metal concentrations varied among lakes and between years; no distinct patterns were observed. Arsenic concentrations exceeded the ISQG of 5.9 µg/g dw in most samples from Lower Lake and in one sample from Mushroom Lake. Chromium concentrations exceeded the ISQG of 37.3 µg/g dw in all samples from Mushroom Lake, most of the samples from Lower Lake, and one sample from Shack Lake. Copper concentrations exceeded the ISQG of 35.7 µg/g dw in one sample from each of the following lakes: Mushroom, Andrew, and Shack. Zinc concentrations exceeded the PEL of 315 µg/g dw in two samples: one from Andrew Lake and the other from Shack Lake. No other guideline exceedances were observed.

Radionuclides were detected at most of the stations in the Lower Lake sub-basin. Concentrations of all radionuclides were less than 0.2 Bq/g dw in all samples.

Caribou Lake Sub-Basin

Particle size distribution in sediment samples collected from lakes in the Caribou Lake sub-basin varied among lakes but was similar within lakes. Sediments from Ridge and Fox lakes consisted primarily of silt and clay; sediments from Cirque and Calf lakes were silty-sand; and sediments from Crash and Caribou lakes were sandy-silt.

Moisture content and TOC varied among lakes and years. Moisture content ranged from 34 to 79% and TOC ranged from 1.3 to 6.3%.

In general, total metal concentrations were similar among sampling stations. The lowest concentrations were observed in a sample collected from Caribou Lake in 2008 and none of the metals concentrations in the sample exceeded sediment quality guidelines.

Arsenic concentrations exceeded the ISQG of 5.9 µg/g dw in most samples. The PEL of 17.0 µg/g dw was exceeded in two samples from Ridge Lake, which had arsenic concentrations of 31 and 45 µg/g dw. Cadmium concentration was equal to the ISQG of 0.6 µg/g dw in one sample from Cirque Lake. Chromium concentrations exceeded the ISQG of 37.3 µg/g dw in two samples from Ridge and Cirque lakes, one from Crash Lake, and all three from Fox Lake. Chromium concentrations in these samples ranged from 27 to 76 µg/g dw. Copper concentrations exceeded the ISQG of 35.7 µg/g dw in one sample from Ridge Lake, all three from Cirque Lake, and one from Fox Lake. Copper concentrations in these samples ranged from 44 to 59 µg/g dw. Zinc concentrations were exceeded in all three samples from Cirque Lake and one sample from Fox Lake. No other guideline exceedances were observed.

Radionuclides were detected at all stations. Concentrations of all radionuclides were less than 0.2 Bq/g dw in all samples.

Judge Sissons Lake Sub-Basin

Particle size distribution in Judge Sissons Lake varied considerably among the five stations sampled in 2008 but was less variable in the stations sampled in 2009 and primarily consisted of silt-clay or sand in 2009. Moisture content varied with particle size and ranged from 18 to 88%. Total organic carbon ranged from 0.2 to 7.7% and was higher in silt-clay samples than in sandy samples.

Total metal concentrations were generally similar among the samples. Arsenic concentrations exceeded the ISQG of 5.9 µg/g dw in three of the five samples collected in 2008 and in all samples from two of the five stations sampled in 2009. In one sample, the arsenic concentration was 39 µg/g dw, which was also higher than the PEL of 17.0 µg/g dw. In all other samples, the highest arsenic concentration reported was 16 µg/g dw. Chromium concentrations exceeded the ISQG of 37.3 µg/g dw in three samples collected in 2008 and three samples collected in 2009; concentrations in these samples ranged from 38 to 53 µg/g dw. Chromium concentrations in the other samples ranged from 3.8 to 35 µg/g dw. Copper concentrations in one sample collected in 2008 and seven samples collected in 2009 ranged from 36 to 43 µg/g dw, which exceeded the ISQG of 35.0 µg/g dw. No other exceedances were observed.

Radionuclides were detected at all stations. Concentrations of all radionuclides were less than 0.3 Bq/g dw in all samples.

Siamese Lake Sub-Basin

Particle size distribution was primarily silt-sand in one sample and silt-clay in the other samples collected from Siamese Lake. Moisture contents were 72 to 82%. Total organic carbon concentrations were 5.6 and 8.5%.

Total metal concentrations were similar between the two samples. Arsenic concentrations exceeded the ISQG of 5.9 µg/g dw in both samples at concentrations of 6.2 and 7.1 µg/g dw. Chromium concentration exceeded the ISQG of 37.3 µg/g dw in one sample at 41 µg/g dw. No other guideline exceedances were observed.

Radionuclides were detected at all stations at concentrations of 0.2 Bq/g dw or less.

Skinny Lake Sub-Basin

Particle size distribution and TOC were not measured in 2007 or 2008 as Skinny Lake was not sampled for benthic invertebrates. Moisture content was only measured in the 2008 samples and ranged from 54 to 77%.

Total metal concentrations were generally similar among samples. Arsenic concentrations exceeded the ISQG of 5.9 µg/g dw in three of four of the samples and ranged from 4.3 to 12 µg/g dw. Copper and zinc concentrations in the 2007 sample exceeded the ISQG of 35.7 and 123 µg/g dw, respectively. Concentrations of these two parameters were higher in the 2007 sample than in the three 2008 samples: copper concentration was 62 µg/g dw in 2007 compared to 9.5 to 31 µg/g dw in 2008, and zinc was 170 µg/g dw in 2007 compared to 40 to 91 µg/g dw in 2008.

Radionuclides were detected at all stations at concentrations of less than 0.3 Bq/g dw. Most concentrations were less than 0.2 Bq/g dw with the exception of Po-210 in two samples (0.24 and 0.28 Bq/g dw) and Pb-210 in one sample (0.24 Bq/g dw).

5.2.2.2 Lakes in the Site Access Local Study Area

Thelon River Watershed

Squiggly Lake was sampled in 2008 and was the only lake sampled in the Thelon River watershed during the 2007 to 2009 programs. Particle size distribution and TOC were not measured in Squiggly Lake as this lake was not sampled for benthic invertebrates. Moisture content ranged from 68 to 77%.

Total metal concentrations were generally similar among samples. Arsenic concentrations exceeded the ISQG of 5.9 µg/g dw in all three samples and ranged from 8.7 to 14 µg/g dw. Copper concentration exceeded the ISQG of 35.7 µg/g dw in one sample (50 µg/g dw). In a different sample, cadmium concentration was 0.6 µg/g dw, equal to the ISQG. No other exceedances were observed.

Radionuclides were detected at all stations. In one sample, Pb-210 and Po-210 concentrations were 0.38 and 0.45 Bq/g dw, respectively. All other radionuclide concentrations were less than 0.3 Bq/g dw.

Baker Lake Sub-Basin

All sediment chemistry results are presented in Attachment X.III; Table X.III-6 and laboratory results. Sediment collected from stations 1 to 4 in 2008 had similar substrate size compositions, with high proportions of sand (57% to 99%, average 81%), low concentrations of clay (less than 1 to 7%, average of 2.8%), silt (1 to 17%, average 9%) and gravel (less than 1% to 18%, average of 7.8%). Organic matter (% TOC) was very low (less than 0.1% to 0.3%). The TOC concentrations were much lower than observed in lakes in the mine site LSA (Attachment X.III, Tables X.III-3 to X.III-5). The sediment sample from Station 5 differed from the others in a considerably higher proportion of smaller substrate types (e.g., 12% clay and 42% silt) and a lower proportion of sand (46%) (Attachment X.III laboratory results).

The sediment samples collected in 2009 from stations 1 and 2 were similar to the 2008 samples in the high proportions of sand (55% to 92%, average 74%), though a higher component of silt was recorded at Station 2 in 2009 (36%). Organic content was identical to that recorded in 2008 (less than 0.1 to 0.3%).

Metals were analyzed in sediments from all sample stations in both 2008 and 2009 (Attachment X.III, Table X.III-6). Results for select metals are shown in Figure 5.2-1. The concentrations of most metals in the lake sediments were similar to results from previous studies in the Kivalliq region (AREVA 2008). Among the five stations sampled in 2008, metals levels were lowest at Station 1 and highest at Station 5. The same local conditions that led to a higher silt and clay content at Station 5 likely contributed to the higher metals levels at this station. At Station 1, most metals parameters were markedly higher in 2009 than in 2008, which may also be related to the higher component of silt collected from the 2009 sample and to seasonal differences (freshet, freshly deposited sediment).

Antimony and cadmium were below their detection limits in all samples. Most metals were present at levels below the ISQG (CCME 2002). Only chromium and arsenic exceeded ISQG (but not PEL). Chromium levels exceeded ISQG at stations 1 and 3 in 2008, but not 2009. Arsenic exceeded ISQG at stations 2, 4 and 5 in 2008 and at stations 1 and 2 in 2009. At Station 1, arsenic levels increased from 2 to 9.1 µg/g (dry weight) between the 2008 and 2009 sampling programs. Concentrations of boron (Station 5), chromium (stations 1 [2008] and 3), titanium (Station 5) and uranium (Station 3) were higher than presented in the AREVA (2008) summary.

Uranium was measurable in samples from all stations and ranged from 0.8 to 10 µg/g (Attachment X.III, Table X.III-6). Levels of uranium were 66% and 90% lower in 2009 than 2008 at stations 1 and 2, respectively There are no CCME guidelines for uranium in sediment.

In 2008, radionuclides were present at levels close to detection limits at all stations and were lower than reference values reported in Thompson et al. (2004). They were not analyzed in 2009.

The concentrations of most metals in the lake sediments were similar to results from previous studies in the Kivalliq region (AREVA 2008). Concentrations of individual PAH compounds were mostly below analytical detection limits in all samples (Attachment X.III; Table X.III-6) and all were well below ISQG. Total PAH levels were less than 0.1 µg/g.

5.3 Summary

Particle size distributions varied considerably among and within lakes and thus a general statement about sediment texture cannot be provided. Particle size should be assessed with reference to specific sampling stations.

The historical dataset did not contain any information about moisture content and very few values for TOC. More recent data (i.e., 2007 to 2009) indicates that these parameters were variable among lakes, with moisture content ranging from 18 to 88% and TOC from less than 0.01 to 7.7%.

Overall, total metal concentrations were similar among the lakes in the mine site LSA and the site access LSA. Arsenic concentrations usually exceeded the ISQG of 5.9 µg/g dw, but not the PEL of 17.0 µg/g dw with the exception of two samples collected in Ridge Lake (31 µg/g dw in 2007 and 45 µg/g dw in 2008) and one sample collected in 2009 from Judge Sissons Lake (39 µg/g dw). Cadmium concentration in one sample collected in 2008 from Cirque Lake and one sample from Squiggly Lake was 0.6 µg/g dw, equal to the ISQG. Chromium concentrations also exceeded the ISQG of 37.3 µg/g dw, but not as frequently as arsenic. A few exceedances of copper and zinc ISQGs and the zinc PEL were observed, but there were no trends evident.

Radionuclides were detected in almost all sediment samples, except those from Baker Lake, and were generally reported at concentrations below 0.3 Bq/g dw. One sample collected in Squiggly Lake in 2008 had a Po-210 concentration of 0.45 Bq/g dw and Pb-210 concentration of 0.38 Bq/g dw

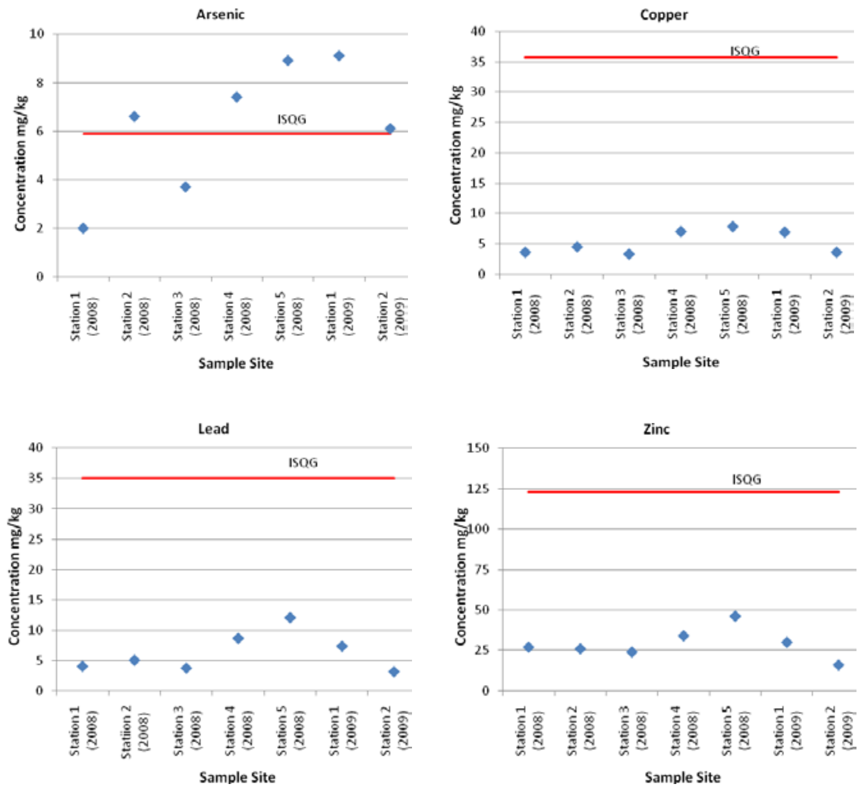


Figure 5.2-1 Levels of Selected Metals in Sediments, September 2008 and August 2009, Baker Lake.

6 Limnology

Limnology studies in the Kiggavik study area were performed between 1979 and 1991. These historical studies broadly covered the study area. The objectives were to collect baseline information on physio-chemical parameters in lakes under open water and under ice conditions.

More recent studies were conducted between 2007 and 2010 to expand and complement the existing baseline information. Limnological measurements were taken as supporting environmental information for water and sediment quality, aquatic macrophyte collection, benthic invertebrate and fish sampling as well as during specific sampling events (e.g., under ice measurements in early spring 2009). The information for lakes and streams sampled and year of collection is presented in Table 6.0-1 (lakes) and Table 6.0-2 (streams). A summary of lakes and streams sampled and the geographic coordinates of the individual sampling stations has been provided in Attachment X.I. Bathymetry maps are presented in Attachment X.IV.

6.1 Overview of Studies

6.1.1 Historical Summary 1979-1991

The 1979 and 1980 field studies were broad in coverage and general in scope, as the Project had not advanced to the conceptual design stage. Field surveys were carried out in 1988 and 1989 to fill in data gaps that became apparent as a more detailed project design developed. These studies also addressed concerns expressed by the Regional Environmental Committee on the Project Design Description document (BEAK 1990).

Aquatic environmental baseline studies began in the Kiggavik Project area in August 1990 (BEAK 1990). Baseline studies continued in 1991 to gather additional data from the Sissons site area (i.e., Lower Lake sub-basin) and to gather data necessary to address Federal Environmental Assessment Review Office requests for additional limnology information (BEAK 1992b). The 1991 program included a winter survey, conducted in late February and early March, to document under-ice conditions in the late winter

Table 6.0-1 Summary of Lakes in the Kiggavik Project Area in which Limnology Measurements were Collected, 1979 to 2010

Watershed	Sub-Basin	Waterbody	BEAK 1990			BEAK 1992a	Golder							Nunami Stantec	
			1979	1980	1988	1991	F07	U08	F08	W09	U09	F09	P10	F08	U09/ F09
Aniguq River	Willow Lake	Escarpment Lake	-	-	X(a)	-	-	-	-	-	-	-	-	-	-
		Scotch Lake	X	X	-	-	-	-	-	-	-	-	-	-	-
		Jaeger Lake	X	-	X(a)	-	-	-	-	-	-	-	-	-	-
		Pointer Pond	-	-	-	-	-	-	-	-	-	-	X	-	-
		Pointer Lake	X	X	X(a)	X	X	X	X	-	-	X	-	-	-
		Sik Sik Lake	-	-	-	-	X	-	X	X(b)	X	X	-	-	-
		Rock Lake	-	-	-	-	-	X	X	X(b)	X	X	-	-	-
		Willow Lake	-	-	-	-	X	-	X	X(b)	X	X	-	-	-
	Lower Lake	Mushroom Lake	-	-	-	X	-	X	X	X	-	-	-	-	-
		Pond 1 to Pond 8	-	-	-	-	-	-	-	-	-	-	X	-	-
		End Grid Lake	-	-	-	-	X	X	X	-	-	-	-	-	-
		Cigar Lake	-	-	-	X	-	X	X	-	-	-	-	-	-
		Knee Lake	-	-	-	-	-	X	X	-	-	-	-	-	-
		Lunch Lake	-	-	-	-	-	X	X	-	-	-	-	-	-
		Andrew Lake	-	-	-	-	X	X	X	X(b)	-	X	-	-	-
		Shack Lake	-	-	-	-	X	X	X	-	-	-	-	-	-
		Lower Lake	-	-	-	-	X	X	X	-	-	-	-	-	-
	Caribou Lake	Ridge Lake	-	-	-	X	X	X	X	-	-	-	-	-	-
		Cirque Lake	-	-	-	-	X	-	X	-	-	-	-	-	-
		Crash Lake	-	-	-	-	X	-	X	-	-	-	-	-	-
		Fox Lake	-	-	-	-	X	X	X	-	-	-	-	-	-
		Caribou Lake	-	-	-	-	-	X	X	-	-	-	-	-	-
		Calf Lake	-	-	-	-	-	X	X	-	-	-	-	-	-
	Judge Sissons Lake	Judge Sissons Lake	X	X	-	X	-	X	X	X	X	X	-	-	-
	Siamese Lake	Siamese Lake	-	-	-	-	-	X	X	X	-	-	-	-	-
		L2	-	-	-	-	-	-	-	X	-	-	-	-	-
	Skinny Lake	Skinny Lake	-	-	X(a)	-	X	-	X	-	-	-	-	-	-
	Kavisilik Lake	Kavisilik Lake	-	X	-	-	-	-	-	-	-	-	-	-	-
Aniguq River	Long Lake	Long Lake	-	-	-	-	-	-	-	X	-	-	-	-	-

Table 6.0-1 Summary of Lakes in the Kiggavik Project Area in which Limnology Measurements were Collected, 1979 to 2010

Watershed	Sub-Basin	Waterbody	BEAK 1990			BEAK 1992a	Golder							Nunami Stantec	
			1979	1980	1988	1991	F07	U08	F08	W09	U09	F09	P10	F08	U09/ F09
	Audra Lake	Audra Lake	-	-	-	-	-	-	-	X	-	-	-	-	-
Thelon River	Squiggly Lake	Squiggly Lake	-	X	-	-	-	-	X	-	-	-	-	-	-
Baker Lake	Baker Lake	Qinguq Bay	-	-	-	-	-	-	-	X	-	-	-	-	-
		Baker Lake	-	-	-	-	-	-	-	X	-	-	-	X	X

Source: BEAK 1990, BEAK 1992a.
(a) Although mentioned in the text of BEAK (1990), original limnology data from 1988 could not be located.
(b) Although mentioned in this table, these four lakes were frozen to the bottom at the time of survey.
F07 = fall 2007; U08 = summer 2008; F08 = fall 2008; W09 = winter 2009; U09 = summer 2009; F09 = fall 2009; P10 = spring 2010; - = not collected.

Table 6.0-2 Summary of Streams in the Kiggavik Project Area in which Limnology Measurements were Collected, 2007 to 2010

Watershed	Sub-Basin	Watercourse	Golder F07	Golder P08	Golder F08	Golder P09	Golder U09	Golder F09	Golder P10
Aniguq River	Willow Lake	Northeast Inflow of Pointer Lake	-	X	X	X	-	X	X
		Upper Tributary to the Northeast Inflow of Pointer Lake	-	-	-	-	-	-	X
		Upper Northwest Inflow of Pointer Lake	-	-	-	-	-	-	X
		Northwest Inflow of Pointer Lake	-	X	X	X	-	-	-
		Pointer/Rock Stream	X	X	X	X	-	-	-
		Sik Sik/Rock Stream	-	X	X	X	-	X	-
		Rock/Willow Stream	-	X	X	X	-	X	-
		Willow/Judge Sissons Stream	-	X	X	X	-	X	-
	Lower Lake	Mushroom/End Grid Stream	-	X	X	-	-	-	-
		End Grid/Shack Stream	-	X	X	-	-	-	-
		Cigar/Lunch Stream	-	X	X	-	-	-	-
		Knee/Lunch Stream	-	X	X	-	-	-	-
		Lunch/Andrew Stream	-	X	X	X	-	-	-
		Andrew/Shack Stream	-	X	X	X	-	-	-
		Shack/Lower Stream	X	X	X	-	-	-	-
		Lower/Judge Sissons Stream	-	X	X	-	-	-	-
	Caribou Lake	Ridge/Crash Stream	-	X	X	-	-	-	-
		Cirque/Crash Stream	-	X	X	-	-	-	-
		Crash/Fox Stream	X	X	X	-	-	-	-
		Fox/Caribou Stream	X	X	X	-	-	-	-
		Caribou/Calf Stream	-	X	X	-	-	-	-
		Calf/Judge Sissons Stream	-	X	X	-	-	-	-
	Aniguq River	Aniguq River	-	-	-	-	-	X	-
Access Local Study Area		several stream crossings (Tables X.IV-7 and X.IV-8)	-	-	X	-	X	X	-

Notes: No stream limnology measurements were collected by Beak during their 1979 to 1991 studies.
F07 = fall 2007; P08 = spring 2008; F08 = fall 2008; P09 = spring 2009; U09 = summer 2009; F09 = fall 2009; P10 = spring 2010; - = not collected.

6.1.1.1 Sampling Period 1979

Limnological measurements (i.e., dissolved oxygen, water temperature, pH, and specific conductivity) were collected in June, July, and August 1979 in four lakes of the study area, including:

- Scotch, Jaeger, and Pointer lakes (Willow Lake sub-basin); and
- Judge Sissons (Judge Sissons Lake sub-basin).

There was one station in each of Scotch and Jaeger lakes, two stations in the outlet of Pointer Lake, ten stations in the main basin of Pointer Lake, and twelve stations in Judge Sissons Lake.

Measurements were collected from a depth of 1 metre (m) from the water surface at all stations with the exceptions of Scotch and Judge Sissons lakes. Scotch Lake was sampled at depths of 1 and 4 m. Judge Sissons Lake was sampled at 1, 18 and 19 m, depending on the maximum depth of the station.

6.1.1.2 Sampling Period 1980

Limnology measurements were collected in June, July, and August 1980 from five lakes in four sub-basins in the study area, including:

- Scotch and Pointer lakes (Willow Lake sub-basin);
- Judge Sissons Lake (Judge Sissons Lake sub-basin);
- Kavisilik Lake sub-basin (Kavisilik Lake sub-basin); and
- Squiggly Lake (Squiggly Lake sub-basin).

Measurements were collected from a depth of 1 m below the surface and near lake bottom at most stations. There was one station in Scotch Lake outlet and Kavisilik Lake outlet, two stations in Pointer Lake outlet and Squiggly Lake outlet, three stations in Scotch, Pointer, Squiggly and Kavisilik lakes, and four stations in Judge Sissons Lake.

6.1.1.3 Sampling Period 1991

Limnology measurements were collected in March or June 1991 from five lakes in the study area, including:

- Pointer Lake (Willow Lake sub-basin);
- Mushroom and Cigar lakes (Lower Lake sub-basin);
- Ridge Lake (Caribou Lake sub-basin); and

- Judge Sissons Lake (Judge Sissons Lake sub-basin).

Vertical profiles of dissolved oxygen and water temperature were taken at 1 m intervals from a depth of 1 m below the surface to near lake bottom at one station per lake.

6.1.2 Recent Field Surveys, 2007 to 2010

6.1.2.1 Sampling Areas

Lakes and Ponds

Limnological measurements were collected during other aquatic sampling (e.g., benthic invertebrate community, aquatic macrophyte collection, and fish sampling) to provide supporting environmental information. The locations of these stations can be found in Attachment X.I, Tables X.I-1 to X.I-12. In some cases, stations were established during the 2007 sampling period and were revisited during subsequent sampling periods (e.g., benthic invertebrate community, water or sediment quality sampling). Surface measurements and vertical profiles of dissolved oxygen, water temperature, pH, and specific conductivity were taken in the various waterbodies sampled in 2007 to 2020.

During the fall 2007 sampling session, measurements were taken in 12 lakes from four sub-basins, including (Attachment X.I, Figure X.I-1):

- Pointer, Sik Sik, and Willow lakes (Willow Lake sub-basin);
- End Grid, Andrew, Shack and Lower lakes (Lower Lake sub-basin);
- Ridge, Cirque, Crash, and Fox lakes (Caribou Lake sub-basin); and
- Skinny Lake (Skinny Lake sub-basin).

In general, there was one station established per lake in 2007 with the exception of Pointer and Ridge lakes, which had two stations each. Vertical limnology profiles (i.e., surface to bottom) were collected at one station in Pointer Lake and two stations in Ridge, Sik Sik, Cirque, and Skinny lakes.

Limnology surface measurements were recorded during summer 2008 in 17 lakes from six sub-basins, including (Attachment X.I, Figure X.I-1):

- Pointer and Rock lakes (Willow Lake sub-basin);
- Mushroom, End Grid, Cigar, Knee, Lunch, Andrew, Shack, and Lower lakes (Lower Lake sub-basin);
- Ridge, Fox, Caribou, and Calf lakes (Caribou Lake sub-basin);
- Judge Sissons Lake (Judge Sissons Lake sub-basin);
- Siamese Lake (Siamese Lake sub-basin); and

- Baker Lake (Baker Lake sub-basin).

Surface measurements (i.e., 0.1 to 0.3 m below the surface) were taken at multiple stations per lake (i.e., between two and 24) during the summer 2008 study (Attachment X.I, Tables X.I-3 to X.I-10). Vertical limnology profiles (surface to bottom) were also recorded in six lakes:

- Pointer Lake (Willow Lake sub-basin);
- Mushroom and Lunch lakes (Lower Lake sub-basin);
- Caribou Lake (Caribou Lake sub-basin);
- Judge Sissons Lake (Judge Sissons Lake sub-basin); and
- Siamese Lake (Siamese Lake sub-basin).

Limnology surface measurements (i.e., 0.1 to 0.3 m below the surface) were recorded during fall 2008 in 23 lakes from eight sub-basins or watersheds (Attachment X.I, Figure X.I-1):

- Pointer, Sik Sik, Rock, and Willow lakes (Willow Lake sub-basin);
- Mushroom, End Grid, Cigar, Knee, Lunch, Andrew, Shack, and Lower lakes (Lower Lake sub-basin);
- Ridge, Cirque, Crash, Fox, Caribou, and Calf lakes (Caribou Lake sub-basin);
- Judge Sissons Lake (Judge Sissons Lake sub-basin);
- Siamese Lake (Siamese Lake sub-basin);
- Skinny lakes (Skinny Lake sub-basin);
- Squiggly Lake (Squiggly Lake sub-basin); and
- Baker Lake (Baker Lake sub-basin).

The fall 2008 limnology program included surface measurements at multiple stations per lake (i.e., between two and 11). Vertical limnology profiles (surface to bottom) were also recorded in most lakes.

Limnology surface (i.e., 0.2 to 0.5 m below the surface) measurements were recorded during summer and fall 2009 in seven lakes from four sub-basins:

- Pointer, Sik Sik, Rock, and Willow lakes (Willow Lake sub-basin);
- Andrew Lake (Lower Lake sub-basin);
- Judge Sissons Lake (Judge Sissons Lake sub-basin); and
- Baker Lake (Baker Lake sub-basin).

Vertical limnology profiles (from immediately beneath the ice to bottom) were recorded during winter 2009 in seven lakes from six sub-basins:

- Mushroom Lake (Lower Lake sub-basin);
- Judge Sissons Lake (Judge Sissons Lake sub-basin);
- Siamese Lake and L2 (unnamed lake; Siamese Lake sub-basin);
- Long Lake (Long Lake sub-basin);
- Audra Lake (Audra Lake sub-basin); and
- Qinguq Bay (Baker Lake sub-basin).

There were multiple stations per lake (i.e., between one and five).

Limnology surface measurements were recorded during spring 2010 in nine ponds from two sub-basins (Attachment X.I, Figure X.I-1):

- Pointer Pond (Willow Lake sub-basin); and
- Pond 1 to Pond 8 (Lower Lake sub-basin).

Streams

Limnology measurements were collected during fall 2007 from four streams in three sub-basins (Attachment X.I, Figure X.I-2 and Table X.I-12):

- Pointer/Rock Stream (Willow Lake sub-basin);
- Shack/Lower Stream (Lower Lake sub-basin); and
- Crash/Fox and Fox/Caribou streams (Caribou Lake sub-basin).

During spring and fall 2008, the sampling area was expanded to include 23 streams:

- Northeast and Northwest Inflow into Pointer Lake; Pointer/Rock, Sik Sik/Rock, Rock/Willow, and Willow/Judge Sissons streams (Willow Lake sub-basin);
- Mushroom/End Grid, End Grid/Shack, Cigar/Lunch, Knee/Lunch, Lunch/Andrew, Andrew/Shack, Shack/Lower, and Lower/Judge Sissons streams (Lower Lake sub-basin);
- Ridge/Crash, Cirque/Crash, Crash/Fox, Fox/Caribou, Caribou/Calf, and Calf/Judge Sissons streams (Caribou Lake sub-basin); and
- Three stream crossings on the proposed 2008 road alignment).

Limnology measurements were collected in spring, summer, and fall 2009 in 42 streams (Attachment X.I, Figure X.I-2 and Table X.I-12):

- Northeast and Northwest Inflow into Pointer Lake; Pointer/Rock, Sik Sik/Rock, Rock/Willow, and Willow/Judge Sissons streams (Willow Lake sub-basin);
- Lunch/Andrew and Andrew/Shack streams (Lower Lake sub-basin);

- Aniguq River (Anaguq River sub-basin) and
- 33 stream crossings on the proposed 2009 road alignment.

There were one or more stations per stream and measurements were taken at the water surface.

Limnology measurements were collected in spring 2010 in three streams in the Willow Lake sub-basin (Northeast Inflow of Pointer Lake and its upper tributary; Upper Northwest Inflow of Pointer Lake; Attachment X.I, Figure X.I-2). There were one or more stations per stream and measurements were taken at the water surface.

6.1.2.2 Data Collection

Limnology profile data were collected from each sampling station using a YSI 600QS water quality meter following methods outlined in Golder's *Technical Procedure 8.23-0: Basic Limnology and Bathymetric Procedures* (unpublished file information). At stations where the maximum water depths were less than 3 m, limnology measurements were recorded at the surface only (i.e., depths less than 0.3 m below the surface). Where the water depth was greater than 3 m, vertical profile measurements were collected at 1 m increments within the water column, with the final measurement about 0.5 m from the bottom sediment. Measurements in Baker Lake were taken with a YSI Model 85 water quality meter. Measurements were taken at 0.5 m increments.

All limnology data were recorded on limnology data sheets and included the following parameters:

- depth (m);
- dissolved oxygen (DO; milligrams per litre [mg/L]);
- pH;
- temperature (degrees Celsius [°C]);
- specific conductivity (microSiemens per centimetre [µS/cm]);
- maximum water depth (m); and
- Secchi depth (m).

In addition, Universal Transverse Mercator (UTM) coordinates, ambient weather, and wind conditions were recorded for each station.

6.1.2.3 Laboratory Analysis

All measurements were taken in the field. No laboratory measurements were required for the limnology component of baseline data collection.

6.1.2.4 Data Analysis

Limnology profile data was entered into emLine™ or Excel spreadsheets. Limnology results were compared among stations within the year of collection. Concentrations of dissolved oxygen (DO) and pH were compared to the most recent Canadian Council of Ministers of Environment's (CCME) Canadian Water Quality Guidelines (CWQG) for the protection of aquatic life (CCME 2007). The DO guideline for cold water freshwater biota is 9.5 mg/L for early life stages and 6.5 mg/L for other life stages. The pH guidelines are a range from pH 6.5 to 9.

6.1.2.5 Quality Assurance/Quality Control

Quality assurance/quality control (QA/QC) procedures were followed to help ensure that all field sampling, data entry, data analysis and report preparation produced technically sound and scientifically defensible results. As part of routine field operations for QA/QC, applicable equipment was frequently calibrated (e.g., the DO senor was calibrated daily; pH and conductivity sensors were calibrated every three days) and all measurements were collected by experienced personnel following standard protocols outlined in Golder's *Technical Procedure 8.23-0: Basic Limnology and Bathymetric Procedures* (unpublished file information). Detailed specific work instructions were provided to Golder field personnel prior to the field programs to help ensure program and sampling success.

Detailed field notes were recorded in pencil in waterproof field notebooks and on pre-printed waterproof field datasheets. Data collected during the field trip underwent a variety of thorough individual QA/QC checks. Field data sheets were verified at the end of each day for completeness and accuracy. All data entry into electronic databases underwent a 100 percent (%) QA/QC check.

6.2 Results

6.2.1 Historical Summary

Surface waters in the Project study area remain ice-covered for most of the year, with ice thawing in June (smaller lakes) and July (larger lakes). Ice begins forming again by September. Judge Sissons Lake is much larger than the other lakes surveyed in the area and is typically slower to warm and lose its ice cover.

The water temperature data indicate that the lakes can be generally characterized as cold, monomictic lakes during the ice-free season. Monomictic lakes have a single period of complete circulation annually. For lakes in the Project study area, mixing occurs during the ice-free period, which is illustrated by the relatively uniform temperature, DO, pH, and specific conductivity measurements with depth in various lakes (Tables 6.2-1 to 6.2-3).

Lakes in the study area tend to be clear. Secchi depths were measured on several occasions in 1979 and were generally equivalent to maximum lake depths (Table 6.2-1). Secchi depths in Judge Sissons Lake ranged between 7 m and 8.5 m during the same year, reflecting low levels of suspended particulates and color.

Table 6.2-1 Limnology Data from Lakes in the Kiggavik Project Area, 1979

Sub-Basin	Waterbody	Sampling Date	Secchi Depth (m)	Profile Depth (m)	Water Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)
Willow Lake	Scotch Lake (deep basin)	27-Aug-79	bottom	1.0	6.0	11.4	6.6	11.0
		27-Aug-79	bottom	4.0	6.0	11.0	6.6	9.0
	Jaeger Lake (deep basin)	27-Aug-79	-	1.0	5.4	11.4	-	-
	Pointer Lake (deep basin)	3-Jul-79	bottom	1.0	1.3	11.3	8.0	8.0
		19-Jul-79	bottom	1.0	10.0	10.2	7.2	10.0
		24-Jul-79	bottom	1.0	8.5	11.0	7.25	10.0
		31-Jul-79	bottom	1.0	7.5	10.9	7.15	10.0
		3-Aug-79	bottom	1.0	8.5	11.0	7.2	10.0
		7-Aug-79	bottom	1.0	8.5	11.3	7.1	10.0
		25-Aug-79	bottom	1.0	7.0	11.2	7.05	10.0
	Pointer Lake (outlet)	21-Jun-79	-	-	-	-	7.0	19.0
		6-Jul-79	bottom	1.0	4.9	11.2	8.0	11.0
		16-Jul-79	bottom	-	-	-	**6.4**	9.4
Judge Sissons Lake	Judge Sissons Lake (deep basin)	21-Jun-79	-	-	-	-	7.2	19.6
		16-Jul-79	-	-	-	-	**6.1**	14.3
		10-Aug-79	-	-	8.5	11.7	7.15	15.0
		10-Aug-79	7	1.0	7.0	10.9	7.2	20.0
		10-Aug-79	-	19.0	7.0	10.8	7.15	20.0
		11-Aug-79	-	-	-	11.7	7.10	15.0
		11-Aug-79	-	-	-	11.3	7.25	15.0
		11-Aug-79	-	-	-	10.2	7.20	25.0
		16-Aug-79	8.5	1.0	8.3	10.8	7.1	20.0
		16-Aug-79	-	18.0	7.9	11.2	7.15	20.0

Table 6.2-1 Limnology Data from Lakes in the Kiggavik Project Area, 1979

Sub-Basin	Waterbody	Sampling Date	Secchi Depth (m)	Profile Depth (m)	Water Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)
		19-Aug-79	-	-	-	11.3	7.05	18.0
		19-Aug-79	-	-	-	11.2	7.15	22.0
		19-Aug-79	-	-	-	11.3	7.20	35.0
		24-Aug-79	7.75	1.0	8.3	10.6	7.1	18.0
		24-Aug-79	-	18.0	8.3	10.6	7.15	18.0
	Judge Sissons Lake (outlet)	21-Jun-79	-	-	-	-	6.9	28.0
		16-Jul-79	-	-	-	-	6.5	20.0

Source: BEAK 1990, 1992a.

Notes: Dissolved oxygen concentrations less than the Canadian Water Quality Guideline (CWQG) of 9.5 mg/L are bolded. Values of pH outside the CWQG of pH 6.5 to 9 are bolded.

m = metre; °C = degrees Celsius; mg/L = milligrams per litre; µS/cm = microSiemens per centimetre; Jun = June; Jul = July; Aug = August; - = no data available.

Table 6.2-2 Limnology Data from Lakes in the Kiggavik Project Area, 1980

Sub-Basin	Waterbody	Sampling Date	Depth (m)	Water Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)
Willow Lake	Scotch Lake (deep area)	17-Jun-80	1	0.8	12.2	**4.8**	11
		17-Jun-80	6	3.6	**6.8**	**4.7**	31
		23-Jul-80	1	11.5	10.5	**5.9**	10
		23-Jul-80	6	11.6	10.4	**6.0**	18
		15-Aug-80	1	14.6	10.1	**5.6**	8
		15-Aug-80	6	14.4	10.0	**5.6**	7
	Scotch Lake Outlet	6-Aug-80	-	16.3	10.0	**6.5**	9
	Pointer Lake (deep area)	14-Jun-80	2	0.5	12.2	**6.2**	26
		10-Jul-80	1	11.4	11.3	**5.9**	8
		10-Jul-80	2	11.4	11.2	**5.9**	8
		5-Aug-80	1	15.4	10.1	**6.1**	9
		5-Aug-80	2	15.4	10.1	**6.1**	8
	Pointer Lake Outlet	28-Jun-80	-	5.2	12.5	**5.6**	10
		5-Aug-80	-	16.3	9.8	6.5	9
Judge Sissons Lake	Judge Sissons Lake (deep area)	17-Jun-80	1	0.2	12.6	**4.1**	0
		17-Jun-80	18	2.8	**3.7**	**5.0**	28
		14-Jul-80	1	6.9	12.8	**6.0**	30
		14-Jul-80	19	5.0	12.9	**5.9**	19
		21-Jul-80	-	7.5	12.4	**6.2**	15
		12-Aug-80	1	12.5	10.6	**6.2**	17
		12-Aug-80	19	11.1	**8.8**	**5.4**	24
Squiggly Lake	Squiggly Lake (deep area)	19-Jun-80	1	0.9	12.8	**4.5**	0
		19-Jun-80	7	2.8	10.2	**5.0**	23
		20-Jul-80	1	9.7	11.5	**6.1**	25
		20-Jul-80	7	9.2	11.5	**6.0**	21

Table 6.2-2 Limnology Data from Lakes in the Kiggavik Project Area, 1980

Sub-Basin	Waterbody	Sampling Date	Depth (m)	Water Temperature (°C)	Dissolved Oxygen (mg/L)	pH	Specific Conductivity (µS/cm)
		19-Aug-80	1	12.8	9.9	**5.4**	9
		19-Aug-80	14	12.8	9.9	**5.6**	9
	Squiggly Lake Outlet	31-Jul-80	-	10.5	11.4	**5.8**	22
		8-Aug-80	-	13.4	10.6	**5.6**	8
Kavisilik Lake	Kavisilik Lake (deep area)	18-Jun-80	1	1.7	11.2	**4.9**	21
		18-Jun-80	6	2.3	13.7	**5.0**	27
		13-Jul-80	1	7.3	12.4	**5.6**	22
		13-Jul-80	6	7.1	12.4	**5.6**	17
		16-Aug-80	1	14.0	10.0	**5.3**	7
		16-Aug-80	9	13.9	10.2	**5.3**	7
	Kavisilik Lake Outlet	29-Jul-80	-	11.9	11.0	**5.7**	6
		7-Aug-80	-	16.3	**9.4**	**5.9**	7

Source: BEAK 1990, 1992a.

Notes: Dissolved oxygen concentrations less than the Canadian Water Quality Guideline (CWQG) of 9.5 mg/L are bolded. Values of pH outside the CWQG of pH 6.5 to 9 are bolded.

m = metre; °C = degrees Celsius; mg/L = milligrams per litre; µS/cm = microSiemens per centimetre; Jun = June; Jul = July; Aug = August; - = no data available.

Table 6.2-3 Limnology Data from Lakes in the Kiggavik Project Area, 1991

Sub-Basin	Waterbody	Sampling Date	Depth (m)	Water Temperature (°C)	Dissolved Oxygen (mg/L)
Willow Lake	Pointer Lake	4-Mar-91	1	0.25	**8.0**
			1.5	1.0	**3.25**
			2.5 (bottom)	-	-
Lower Lake	Mushroom Lake	3-Mar-91	1	2.0	13.6
			2	2.0	15.8
			3	3.5	12.1
			4	3.5	11.5
			5	3.5	10.4
			6	3.5	11.5
			7	3.5	10.7
			7.5 (bottom)	-	-
	Cigar Lake	3-Mar-91	1	0.5	14.5
			2	2.0	10.0
			3	3.0	**7.5**
			3.2 (bottom)	-	-
Caribou Lake	Ridge Lake	4-Mar-91	1	1.0	>20
			2	2.0	>20
			3	3.0	>20
			4	3.0	>20
			5	3.0	19
			6	3.0	18
			7	3.0	13
			7.5 (bottom)	-	-
Judge Sissons Lake	Judge Sissons Lake	4-Mar-91	1	1.5	14.2
			2	1.5	15.3
			3	1.75	15.0
			4	1.75	15.7

Table 6.2-3 Limnology Data from Lakes in the Kiggavik Project Area, 1991

Sub-Basin	Waterbody	Sampling Date	Depth (m)	Water Temperature (°C)	Dissolved Oxygen (mg/L)
			5	1.75	18.0
			6	2.0	17.0
			7	2.0	15.4
			8	2.0	14.5
			9	2.5	13.6
			10	2.5	11.0
			11	2.9	**9.4**
			12	3.0	**8.8**
			13	3.0	**8.0**
			14	3.0	**8.0**
			15	3.0	**6.5**
			16	3.1	**5.8**
			17 (bottom)	-	-

Source: BEAK 1992a.

Notes: Dissolved oxygen concentrations less than the Canadian water quality guideline (CWQG) of 9.5 mg/L are bolded. Values of pH outside the CWQG of pH 6.5 to 9 are bolded.

m = metre; °C = degrees Celsius; mg/L = milligrams per litre; Mar = March; Jun = June; - = no data available.

Dissolved oxygen concentrations were similar between the 1979 and 1980 open water seasons. Concentrations of DO were generally above the CWQG of 9.5 mg/L for the protection of early life-stages of cold water biota (Tables 6.2-1 and 6.2-2) except for three occasions:

- Two values observed in June 1980 (3.7 mg/L at 18 m depth in Judge Sissons Lake; 6.8 mg/L at the 6 m station in Scotch Lake) were below the CWQG of 9.5 mg/L. These values reflected late winter DO concentrations, indicating that the deep lakes had not yet begun to mix.
- One value of 8.8 mg/L was observed in August 1980 at 19 m depth in Judge Sissons Lake.

Dissolved oxygen concentrations were generally lower under ice conditions measured in 1991 (Table 6.2-3). In Cigar and Judge Sisson lakes, DO concentrations were less than the CWQG of 9.5

mg/L near the bottom of the lakes (i.e., 3 m in Cigar Lake and below 11 m in Judge Sissons Lake). Concentrations were also lower at both depths measured in Pointer Lake (1.0 and 2.5 m).

Specific conductivity varied among sampling events within lakes and among years. Values ranged from 6 to 35 µS/cm. Values of pH were higher in 1980 (i.e., pH 6.1 to 8.0) than in 1979 (i.e., pH 4.1 to 6.5). The reason for the difference in pH between years is unknown. Three pH values in 1979 were outside of the CWQG of pH 6.5 to 9; all values but one were lower than the minimum CWQG of pH 6.5 in 1980.

6.2.2 Recent Sampling Period 2007 to 2010

Limnology data are presented in Attachment X.IV by sampling year, season, and waterbody type. Location of individual sampling stations is presented in Attachment X.I. Bathymetry maps are presented in Attachment X.IV.

6.2.2.1 Lakes in the Mine Site Local Study Area

Measurements of DO, temperature, pH and conductivity were taken at various lake sampling stations in the mine site LSA during the 2007 to 2010 sampling sessions (Table 6.0-1). The results from 2007 to 2009 are summarized in the following sections.

Willow Lake Sub-Basin

2007

Limnology surface measurements were taken in Pointer, Sik Sik and Willow lakes in fall 2007 (Attachment IV, Table IV-1). Pointer Lake had the highest measured value of pH (9.9), which was outside of the range of CWQG of pH 6.5 to 9. All other field-measured pH values at surface were within CWQG. Sik Sik Lake had the highest specific conductivity (54 µS/cm). All other lakes had specific conductivities that ranged from 12 to 18 µS/cm. Dissolved oxygen concentrations near surface ranged from 11.8 to 12.1 mg/L and were above the CWQG of 9.5 mg/L. Surface water temperatures ranged from 6.3ºC (Sik Sik Lake) to 7.6ºC (Willow Lake).

Limnology measurements were taken in Pointer Lake (Station 1) and Sik Sik Lake. At these two stations, the maximum depths were 3.0 m (Pointer Lake Station 1) and 1.7 m (Sik Sik Lake). All other sampling stations had depths of 1.0 or 2.0 m. Thermal stratification was not observed in either lake (Attachment X.IV, Table X.IV-1). Dissolved oxygen concentration was 6.8 mg/L at 2.8 m (bottom) in Pointer Lake (Station 1), which was less than the CWQG of 9.5 mg/L for the protection of early life-stages of cold water biota, but above the CWQG of 6.5 mg/L for the protection of other life-stages. All other DO concentrations were higher than the CWQG specifications.

Secchi depth provides a measure of water clarity. Secchi depth was 1.9 m at Station 1 in Pointer Lake and 0.9 m in Sik Sik Lake. Secchi depth equalled the maximum depth in Willow Lake (2 m).

2008

Limnology surface measurements were taken in Pointer and Rock lakes in both summer and fall 2008 and in Sik Sik and Willow Lakes in fall 2008 (Attachment X.IV, Tables X.IV-2 and X.IV-3). With a maximum depth of about 3 m, Pointer Lake was the deepest lake sampled in the Willow Lake sub-basin in 2008. The other lakes sampled (i.e., Sik Sik, Rock and Willow lakes) had maximum depths ranging from 1.2 to 1.9 m. Secchi depth was equal to the maximum depths in all lakes. Pointer Lake had the lowest measured values of pH (6.7) and specific conductivity (14 µS/cm), whereas Sik Sik Lake had the highest values (pH 7.6 and 61 µS/cm). All pH values were within the CWQG of pH 6.5 to 9. Concentrations of DO ranged from 11.3 to 12.0 mg/L in the fall and from 10.1 to 10.6 mg/L in the summer. Rock Lake had the highest DO concentration, while Pointer Lake had the lowest. Dissolved oxygen concentrations in all waterbodies were above the CWQG of 9.5 mg/L. Water temperatures ranged from 13.5ºC (Rock Lake) to 16.7ºC (Pointer Lake) in the summer and 6.5ºC (Willow Lake) to 8.9ºC (Pointer Lake) in the fall.

Limnology profiles were taken in Pointer Lake in summer and fall 2008 (Figure 6.2-1). Thermal stratification was not recorded at any station (Attachment X.IV, Tables X.IV-2 and X.IV-3). Concentrations of DO were above the CWQG of 9.5 mg/L at all depths.

2009

Limnology near-surface measurements were taken at one station in Sik Sik, Rock, and Willow lakes in summer 2009 and at multiple stations in Pointer, Sik Sik, Rock, and Willow lakes in fall 2009 (Attachment X.IV, Table X.IV-4). With a maximum depth of about 3 m, Pointer Lake was the deepest lake sampled. The other lakes sampled (i.e., Sik Sik, Rock and Willow lakes) had maximum depths ranging from 0.9 to 1.9 m. Secchi depth was equal to the maximum depths in all lakes. Pointer Lake had the lowest measured values of pH (7.0) and specific conductivity (13 µS/cm), whereas Sik Sik Lake had the highest values (pH 8.2 and 58 µS/cm). All pH values were within the CWQG of pH 6.5 to 9. Concentrations of DO ranged from 10.1 to 12.0 mg/L, which were above the CWQG of 9.5 mg/L. Water temperatures ranged from 8.7ºC (Pointer Lake) to 13.3ºC (Sik Sik Lake).

Limnology profiles were taken in Sik Sik and Willow lakes in fall 2009. Thermal stratification was not recorded at any station (Attachment X.IV, Table X.IV-4). Concentrations of DO were above the CWQG of 9.5 mg/L at all depths.

Late winter sampling was attempted in Sik Sik, Rock, and Willow lakes in May 2009. All three lakes were frozen to the lake bottom at the time of sampling (Attachment X.IV, Table X.IV-5).

2010

Limnology near-surface measurements were only taken in spring 2010 at Pointer Pond (Attachment X.IV, Table X.IV-9). Concentrations of DO was 12.1 mg/L, which was above the CWQG of 9.5 mg/L. Water temperature was 4.2ºC.

Lower Lake Sub-Basin

2007

Limnology surface measurements of four lakes in the Lower Lake sub-basin were taken in fall 2007: End Grid, Andrew, Shack, and Lower lakes (Attachment X.IV, Table X.IV-1). All lakes sampled were less than 1.4 m deep. Secchi depth equalled the maximum depth at all lakes (i.e., the Secchi disk was visible on the lake bottom). Specific conductivity ranged from 25 (End Grid Lake) to 34 µS/cm (Lower Lake). Field measurements of pH ranged from pH 7.5 in Lower Lake to pH 8.0 in Shack Lake. None of the pH values were outside the CWQG of pH 6.5 to 9. Concentrations of DO ranged from 11.63 mg/L (Andrew Lake) and 11.97 mg/L (Shack Lake), which were above the CWQG of 9.5 mg/L. Water temperatures ranged from 6.8ºC (End Grid Lake) to 8.3ºC (Lower Lake). Limnology profiles were not taken due to the shallow depths of the lakes.

2008

Limnology surface measurements of eight lakes in the Lower Lake sub-basin were taken in the summer and fall of 2008 (Mushroom, End Grid, Cigar, Knee, Lunch, Andrew, Shack, and Lower lakes) (Attachment X.IV, Tables X.IV-2 and X.IV-3). The deepest lake sampled was Mushroom Lake at 8.8 m, while the shallowest lake was End Grid Lake at 0.9 m. In the summer and fall, Cigar and Knee lakes had the lowest and highest specific conductivity, respectively. The surface water pH ranged from 6.3 in Cigar Lake to 8.0 in Lunch Lake. Cigar Lake had the lowest pH values, with some summer pH values and all of the fall pH values below the CWQG of pH 6.5 to 9. Dissolved oxygen concentrations ranged from 9.4 mg/L (Mushroom Lake) to 11.0 mg/L (Shack Lake) in the summer and between 10.8 mg/L (Cigar Lake) and 12.5 mg/L (Knee Lake) in the fall. Dissolved oxygen concentrations were above the CWQG of 9.5 mg/L, with the exception of some stations in Cigar, Knee, Mushroom and End Grid lakes in the summer. Water temperatures ranged from 10.3ºC (Lower Lake) to 18.9ºC (End Grid Lake) in the summer and 5.5ºC (Lower Lake) to 9.1ºC (Shack Lake) in the fall.

Limnology profiles were taken in Mushroom Lake in summer and fall 2008 (Figure 6.2-1) and in Cigar and Lower lakes in fall 2008. Lakes were uniform and thermal stratification was not present in any lake sampled (Attachment X.IV, Tables X.IV-2 and X.IV-3). Dissolved oxygen concentrations were above the CWQG of 9.5 mg/L at all depths in lakes measured in the fall. In the summer, DO concentrations at lake bottom ranged from 7.6 to 9.4 mg/L in Lunch and Mushroom lakes, which were less than the CWQG of 9.5 mg/L for the protection of early life-stages of cold water biota, but higher than the CWQG of 6.5 mg/L for other life-stages.

Secchi depth often equalled the maximum depth with the exception of Mushroom Lake. The Secchi depth at stations in Mushroom Lake was 5 m in the summer and 3 m in the fall (maximum depths at these stations were 8.2 m and 8.8 m, respectively).

2009

Limnology surface measurements were taken in fall 2009 from Andrew Lake (Attachment X.IV, Table X.IV-4). Station depths ranged from 0.5 to 1.0 m. Secchi depth equalled the maximum depth at all measurement locations. Specific conductivity was 31 µS/cm. Field measurements of pH ranged from pH 7.2 to 7.3, which were within the CWQG of pH 6.5 to 9. Concentrations of DO ranged from 11.1 to 11.4 mg/L, which were above the CWQG of 9.5 mg/L. Water temperatures ranged from 9.6 to 10.5ºC. Limnology profiles were not taken.

A limnology profile was taken in winter 2009 from Mushroom Lake (Attachment X.IV, Table X.IV-5). Measurements were collected from immediately beneath the ice (ice thickness was 2.0 m) to lake bottom (7.3 m). Specific conductivity did not vary with depth and ranged from 48 to 49 µS/cm. Water temperatures ranged from 2.3 to 3.0°C. Dissolved oxygen and pH values declined with increasing depth. Concentrations of DO ranged from 12.3 mg/L at 2.0 m to 9.6 mg/L at 7.0 m. All DO concentrations were higher than the CWQG of 9.5 mg/L. Values of pH ranged from pH 7.4 at 2.0 m to pH 7.1 at 7.0 m and all values were within the CWQG of pH 6.5 to 9. Winter sampling was attempted in Andrew Lake in May 2009, but Andrew Lake was frozen to the lake bottom at the time of sampling (Attachment X.IV, Table X.IV-5)

2010

Near-surface measurements were taken at six to ten stations in each of the ponds (Pond 1 to Pond 8) located north of Andrew Lake (Attachment X.IV, Table X.IV-9). Station depths ranged from 0.2 to 0.7 m. Field measurements of pH ranged from pH 7.1 to 8.8, which were within the CWQG of pH 6.5 to 9. Concentrations of DO ranged from 9.8 to 11.9 mg/L, which were above the CWQG of 9.5 mg/L. Water temperatures ranged from 4.9 to 12.0ºC.

Caribou Lake Sub-Basin

2007

Surface measurements were taken in four lakes in the Caribou Lake sub-basin in fall 2007 (Ridge, Cirque, Crash, and Fox lakes) (Attachment X.IV, Table X.IV-1). Specific conductivity ranged from 11 µS/cm (Cirque Lake) to 25 µS/cm (Crash Lake). Field measurements of pH ranged from pH 7.2 in Ridge Lake to pH 7.6 in Fox Lake. All pH values were within the CWQG specifications. Surface DO concentrations ranged from 11.6 mg/L (Fox Lake) and 12.1 mg/L (Crash Lake), which were above the CWQG of 9.5 mg/L. Surface water temperatures ranged from 5.2ºC (Crash Lake) to 7.8ºC (Ridge Lake).

Limnology profiles were taken in Ridge Lake (2 stations) and Cirque Lake. The maximum water depths at these stations were 7.1 m (Ridge Lake Station 1), 3.5 m (Ridge Lake Station 2), and 5.0 m (Cirque Lake). Thermal stratification was not observed in the lakes sampled (Attachment X.IV, Table X.IV-1). Dissolved oxygen concentrations were above the CWQG of 9.5 mg/L at all depths.

Secchi depth ranged from 2.2 m (Cirque Lake) to 3.0 m (Ridge Lake). Secchi depth equalled the maximum depth at all other stations.

2008

Limnological measurements were collected in four lakes in the Caribou Lake sub-basin in the summer and fall 2008 (Ridge, Fox, Caribou, and Calf lakes) (Attachment X.IV, Tables X.IV-2 and X.IV-3). Surface measurements were also taken in Cirque and Crash lakes in fall 2008. The deepest lake was Ridge Lake at 6.1 m, while the shallowest lake (at 0.9 m) was Crash Lake. In the summer, specific conductivity ranged from 15 µS/cm (Fox Lake) to 21 µS/cm (Calf Lake). In the fall, specific conductivity ranged from 13 to 29 µS/cm, with Cirque Lake having the lowest and Crash Lake having the highest. The pH ranged from 6.9 in Cirque Lake to 7.1 in Ridge Lake. All pH values were within the CWQG of pH 6.5 to 9. Dissolved oxygen concentrations ranged from 7.4 mg/L (Caribou Lake) to 10.5 mg/L (Calf Lake) in the summer and from 11.5 mg/L (Cirque Lake) to 12.9 mg/L (Crash Lake) in the fall. Surface DO concentrations were above the CWQG of 9.5 mg/L. Water temperatures ranged from 13.7ºC (Calf Lake) to 16.6ºC (Fox Lake) in the summer and 4.7ºC (Crash Lake) to 7.1ºC (Calf Lake) in the fall.

Limnology profiles were taken in Caribou Lake in summer and fall 2008 and in Ridge, Cirque, and Fox lakes in fall 2008. Thermal stratification was not observed in any lake (Attachment X.IV, Tables X.IV-2 and X.IV-3). Concentrations of DO were above the CWQG of 9.5 mg/L at all depths with the exception of Caribou Lake in spring 2008. At 2.0 m and 2.5 m, DO concentrations were 9.3 mg/L and 7.4 mg/L, respectively, which were lower than the CWQG of 9.5 mg/L for the protection of early life stages of cold water biota but above the CWQG of 6.5 mg/L for other life stages.

Secchi depth equaled the maximum depth of most lakes sampled, with the exception of Ridge and Cirque lakes. Secchi depth was 4.0 m in Ridge Lake (maximum depth of 6.1 m) and 2.2 m in Cirque Lake (maximum depths of 6.1 m and 5.2 m).

Judge Sissons Lake Sub-Basin

2008

As previously noted, many of the lakes in the mine site LSA are small and shallow. Judge Sissons Lake is the largest and deepest lake in the LSA. Limnology surface measurements were collected in Judge Sissons Lake in summer and fall 2008 (Attachment X.IV, Tables X.IV-2 and X.IV-3). Specific conductivity ranged from 17 to 27 µS/cm. Values of pH ranged from 6.6 to 7.5, which were within the CWQGs of pH 6.5 to 9. Surface DO concentrations ranged from 9.5 to 12 mg/L, which were above the CWQG of 9.5 mg/L. Surface water temperatures ranged from 7.0 to 15.2ºC.

Station depths in Judge Sissons Lake ranged from 1.0 to 19.5 m. Limnology profiles were taken at all stations (excluding fishing stations for which surface measurements were taken) in Judge Sissons Lake in summer and fall 2008. Maximum Secchi depth was 5.5 m at the deepest station (19.1 m) in summer 2008. Thermal stratification was not observed in any of the profiles measured in Judge Sissons Lake (Figure 6.2-1; Attachment X.IV, Tables X.IV-2 and X.IV-3). Concentrations of DO were above the CWQG of 9.5 mg/L at all depths with the exception of a bottom measurement at one station (9.4 mg/L).

2009

Limnology surface measurements were collected in Judge Sissons Lake in summer and fall 2009 (Attachment X.IV, Table X.IV-4). Specific conductivity ranged from 20 to 24 µS/cm. Values of pH ranged from 7.1 to 8.4, which were within the CWQG of pH 6.5 to 9. Surface DO concentrations ranged from 11.1 to 11.2 mg/L, which were above the CWQG of 9.5 mg/L. Surface water temperatures ranged from 5.6 to 10.8ºC.

Limnology profiles were taken at all sampling stations in summer and fall 2009, except macrophyte and angling stations in Judge Sissons Lake (Attachment X.IV, Table X.IV-4). Station depths in Judge Sissons Lake ranged from 0.8 to 20.6 m. Maximum Secchi depth was 8 m at the deepest station (20.6 m). Thermal stratification was not observed. Concentrations of DO were above the CWQG of 9.5 mg/L at all depths with the exception of a bottom measurement at one station (9.4 mg/L).

A limnology profile was taken in winter 2009 at one station in Judge Sisson Lake (Attachment X.IV, Table X.IV-5). Ice thickness was 1.8 m and station depth was 18.5 m. Specific conductivity increased with depth, ranging from 23 µS/cm at 2.0 m to 48 µS/cm at 18.0 m. Water temperature ranged from 1.2 to 3.4°C. Dissolved oxygen and pH values declined with increasing depth. Concentrations of DO ranged from 13.5 mg/L at 2.0 m to 0.3 mg/L at 18.0 m. At depths below 7.0 m, DO concentrations were less than the CWQG of 9.5 mg/L. Values of pH ranged from pH 7.6 at 2.0 m to pH 6.5 at 7.0 m; all pH values were within the CWQGs of pH 6.5 to 9.

Siamese Lake Sub-Basin

2008

Limnology profiles were taken at two stations in Siamese Lake in summer and fall 2008 (Attachment X.IV, Tables X.IV-2 and X.IV-3). Station depths ranged from 10.0 to 12.0 m. Secchi depths were similar between stations and seasons at 5.75 to 6.25 m. Specific conductivity was similar between seasons (15 µS/cm). Concentrations of DO and pH were lower in the summer than in the fall. In the summer, DO concentrations ranged from 9.4 to 9.8 mg/L, with all but one value above the CWQG of 9.5 mg/L. In the fall, DO concentrations ranged from 10.3 to 11.3 mg/L. In the summer, pH values at various depths ranged from pH 6.1 to 6.6, with all pH values from one station (SML-001-U08) less than the minimum CWQG of pH 6.5. Values were higher in the fall at pH 6.8 to 7.0. Water temperatures were higher in the summer (14.1 to 14.9°C) than in the fall (8.7 to 8.8°C). Thermal stratification was not observed. Limnology surface measurements were also taken at four fishing stations in the summer and two in the fall; in general, these measurements were similar to those observed in the profiles, although surface pH values were higher in the summer (pH 7.0 to 7.1).

2009

A limnology profile was taken in winter 2009 at five stations in Siamese Lake (Attachment IV, Table IV-5). Ice thickness ranged from 0.5 to 2.1 m and station depth ranged from 3.1 to 11.3 m. Specific conductivity generally ranged from 19 to 35 µS/cm, except near the bottom at two stations, where specific conductivity was 43 to 143 µS/cm). Water temperature ranged from 1.2 to 3.9°C. Dissolved oxygen and pH values declined with increasing depth. At depths at or below 4.0 m, DO concentrations were less than the CWQG of 9.5 mg/L. Values of pH ranged from pH 6.3 to 8.0. Values near the lake bottom at two stations were lower than the minimum CWQG of pH 6.5.

Skinny Lake Sub-Basin

2007

A limnology profile was taken at one station in Skinny Lake in fall 2007 (Attachment X.IV, Table X.IV-1). Station depth was 6.0 m and Secchi depth was 4.8 m. Specific conductivity, pH, DO, and water temperature were similar among depths. Specific conductivity was 16 µS/cm, pH ranged from 6.9 to 7.1. Dissolved oxygen ranged from 10.8 to 11.7 mg/L, and temperature ranged from 7.7 to 8.0°C. Thermal stratification was not observed.

2008

Limnology profiles were taken at three stations in Skinny Lake in fall 2008 (Attachment X.IV, Table X.IV-3). Station depths ranged from 2 to 12.8 m. Secchi depths ranged from 4.8 m at the deepest station (12.8 m). Specific conductivity, pH, DO, and water temperature were similar among stations and depths. Specific conductivity ranged from 17 to 19 µS/cm, pH ranged from 6.8 to 7.0, DO ranged from 10.9 to 11.4 mg/L, and temperature ranged from 7.4 to 8.8°C. Thermal stratification was not observed.

6.2.2.2 Streams of the Mine Site Local Study Area

Measurements of DO, temperature, pH and conductivity were taken at various stream sampling stations in the LSA during the 2007 to 2010 sampling sessions (Table 6.0-2). The results are summarized in the following sections.

Willow Lake Sub-Basin

2007

Surface measurements were collected in Pointer/Rock Stream in fall 2007 (Attachment X.IV, Table X.IV-1). The maximum depth of this stream at the sample station was 0.2 m. Specific conductivity was 12 µS/cm. The pH value was 7.35, which was within the range of CWQG of pH 6.5 to 9. Dissolved oxygen concentration was 12.1 mg/L, which was above the CWQG of 9.5 mg/L. Water temperature was 7.4ºC.

2008

Six streams in the Willow Lake sub-basin were sampled in the spring and fall 2008 (Attachment X.IV, Tables X.IV-6 and X.IV-7). Maximum depths of stations in the summer ranged from 0.15 m (Northeast Inflow of Pointer Lake) to 0.75 m (Pointer/Rock Stream). Maximum depths of stations in the fall ranged from 0.15 m (Pointer/Rock Stream) to 0.50 m (Willow/Judge Sissons Stream). Specific conductivity was lowest in the spring, likely reflecting the snow melt run-off, ranging from 13 µS/cm (Sik Sik/Rock Stream) to 27 µS/cm (Northeast Inflow of Pointer Lake). In the fall, specific conductivity ranged from 14 µS/cm (Pointer/Rock Stream) to 45 µS/cm (Sik Sik/Rock Stream). In the spring, Sik Sik/Rock Stream had the lowest pH (6.6), while Willow/Judge Sissons Stream had the highest (pH 7.4). In the fall, pH values ranged from pH 6.3 (Rock/Willow Stream) to pH 7.1 (Willow/Judge Sissons Stream). All pH values were within the CWQG of pH 6.5 to 9, with the exception of Rock/Willow Stream (pH 6.3). In the spring, DO concentrations ranged from 10.4 mg/L (Northwest Inflow of Pointer Lake) to 13.4 mg/L (Rock/Willow Stream). In the fall, DO concentrations ranged from 10.9 to 13.0 mg/L at the Northeast Inflow of Pointer Lake and Willow/Judge Sissons

Stream, respectively. In both seasons, DO concentrations for all streams were above the CWQG of 9.5 mg/L. In the spring, water temperatures ranged from 1.9 to 11.1ºC for Pointer/Rock Stream and the Northwest Inflow of Pointer Lake, respectively. Water temperature in the fall ranged from 5.6 to 7.3ºC with Northwest Inflow of Pointer Lake being the lowest and Willow/Judge Sissons Stream being highest.

2009

Six streams in the Willow Lake sub-basin were sampled in spring and fall 2009 (Attachment X.IV, Table X.IV-8). Specific conductivity was generally lower in the spring (ranging from 11 to 24 µS/cm) than in the fall (17 to 45 µS/cm). Generally, pH values ranged from pH 6.5 to 8.0. All pH values were within the CWQG of pH 6.5 to 9, with the exception of the two values from Pointer/Rock Stream (pH 6.46 and pH 6.47). Concentrations of DO ranged from 9.2 to 13.3 mg/L and were above the CWQG of 9.5 mg/L, except for one value in Sik Sik/Rock Stream (9.2 mg/L). Water temperatures ranged from 2.2 to 14.4ºC.

2010

Three streams were sampled in spring 2010 in the Willow Lake sub-basin, including the upper reach of a tributary of the Northeast Inflow of Pointer Lake, the lower reach of the Northeast Inflow of Pointer Lake, and the upper reach of Northwest Inflow of Pointer Lake (Attachment X.IV, Table X.IV-9). Water temperature ranged from 4.2 to 7.7 ºC. Dissolved oxygen concentrations were above the CWQG of 9.5 mg/L. All pH values were within the CWQG of pH 6.5 to 9.0.

Lower Lake Sub-Basin

2007

Surface measurements were collected in Shack/Lower Stream in fall 2007 (Attachment X.IV, Table X.IV-1). The maximum depth at the sample station was 1.0 m. The specific conductivity was 33 µS/cm. The pH of 7.5 was within the CWQG of pH 6.5 to 9. The surface DO concentration of 12.0 mg/L was above the CWQG of 9.5 mg/L. The water temperature was 8.7ºC.

2008

Limnology measurements were collected from eight streams in the Lower Lake sub-basin in spring and fall 2008 (Attachment X.IV, Tables X.IV-6 and X.IV-7). Station depths in the spring ranged from 0.4 to 1.3 m and were less than 0.3 m in the fall. Specific conductivity was lower in the spring than in the fall, ranging from 13 µS/cm (Cigar/Lunch Stream) to 21 µS/cm (End Grid/Shack Stream) in the spring and from 27 µS/cm (Mushroom/End Grid Stream) to 46 µS/cm (Knee/Lunch Stream) in the fall. In the spring, Shack/Lower Stream had the lowest pH (7.0), while Lower/Judge Sissons Stream had the highest (7.7). In the fall, pH values ranged from 6.9 (Mushroom/End Grid Stream) to 7.3 (Cigar/Lunch Stream). All field-measured pH values were within the CWQG of pH 6.5 to 9. In the spring, DO concentrations ranged from 10.6 mg/L (Shack/Lower Stream) to 12.7 mg/L (Cigar/Lunch Stream). In the fall, DO concentrations ranged from 11.1 mg/L (Mushroom/End Grid Stream) to 12.8 mg/L (Shack/Lower Stream). In both seasons, DO concentrations for all streams were above the CWQG of 9.5 mg/L. In the spring, water temperatures ranged from 4.1 to 10.6ºC for Lunch/Andrew Stream and Knee/Lunch Steam, respectively. Water temperature in the fall ranged from 5.7 to 7.4ºC with End Grid/Shack Stream being the lowest and Andrew/Shack Stream being highest.

2009

Lunch/Andrew and Andrew/Shack streams in the Lower Lake sub-basin were sampled in spring 2009 (Attachment X.IV, Table X.IV-8). Specific conductivity ranged from 14 to 18 µS/cm. Values of pH ranged from pH 7.4 to 7.8, which were within the CWQG of pH 6.5 to 9. Concentrations of DO ranged from 10.1 to 11.8 mg/L and were above the CWQG of 9.5 mg/L. Water temperatures ranged from 9.5 to 16.1ºC.

Caribou Lake Sub-Basin

2007

Surface measurements were collected in Crash/Fox and Fox/Caribou streams in fall 2007 (Attachment X.IV, Table X.IV-1). The station depths ranged from 0.3 to 0.5 m. Specific conductivity ranged from 7 to 25 µS/cm. Field pH values were 7.3 and 7.1, which were within the CWQG of pH 6.5 to 9. Surface DO concentration were 12.1 mg/L (Crash/Fox Stream) and 12.0 mg/L (Fox/Caribou Stream), which were above the CWQG of 9.5 mg/L. Water temperature was 5.0ºC in Crash/Fox Stream and 7.3ºC in Fox/Caribou Stream.

2008

Six streams were sampled in the Caribou Lake sub-basin during the spring and fall 2008 sampling sessions (Attachment X.IV, Tables X.IV-2 and X.IV-3). Station depths ranged from 0.2 to 1.5 m. Specific conductivity ranged from 12 µS/cm (Cirque/Crash Stream) to 18 µS/cm (Fox/Caribou and Calf/Judge Sissons streams) in the spring. Specific conductivity was higher in the fall and ranged from 14 µS/cm (Cirque/Crash Stream) to 26 µS/cm (Crash/Fox Stream). In the spring, Calf/Judge Sissons Stream had the lowest pH (6.8), while Caribou/Calf Stream had the highest (7.6). In the fall, pH values ranged from 6.6 to 6.9, with Cirque/Crash Stream being the lowest and Fox/Caribou Stream being the highest. All pH values were within the CWQG of pH 6.5 to 9. In the spring, DO concentrations ranged from 12.5 mg/L (Crash/Fox Stream) to 13.4 mg/L (Calf/Judge Sissons Stream). Dissolved oxygen concentrations were lower in the fall, and ranged from 11.4 mg/L

(Crash/Fox Stream) to 12.0 mg/L (Fox/Caribou Stream). In both seasons, DO concentrations for all streams were above the CWQG of 9.5 mg/L. In the spring, water temperatures ranged from 5.2ºC to 12.2ºC for Cirque/Crash Stream and Crash/Fox Steam, respectively. Water temperature in the fall ranged from 6.4ºC (Calf/Judge Sissons Stream) to 9.4ºC (Ridge/Crash Stream).

6.2.2.3 Lakes in the Site Access Local Study Area

Squiggly Lake Sub-Basin

2008

Limnology profiles were taken at three stations in Squiggly Lake in fall 2008 (Attachment X.IV, Table X.IV-3). Station depths ranged from 12 to 17.6 m. Secchi depths were similar among stations at 6 m. Specific conductivity, pH, DO, and water temperature were similar among stations and depths. Specific conductivity was 13 µS/cm, pH ranged from 6.5 to 6.8, DO ranged from 10.9 to 11.1 mg/L, and temperature ranged from 8.4 to 8.8°C. Thermal stratification was not observed.

Baker Lake Sub-Basin

2008/2009

Five stations were sampled in Baker Lake. The uniform temperature profiles observed at Stations 1, 2, and 3 indicate that the lake was well mixed (Figure 6.2-2) The water was isothermal at just under 5ºC in 2008 and had a narrow temperature range between 8.6ºC and 6.9ºC in 2009. Complete mixing (turn over) typically occurs during temperature changes, high winds, or as a result of external sources such as inflowing tributaries. The mean depth of Baker Lake is approximately 15 m (AREVA 2008). Given the uniform water temperature profiles measured in September 2008, the lake was not thermally stratified at that time.

Dissolved oxygen levels were also uniformly distributed with depth in both years, indicating the water was well mixed to the lake bottom at the time of sampling (Figure 6.2-3). Oxygen levels were high with saturation levels between 98% and 105% in 2008, and 100% and 104% in 2009.

The pH and conductivity profiles (not illustrated) at Stations 1, 2 and 3 were also relatively consistent with depth. The largest variation in pH occurred at Station 1 in 2008, ranging from pH 5.7 at the surface to pH 6.3 at 5 m depth.

The results for 2008 and 2009 are consistent with historic studies of Baker Lake and other lakes in the region, which indicate vertical mixing during the ice-free season, as evidenced by the uniform temperature, dissolved oxygen, pH, and conductivity levels (AREVA 2008).

Other Sub-Basins

2009

Limnology profiles were taken in four other waterbodies in winter 2009: L2 (unnamed lake; Siamese Lake sub-basin), Long Lake (Long Lake sub-basin), Audra Lake (Audra Lake sub-basin), Qinguq Bay (Baker Lake sub-basin; Attachment X.IV, Table X.IV-5). There were one to five stations per lake. Ice thickness ranged from 1.7 to 2.0 m and station depth ranged from 2.25 to 8.0 m. Specific conductivity varied among stations and lakes and ranged from 22 µS/cm (L2) to 274 µS/cm (one station in Audra Lake). Water temperature ranged from 0.5 to 3.1°C. Dissolved oxygen and pH values differed between lakes. Concentrations of DO were generally less than the CWQG of 9.5 mg/L at depths at or below 4.0 m in Audra Lake, near bottom in L2 (i.e., 7.0 m), and at all depths in Qinguq Bay and Long Lake. Values of pH ranged from pH 5.9 to 7.2. The lowest pH values were observed in Qinguq Bay and Long Lake.

6.2.2.4 Streams in the Site Access Local Study Area

Several different road corridors have been examined during the 2007 to 2010 sampling period. Fish sampling and habitat assessments were conducted where the proposed road corridors crossed the streams. Surface measurements of DO, temperature, pH and conductivity were taken to provide supporting environmental characteristics.

Three streams crossings were sampled in the fall 2008 (Attachment X.IV, Table X.IV-7). Maximum depth of streams at the proposed crossing ranged from 0.5 to 1.5 m. Specific conductivity varied among streams, ranging from 18 µS/cm in Stream X33, 27 µS/cm in Thelon River (road crossing 174.8), and 109 µS/cm in X28 Stream. Stream X28 had the lowest pH (7.1), while X33 Stream had the highest (7.6). Concentrations of DO were similar among streams, ranging from 11.8 to 12.7 mg/L. All concentrations were above the CWQG of 9.5 mg/L. Water temperature ranged from 4.0ºC (X28 Stream) to 6.9ºC (Thelon River – road crossing 174.8).

Thirty-three stream crossings were sampled in summer and fall 2009 (Attachment X.IV, Table X.IV-8). Specific conductivity varied among streams and stations ranging from 11 µS/cm in road crossing 109.8 to 154 µS/cm in W5 Stream. Values of pH ranged from pH 6.4 (W5 Stream) to pH 8.7 (road crossing 145.3). Only one pH value was outside of the CWQGs of pH 6.5 to 9. Concentrations of DO were variable among the streams, ranging from 3.8 to 12.3 mg/L. Several streams had DO concentrations that were less than the CWQG of 9.5 mg/L. Water temperature ranged from 9.6 to 19.0°C.

A bathymetric survey of the Thelon River (road crossing 174.8) was completed in fall 2010 (Attachment X.IV, Figure X.IV-41).

6.3 Summary

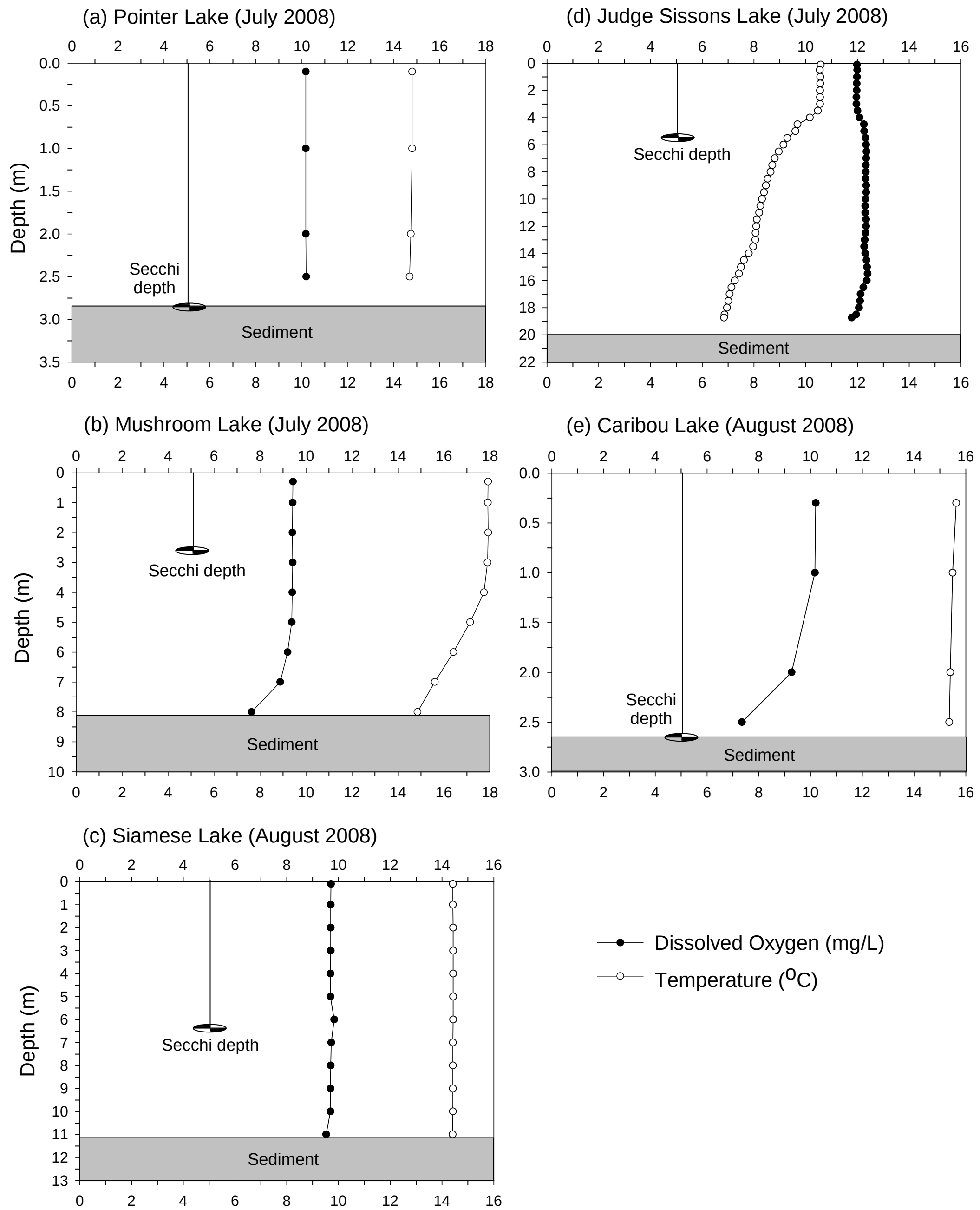
The majority of the lakes in the mine site LSA are shallow (i.e., less than 3 m in depth), although there are several lakes in the LSA that are between 10 and 20 m deep. Ice cover can reach 2 m in thickness in late winter. Smaller lakes begin to open up in mid-June and larger lakes, such as Judge Sissons Lake, may not be ice free until well into July.

Lakes in the mine site LSA are cold, monomictic lakes, that is, vertical mixing of the water column occurs only during the brief ice-free period in the summer. Thermal stratification does not occur in these lakes in open water conditions (Figure 6.2-1), likely due to the low heat input during the short summer in combination with the prevailing high winds and shallow nature of many of the lakes, which promotes complete mixing of the lakes. Even the deepest lakes in the mine site LSA do not thermally stratify.

Dissolved oxygen concentrations at all depths were typically higher than the CWQG of 9.5 mg/L for the protection of early life stages of cold freshwater biota. In some lakes there appears to be some oxygen depletion under winter ice-covered conditions. While the lakes were not anoxic, several lakes sampled late in the winter or early spring had DO concentrations below the CWQG guidelines for the protection of aquatic life (e.g., Judge Sissons Lake, Siamese Lake). For example, the DO concentrations between the 12 to 18 m depth strata of Judge Sissons Lake were below the minimum CWQG concentration for the protection of aquatic life of 6 mg/L, which suggests that the ability of some fish to over winter at these depths may be restricted during the latter part of the winter.

Dissolved oxygen concentrations were observed to reach supersaturation levels under ice cover in late winter in some lakes. This was noted by Beak (1990), where water was observed to be effervescent when a hole was cut in the ice. Supersaturation concentrations were also noted in several lakes sampled in the late winter of 2009.

Streams in the mine site LSA are generally well-oxygenated during open-water conditions. With the exception of Stream X28, conductivity in the streams was very low, usually less than 30 µS/cm.



Stations include: (a) PRL-001-U08, (b) MSL-002-U08, (c) SML-002-U08 (d) JSL-002-U08, and (e) CBL-001-U08.

Figure 6.2-1 Temperature and Dissolved Oxygen Profiles and Secchi Depth Recorded for the Deepest Stations in Lakes in the Kiggavik Project Area, Summer 2008

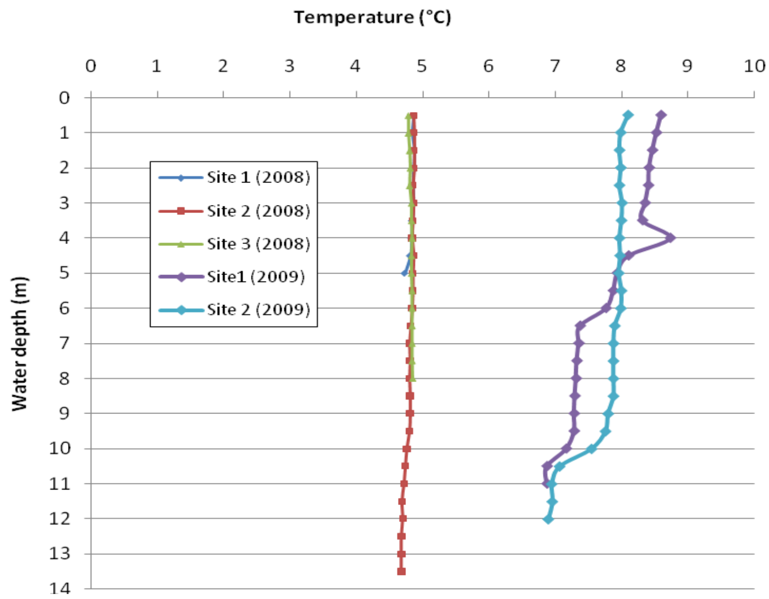


Figure 6.2-2 **Temperature Profiles at Sites Greater than 1.5 m Depth, September 2008 and August 2009, Baker Lake**

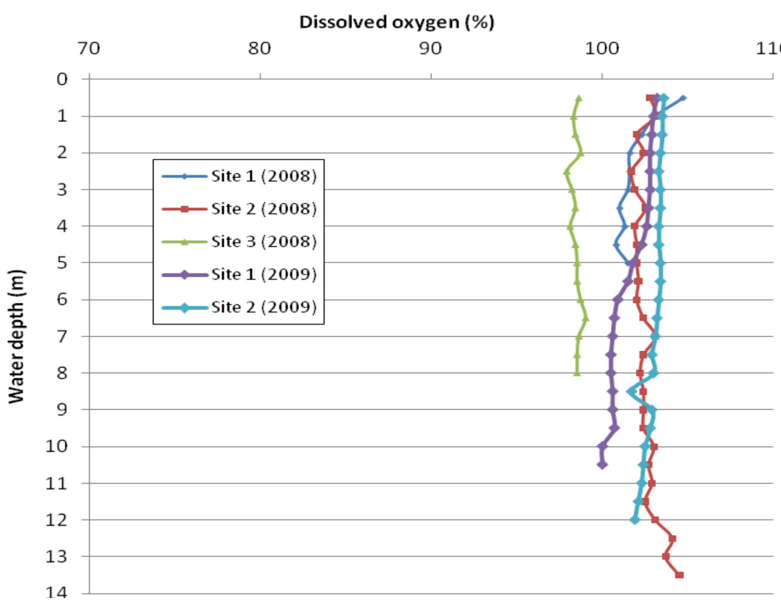


Figure 6.2-3 **Oxygen Profiles at Sites Greater than 1.5 m Depth, September 2008 and August 2009, Baker Lake**

7 Benthic Invertebrate Communities

Benthic invertebrates are also referred to as “benthic macroinvertebrates” because of their large size, with some species reaching a few centimetres in length. Benthic invertebrates are frequently sampled to monitor the environmental quality of waterbodies because they are present in nearly all waterbodies, are typically abundant, and remain in a small area throughout the aquatic phase of their life cycle so exposure to any contaminants or enrichment is maximized (Rosenberg and Resh 1993). In addition, benthic invertebrates are sensitive to a large variety of disturbances and exhibit predictable response patterns (Rosenberg and Resh 1993).

Benthic invertebrate community (BIC) surveys were carried out in the mine site local study area (LSA) between 1979 and 1991. More recent surveys were conducted between 2007 and 2009 to expand and complement the existing baseline information. Table 7.0-1 provides a summary of the lakes sampled between 1979 and 2009. Table 7.0-2 provides a summary of the streams sampled between 1989 and 2009.

7.1 Overview of Studies

7.1.1 Historical Summary 1979 to 1991

The BIC samples were generally collected from deep basins of lakes using a standard Ponar grab (1979 and 1980) or an Ekman grab (1990 and 1991), and sieved through a 500 micrometre (µm) sieve (BEAK 1990; BEAK 1992a). The number of stations within a lake varied from one to six. Samples were preserved with 10% buffered formalin (BEAK 1992a).

Stream samples were collected in triplicate using a standard Surber sampler equipped with a 500 µm mesh collection bag (BEAK 1990; BEAK 1992). Samples were preserved with 10% buffered formalin (BEAK 1992a).

Table 7.0-1 Summary of Lakes Sampled for Benthic Invertebrates in the Kiggavik Project Area, 1979 to 2009

Watershed	Sub-Basin	Waterbody	BEAK 1990		BEAK 1992a		Golder			Nunami Stantec
			1979	1980	1990	1991	2007	2008	2009	2008
Aniguq River	Willow Lake	Scotch Lake	X	X	-	-	-	-	-	-
		Pointer Lake	X	X	-	-	X	X	-	-
		Sik Sik Lake	-	-	-	-	X	X	X	-
		Rock Lake	-	-	-	-	-	X	X	-
		Willow Lake	-	-	-	-	X	X	X	-
	Lower Lake	Mushroom Lake	-	-	-	X	-	X	-	-
		End Grid Lake	-	-	-	-	X	X	-	-
		Cigar Lake	-	-	-	X	-	X	-	-
		Knee Lake	-	-	X	-	-	-	-	-
		Lunch Lake	-	-	X	-	-	X	-	-
		Andrew Lake	-	-	-	-	X	X	X	-
		Shack Lake	-	-	X	-	X	X	-	-
		Lower Lake	-	-	-	-	X	X	-	-
	Caribou Lake	Ridge Lake	-	-	-	-	X	X	-	-
		Cirque Lake	-	-	-	-	X	X	-	-
		Crash Lake	-	-	-	-	X	X	-	-
		Fox Lake	-	-	-	-	X	X	-	-
		Caribou Lake	-	-	-	-	-	X	-	-
		Calf Lake	-	-	-	-	-	X	-	-
	Judge Sissons Lake	Judge Sissons Lake	X	X	-	-	-	X	X	-
	Siamese Lake	Siamese Lake	-	-	-	-	-	X	-	-
	Kavisilik Lake	Kavisilik Lake	-	X	-	-	-	-	-	-
Thelon River	Squiggly Lake	Squiggly Lake	-	X	-	-	-	-	-	-
Baker Lake	Baker Lake	Baker Lake	-	-	-	-	-	-	-	X

\- = not collected.

Table 7.0-2 Summary of Streams Sampled for Benthic Invertebrates in the Kiggavik Project Area, 1989 to 2009

Watershed	Sub-Basin	Watercourse	BEAK 1990	BEAK 1992a		Golder	
			1989	1990	1991	2008	2009
Aniguq River	Willow Lake	Northeast Inflow of Pointer Lake	-	-	-	X	X
		Northwest Inflow of Pointer Lake	-	-	-	X	-
		Jaeger Lake outlet	X	-	-	-	-
		Pointer/Rock Stream	X	-	X	X	-
		Sik Sik/Rock Stream	-	-	-	-	X[(a)]
		Rock/Willow Stream	-	-	-	X	X
		Willow/Judge Sissons Stream	-	-	-	X	X
	Lower Lake	Mushroom/End Grid Stream	-	-	-	X	-
		End Grid/Shack Stream	-	-	-	X	-
		Shack Lake Inlet Stream	-	X	-	-	-
		Cigar/Lunch Stream	-	-	-	X	-
		Lunch Lake Inlet Stream	-	X	-	-	-
		Knee Lake Inlet Stream	-	X	-	-	-
		Knee/Lunch Stream	-	-	-	X	-
		Lunch/Andrew Stream	-	-	-	X	-
		Andrew/Shack Stream	-	-	-	X	-
		Andrew Lake Study Area outflow	-	-	X	-	-
		Shack/Lower Stream	-	X	-	X	-
		Lower/Judge Sissons Stream	-	-	-	X	-
	Caribou Lake	Ridge/Crash Stream	X	-	-	X	-
		Cirque/Crash Stream	-	-	-	X	-
		Crash/Fox Stream	-	-	-	X	-
		Fox/Caribou Stream	-	-	-	X	-
		Caribou/Calf Stream	-	-	-	X	-
		Calf/Judge Sissons Stream	-	-	-	X	-
	Judge Sissons Lake	Judge Sissons Lake outlet	-	-	X	-	-
	Skinny Lake	Skinny Lake outlet	X	-	-	-	-
	Aniguq River	Aniguq River	-	-	-	-	X

(a) = sampling was not completed at this station due to inappropriate substrate type.
\- = not collected.

7.1.2 Recent Field Surveys 2007 to 2009

The BIC were sampled concurrently with water quality (Section 4), sediment quality (Section 5) and other lower trophic communities (i.e., plankton and periphyton) (Section 9) sampling programs in the fall 2007, 2008 and 2009 field programs. Samples were collected from both lake (depositional) and stream (erosional) habitats.

7.1.2.1 Lake Sampling Methods

Lakes in the Mine Site Local Study Area

Benthic invertebrate community samples were collected from depositional areas in 19 lakes within the Project area (Attachment X.I; Figure X.I-1; Table X.I-4). Samples were collected following Golder's *Aquatic Technical Procedure 8.6-1: Benthic Invertebrate Sampling* (unpublished file information). At each sampling station, five sub-samples were collected using an Ekman grab sampler with a sampling area of 0.0232 square metres (m^2). Sub-samples were sieved in the field using a 500 µm Nitex mesh sieve bag, transferred to a one litre Nalgene container, and preserved with 10% buffered formalin. The subsample was combined into a single composite sample for each sampling station. Samples were shipped in sealed coolers to Golder's Saskatoon office prior to submission to a qualified taxonomist for analysis.

A single surficial sediment sample was collected at each of the sampling stations to characterize the habitat at each station. Sediment samples were double bagged in food-grade polyethylene bags. Samples were frozen and shipped in sealed coolers to Golder's Saskatoon office prior to submission to Saskatchewan Research Council Laboratories (SRC) for total organic carbon (TOC) and particle size analysis. The results of the sediment analysis are presented in Section 5 of this volume. The following additional supporting environmental information was recorded during the depositional BIC sample collection:

- sampling date and time;
- ambient weather and wind conditions;
- Universal Transverse Mercator (UTM) coordinates;
- general habitat description;
- water depth; and
- in situ limnology measurements (i.e., water temperature, dissolved oxygen, specific conductivity and pH) (refer to Section 6: Limnology).

Lakes in the Site Access Local Study Area

Benthic invertebrates were sampled from Baker Lake to characterize community diversity and abundance. Three replicate samples were collected using a petite Ponar (0.023 m^2 sampling area) at each of the five stations in 2008 and again at stations 1 and 2 in 2009 (Attachment X.I, Figure X.I-3). Samples at Station 5 were taken approximately 225 metres (m) from shore due to difficult sampling conditions near shore (i.e., abundance of rocks and boulders on lake bottom). The contents of each grab sample were temporarily placed in plastic bags and brought to shore. Once on shore, the samples were sifted through a 250 micrometres (µm) metal sieve using de-ionized water, transferred to a 500 millilitres (mL) plastic bottle and preserved with 10% buffered formalin. All sample bottles were kept in a cooler with ice packs and sent to Biologica Environmental Services Ltd. (Biologica) in Victoria, BC for analysis. Taxonomic analysis was performed on each individual grab sample, except for Station 5, where two replicates were composited in the field due to insufficient storage bags.

Field quality assurance/quality control (QA/QC) measures were based on Guidelines for Monitoring Benthos in Freshwater Environments (Gibbons et al. 1993). The Guidelines stipulate the need for adequate training of all personnel, consistent sampling methods, correct collection, labelling and preservation of samples, proper cleaning of equipment, maintenance of detailed field notes, use of chain-of-custody forms, and safe shipping and storage methods.

7.1.2.2 Stream Sampling Methods

BIC samples were collected from erosional areas within 19 streams and the Aniguq River within the mine site Local Study Area (Attachment X.I, Figure X.I.-2; Table X.I-5). The areas selected for sampling were undisturbed, shallow, riffle or run habitat with gravel/cobble substrate. Samples were collected following Golder’s *Aquatic Technical Procedure 8.6-1: Benthic Invertebrate Sampling* (unpublished file information). At each sampling station, five sub-samples were collected using a Serber sampler with a detachable Dolphin bucket. Mesh size of the Serber sampler was 243 µm and the sampling area was equal to 0.1 m^2. Benthic invertebrates were brushed from individual rocks with a gloved hand; extra care was taken not to exert too much pressure. Each rock was placed outside the Serber sampler once the benthic invertebrates were removed. Once all rocks from the sampling area were cleaned and removed, the substrate was stirred to a depth of approximately 5 to 10 centimetres (cm) with gloved hands for a period of 1 minute. All samples were collected by the same crew member for a sampling session to maintain consistency in the sampling methods.

The five sub-samples were combined into a single composite sample. Each sample was transferred to a one litre Nalgene container and preserved with 10% buffered formalin. Samples were shipped in sealed coolers to Golder’s Saskatoon office prior to submission to the taxonomist for analysis.

Additional supporting environmental information was collected during the erosional BIC sampling and included the following:

- sampling date and time;
- ambient weather and wind conditions;
- UTM coordinates;
- general habitat description (including photographs of the substrate);
- water depth;
- water velocity (Swoffer 2100-C140 Open Stream Current Velocity Meter; Attachment X.V, Table X.V-15); and
- in situ measurements (i.e., water temperature, dissolved oxygen, specific conductivity and pH) (refer to Section 6: Limnology).

7.1.2.3 Laboratory Analysis

Lakes and Streams in the Mine Site Local Study Area

Samples were submitted to Dr. J. Zloty, Ph.D. (Jack Zloty/Environmental Research and Consulting, Summerland, BC), for enumeration and taxonomic identification. Each composite BIC sample was sorted into fine and coarse fractionations according to standard taxonomic methods (Wrona et al. 1982). These methods were modified accordingly by the taxonomist depending on the material being analyzed (Zloty pers. comm. 2008).

Benthic invertebrates were identified to the lowest practical taxonomic level, using current literature and nomenclature. Target taxonomic levels were as follows:

- phylum level - Nematoda;
- sub-class level – Ostracoda;
- order level - Hydracarina;
- family level - Enchytraeidae, Naididae, Sphaeriidae, Tubificidae;
- genus level – Ceratopogonidae, Chironomidae, Coleoptera, Collembola, Dolichopodidae, Empididae, Ephemeroptera, Gastropoda, Lumbriculidae, Muscidae, Oligochaeta, Plecoptera, Simuliidae, Tanypodinae, Tipulidae, and Trichoptera; and
- species level - Amphipoda, Collembola (where possible), and Gastropoda (where possible).

Organisms that could not be identified to the desired level (e.g., immature or damaged specimens) were reported as a separate category at the lowest level of taxonomic resolution possible. Typically, this is to the family level, which is the level recommended in the Metal Mining Effluent Regulations (MMER) Technical Guidance Document (TGD) (Environment Canada [EC] 2002). The most common taxa were distinguishable based on gross morphology and required only a few (five to ten) slide mounts for verification. Organisms that required detailed microscopic examination for identification (e.g., Chironomidae and Oligochaeta) were slide mounted using an appropriate mounting medium (e.g., Hoyers). All rare or less commonly occurring taxa were also slide mounted for identification. A reference collection was prepared, consisting of several representative specimens from each taxon. The reference collection will be archived at the Golder Saskatoon office, for possible comparative purposes with BIC data from future studies and quality control of future taxonomic identification.

Surficial sediment samples were submitted to SRC for analysis of the following parameters:

- total organic carbon (TOC) content;
- loss on ignition (LOI);
- percent (%) moisture; and
- particle size.

Particle size was analyzed according to the following classification (EC 2002):

- gravel (2 to 16 millimetres [mm]);
- course sand (0.2 to less than 2 mm);
- fine sand (0.062 to less than 0.2 mm);
- silt (0.0039 to less than 0.062 mm); and
- clay (less than 0.0039 mm).

Baker Lake

Samples from Baker Lake were submitted to Biologica Environmental Services Ltd. (Victoria, BC). Detailed enumeration techniques and methods used by Biologica are provided in Attachment X.V. Samples were referenced, split, preserved, sorted, and then sub-sampled by weight. Invertebrates were identified to the lowest practical taxonomic level. Results were entered and delivered in a Microsoft Excel workbook. Analytical QA/QC were based on Biologica's internal QA/QC procedures (Attachment X.V).

7.1.2.4 Data Analysis

Lakes and Streams in the Mine Site Local Study Area

Raw benthic invertebrate density were received from the taxonomist in an electronic format. Supporting BIC survey data from the field was added to the electronic taxonomy data and the complete dataset was imported into the emLine™ database (emLine™). Data was then exported from emLine™ into Excel for analysis.

During the preparation of the data set for analysis, the following organisms were removed from the dataset:

- Crustacea – Cladocera, Cyclopoida, Calanoida and Harpacticoida (planktonic organisms);
- Insecta – Hydrozoa and Isotomidae (not strictly benthic organisms); and
- Nematoda - removed from lake samples because samples were sieved through 500 μm mesh sieve and the abundance of this meiofauna is not representative; nematodes were also removed from stream samples to maintain consistency in screening methods.

For each BIC sample, the raw abundance data was converted to number of organisms per square metre (organisms/m^2) for each taxon by the following equation:

- number of organisms per sample (sampling area *number of sub-samples)

The following BIC descriptors and biological variables were calculated for each station:

- total invertebrate density;
- relative density of major taxon;
- family level richness;
- lowest taxonomic level richness; and
- Simpson's Diversity Index (SDI).

Density is the total number of organisms/m^2. The relative density quantifies the relative proportion of each family composing the BIC. Richness is the total number of taxonomic groups (i.e., family and lowest taxonomic level). Richness provides an indication of the diversity of benthic invertebrates in an area; a higher richness value usually indicates a more healthy and balanced community.

Simpson's diversity index measures the proportional distributions of organisms in the community, taking into account the abundance patterns and taxonomic richness of the community. Certain environmental conditions may favour or affect one organism more over another; thus, not all organisms have the same success in a given environment. The SDI values are between 0 and 1. Higher values indicate a community consisting of more taxa among which, abundance is more equitably distributed. Lower values indicate a community dominated by only a few taxonomic groups, which may reflect natural or anthropogenic stresses.

Baker Lake

To facilitate data analysis and presentation, the various life stages of individual taxa were combined (i.e., adult, juvenile, and larval stages). Additionally, data for the three replicate samples were pooled prior to data analysis. For most taxa, only results at the family level were used to calculate descriptors of benthic community composition, although higher taxonomic levels were used for organisms that could not be identified to family, including:

- Orders Ostracoda, Amphipoda, and Tricoptera;
- Sub-class Acari; and
- Class Nematoda.

Planktonic organisms (Cyclopoida, Harpacticoida) were not included in the data analysis, nor were any identified terrestrial organisms.

Benthic data was analyzed at the family level using descriptors selected for consistency with monitoring programs typically developed under federal *Metal Mining Effluent Regulations* and the associated *Metal Mining Guidance Document for Aquatics Environmental Effects Monitoring* (Environment Canada 2002). Data were averaged across the three replicate samples at each location and the following indices were calculated:

- mean invertebrate density: mean number of individuals collected in the three replicate samples expressed per unit area (m^2) and standard deviation;
- taxonomic (i.e., family) richness: number of distinct taxa for all samples combined, estimated at the family level;
- Simpsons Evenness Index (SEI); and
- SDI.

Simpson's evenness index, or equitability, is a measure of the relative abundance of the different taxa contributing to richness in the area. This index compares the observed community to a hypothetical community, which consists of the same number of equally abundant taxa. A community dominated by one or two species is considered to be less diverse than one in which several different species have similar abundances. SEI values range between 0 and 1. Higher values indicate a balanced community consisting of more taxa that are evenly distributed among taxonomic groups. Lower values indicate a community dominated by a few taxa. These communities are often referred to as "stressed", and may reflect the influence of natural or anthropogenic disturbances. Because determining an SEI requires multiple samples for each lake, it was not calculated for lakes in the mine site LSA.

7.1.2.5 Quality Assurance/Quality Control

Detailed specific work instructions outlining each field task were provided to field personnel prior to the field program. Samples were collected, labelled, preserved, and shipped according to Golder's *Technical Procedure 8.6-1: Benthic Invertebrate Sampling* (unpublished file information) and laboratory protocols. Detailed field notes were recorded in waterproof field notebooks and on pre-printed waterproof field data sheets. Sample jars were labelled in waterproof ink, and a second waterproof label was inserted into each jar. All double-bagged sediment samples were labelled with waterproof ink and a waterproof label was inserted between the inner and outer bags.

Data collected during the field program underwent a variety of individual QA checks. Field data sheets were checked at the end of each day for completeness and accuracy. Golder Chain of Custody (COC) forms were used to track BIC and sediment sample shipment from the field to Golder's Saskatoon office. The COC forms were also used to track the BIC sample shipments to the taxonomist. SRC analytical request forms were submitted with the surficial sediment samples.

Benthic invertebrate sample processing first involved sorting organisms from debris and in some instances sub-sampling sorted organisms for detailed identification. Verification of sorting efficiency was performed on a spot-check basis of the retained debris from a sample. At least 10% of all samples were re-sorted and had to contain 10% or less of the total number of organisms found during the initial count to be considered acceptable. If more than 10% of the total number was found during the re-sort, then all the samples within that group of samples were re-sorted. The factors that were considered when determining similar groups of samples included: sampling area, habitat class, and individual sorters. A further criterion that would require samples to be re-sorted was if an entire taxonomic group was missed by the sorter, regardless of whether the missed organisms constituted less than 10% of the total. Unsorted and sorted fractions are retained until taxonomy and sorting efficiency are confirmed (Zloty pers. comm. 2008).

The electronic taxonomy data underwent a visual QA/QC check for obvious errors. Any data entered into emLine™ underwent a 100% transcription check by a second person not involved in the initial data entry process. All datasets generated by the database and all summary tables underwent an additional QA/QC screening.

7.2 Results

Various lakes and streams were sampled between 1979 and 2009 (Table 7.0-1 and 7.0-2). The following sections provide a summary of the historical data as well as the results of the more recent sampling (i.e., 2007 to 2009). Detailed results have been included in Attachment X.V.

7.2.1 Historical Summary

Benthic invertebrate community samples were collected between 1979 and 1991 in the mine site LSA. The field studies conducted between 1979 and 1989 were general in scope, and the objectives were to collect baseline information on BIC within the Project area. The 1990 to 1991 sampling programs were designed to collect replicate BIC samples from the Project area lakes as per the request of the Federal Environmental Assessment Review Office (BEAK 1992b). Attempts were made to collect samples from the deep basin of Judge Sissons Lake in 1991 (BEAK 1992a); however, the sediment in the vicinity of the deep basin was comprised of hard packed clay and after considerable effort, no samples were recovered.

In reviewing the historical data, it should be noted that analytical methods have changed since the sampling was done and the original environmental assessment documents were prepared. For example, Environment Canada (2002) suggests Nematoda (nematodes) and Harpacticoida (harpacticoid copepods) should be removed from any data analysis of samples sieved through 500 µm mesh. These meiofauna (i.e., organisms of a size that can pass unharmed through 500 to 1,000 µm mesh) should be removed because only a fraction of the specimens will be retained by 500 µm meshes and the numbers will not be representative. Nematodes and harpacticoid copepods were included in the original historical data assessments (i.e., BEAK 1990, 1992) even though these samples were sieved through 500 µm mesh (see Section 7.1.1). In addition, the benthic indices calculated in the historical documents were done at the family level, rather than to the lowest level of taxonomic identification, as is currently the preferred method. The original 1979 to 1991 results are presented below (Table 7.2-1) and have not been altered from the original reports.

Table 7.2-1 Summary of Benthic Invertebrate Community Data for Lakes in the Kiggavik Project Area, 1979 to 1991

Waterbody	Family Level Richness (# of Taxa)	Density ($\#/m^2$)
1979		
Pointer Lake	4 to 8	533.8 to 1,799.9
Judge Sissons Lake	3 to 16	11.4 to 3,375.5
Scotch Lake	13	1,825.5
1980		
Pointer Lake	4 to 8	459.2 to 1,550
Judge Sissons Lake	0 to 5	0 to 10,639
Scotch Lake	10	11,289
Squiggly Lake	7	2,105
Kavisilik Lake	3	344.4
1990		
Knee Lake	12 to 16	2,304 to 4,478
Lunch Lake	1 to 10	87 to 3,087
Shack Lake	7 to 9	565 to 1,696
1991		
Cigar Lake	14 to 19	15,304 to 18,957
Mushroom Lake	9 to 13	1,913 to 5,913

Source: BEAK 1992a.
Note: Values reported represent the range of values.
\# = number; $\#/m^2$ = number of organisms per square metre.

7.2.1.1 Lakes in the Mine Site Local Study Area

Benthic invertebrate density in the lakes within the Project area ranged over five orders of magnitude, from zero to 18,957 organisms/m^2 (Table 7.2-1). Family level richness ranged from zero to 19 families (Table 7.2-1). Chironomidae (chironomids) and Sphaeriidae (fingernail clams) were consistently the dominant taxa. Benthic invertebrates observed in fish stomach contents included Plecoptera (stoneflies), Trichoptera (caddisflies), Amphipoda (amphipods), and Gastropoda (snails; 1991 only) (BEAK 1992a).

7.2.1.2 Streams in the Mine Site Local Study Area

Between 1989 and 1991, benthic invertebrate density[6] in streams within the Project area ranged over two orders of magnitude, from 215 to 32,489 organisms/m^2 (Table 7.2-2). Family level richness ranged from eight to 30 families (Table 7.2-2). Chironomids were the dominant taxa in the benthic invertebrate communities of streams. *Hydra* sp. was abundant in the Jaeger Lake Outlet Stream and the Pointer Lake Outlet Stream, but was present in low numbers or absent from other streams sampled within the Project area. Fingernail clams, oligochaete worms, and snails were also abundant in a number of the Project area streams (Attachment X.V, Table X.V-1).

Table 7.2-2 Summary of Benthic Invertebrate Community Data for Streams in the Kiggavik Project Area, 1989 to 1991

Watercourse	Lowest Level Taxonomic Richness (# of Families)	Total Invertebrate Density (#/m^2)
1989		
Jaeger Lake outlet	18 to 23	1,411 to 3,522
Ridge Lake outlet	15 to 20	2,044 to 15,111
Skinny Lake outlet	11 to 17	333 to 3,111
Pointer Lake outlet	14 to 20	5,778 to 32,489
1990		
Pond 1 km upstream of Lower Lake	14 to 16	10,043 to 13,478
Pond 2 km upstream of Lower Lake	8 to 13	2,000 to 7,478
Knee Lake inlet	9 to 20	215 to 1,290
Lunch Lake inlet	14 to 20	344 to 6,516
Shack Lake inlet	11 to 15	215 to 398
Inlet 1 km upstream of Lower Lake	14 to 19	538 to 1,226
Inlet 2 km upstream of Lower Lake	12 to 16	624 to 3,742

[6] See caveat in Section 7.2.1.1 regarding changes in methods for enumerating benthic invertebrates.

Table 7.2-2 Summary of Benthic Invertebrate Community Data for Streams in the Kiggavik Project Area, 1989 to 1991

Watercourse	Lowest Level Taxonomic Richness (# of Families)	Total Invertebrate Density ($\#/m^2$)
1991		
Andrew Lake outlet	26 to 30	10,419 to 13,269
Pointer Lake outlet	11 to 18	505 to 1,753
Judge Sissons Lake outlet	14 to 21	2,258 to 18,957

Source: BEAK 1992a.
Note: Values reported represent the range of values.
\# = number; $\#/m^2$ = number of organisms per square metre; km = kilometre.

7.2.2 Recent Sampling Period 2007 to 2009

7.2.2.1 Lakes in the Mine Site Local Study Area

Detailed taxonomic results for the 2007 mine site Local Study Area lakes' benthic invertebrate community data are presented in Attachment X.V, Tables X.V-2 and X.V-3. The detailed results for the 2008 sampling are provided in Attachment X.V, Tables X.V-4 and X.V-5. The detailed results for the 2009 sampling are provided in Attachment X.V, Tables X.V-10 and X.V-11.

Willow Lake Sub-Basin

2007

Density in the Willow Lake sub-basin ranged from 273 organisms/m^2 (Willow Lake) to 4,405 organisms/m^2 (Sik Sik Lake). Willow Lake had the lowest benthic invertebrate densities of 273 and 810 organisms/m^2 at Station 1 and Station 2, respectively.

Lowest practical level taxonomic richness varied from a minimum of eight taxa (Willow Lake) to a maximum of 20 taxa (Sik Sik Lake) (Table 7.2-3). SDI values in the Willow Lake sub-basin ranged from 0.38 (Pointer Lake) to 0.67 (Sik Sik Lake) (Table 7.2-3). These values indicate benthic invertebrate communities of moderate richness with several dominant taxa present, but with abundance somewhat equally distributed among taxa.

Chironomids were the dominant taxa (45.7 to 56.4%) in the three lakes within this sub-basin (Attachment X.V, Table X.V-8). Fingernail clams accounted for 20.4% of the benthic invertebrate community in Sik Sik Lake and 26.0% in Pointer Lake, but were only a small proportion of the benthic invertebrate community in Willow Lake (1.6%). Tubificid worms were also predominant in Willow Lake (39.0%) and Sik Sik Lake (23.2%), but accounted for only 6.4% of the benthic invertebrate community in Pointer Lake.

The following taxa were identified as unique to the Willow Lake sub-basin (Attachment X.V, Table X.V-2):

- *Dicranota* sp (Pointer lake);and
- *Gyralus* sp. (Willow Lake).
- *Paratendipes* sp. (Sik Sik Lake); and
- Unidentified new species of Orthocladiinae (Willow Lake).

Table 7.2-3 Summary of Benthic Invertebrate Community Data for Lakes in the Kiggavik Project Area, 2007 to 2009

Sub-Basin	Waterbody[a]	2007			2008			2009		
		Total Invertebrate Density ($\#/m^2$)	Lowest Level Taxonomic Richness (# of Taxa)	Simpson's Diversity Index	Total Invertebrate Density ($\#/m^2$)	Lowest Level Taxonomic Richness (# of Taxa)	Simpson's Diversity Index	Total Invertebrate Density ($\#/m^2$)	Lowest Level Taxonomic Richness (# of Taxa)	Simpson's Diversity Index
Local Study Area										
Willow Lake	Pointer Lake[b]	3,319 to 3,603	13 to 15	0.38 to 0.59	1,439 to 14,345	15 to 22	0.17 to 0.57	-	-	-
	Sik Sik Lake	3,560 to 4,405	17 to 20	0.43 to 0.67	5,138	16	0.39	35,983	22	0.41
	Rock Lake	-	-	-	12,879	20	0.44	23,845	22	0.24
	Willow Lake	273 to 810	8 to16	0.40 to 0.43	2,405	14	0.37	31,991	26	0.56
Lower Lake	Mushroom Lake[b]	-	-	-	7,431 to 14,948	17 to 22	0.19 to 0.51	-	-	-
	End Grid Lake	198 to 784	7 to 8	0.16 to 0.23	2,560	13	0.16	-	-	-
	Cigar Lake	-	-	-	37,259	16	0.11	-	-	-
	Lunch Lake	-	-	-	940	10	0.72	-	-	-
	Andrew Lake	509 to 802	6 to 8	0.32 to 0.68	68,552	9	0.05	2,897	17	0.55
	Shack Lake	431 to 1,233	9 to 10	0.11 to 0.56	33,138	12	0.01	-	-	-
	Lower Lake	3,578 to 6,853	14 to 21	0.37 to 0.66	16,224	20	0.37	-	-	-
Caribou Lake	Ridge Lake	948 to 5,293	13 to 17	0.50 to 0.53	3,043	15	0.59	-	-	-
	Cirque Lake	11,741 to 112,224	8	0.06 to 0.49	11,440	11	0.61	-	-	-
	Crash Lake	534 to 1,422	6	0.41 to 0.55	9,759	17	0.13	-	-	-
	Fox Lake	2,466 to 12,259	12 to 14	0.53 to 0.74	16,414	20	0.43	-	-	-
	Caribou Lake	-	-	-	15,259	18	0.66	-	-	-
	Calf Lake	-	-	-	1,957	11	0.13	-	-	-
Judge Sissons Lake	Judge Sissons Lake[b,c]	-	-	-	1,586 to 14,379	9 to 23	0.14 to 0.77	2,897 to 24,474	13 to 39	0.39 to 0.79
Siamese Lake	Siamese Lake[b]	-	-	-	5,974 to 18,474	16 to 17	0.17 to 0.39	-	-	-

Note: Values reported represent the range of values.
(a) Two stations were sampled in all lakes in 2007.
(b) Five stations were sampled in Pointer Lake, three stations were sampled in Mushroom Lake, five stations were sampled in Judge Sissons Lake, and two stations were sampled in Siamese Lake in 2008.
(c) Five stations were sampled in Judge Sissons Lake in 2009.
= number; $\#/m^2$ = number of organisms per square metre.

2008

Within the Willow Lake sub-basin, benthic invertebrate density ranged from 1,440 organisms/m2 to 14,345 organisms/m2 (both in Pointer Lake; Table 7.2-3; Attachment X.V, Table X.V-5). As in 2007, density of benthic invertebrates remained low in Willow Lake.

Lowest level taxonomic richness varied from a minimum of 14 taxa (Willow Lake) to a maximum of 22 taxa (Pointer Lake) (Table 7.2-3). The SDI values in the Willow Lake sub-basin ranged from 0.17 to 0.57, both in Pointer Lake, with most lakes ranging from 0.37 to 0.44 (Table 7.2-3).

Chironomids were the dominant taxa (68.5 to 78.5%) in the four lakes sampled within this sub-basin (Attachment X.V, Table X.V-8). Fingernail clams accounted for 19.8% of the benthic invertebrate community in Pointer Lake and 13.4% in Sik Sik Lake; these taxa were absent from both Willow Lake and Rock Lake. Ostracoda (seed shrimp) were relatively predominant in Rock Lake (23.4%), but were very low in Pointer Lake (0.8%) and absent from both Sik Sik Lake and Willow Lake. The following three taxa were identified only in Pointer Lake: Naididae (oligochaete worms); Parachironomus sp. (chironomid); and Mystacides sp. (Leptoceridae - caddisflies).

2009

In 2009, density ranged from 23,845 organisms/m2 (Rock Lake) to 35,983 organisms/m2 (Sik Sik Lake; Table 7.2-3; Attachment X.V, Table X.V-11). Lowest taxonomic richness was similar in all three lakes sampled in the Willow Lake sub-basin, ranging from 22 (Rock Lake and Sik Sik Lake) to 26 taxa (Willow Lake) (Table 7.2-3). SDI values for the Willow Lake sub-basin ranged from 0.24 (Rock Lake) to 0.56 (Willow Lake) (Table 7.2-3).

Chironomids were the dominant taxa (61.2% to 86.9%) in the three lakes sampled within this sub-basin (Attachment X.V, Table X.V-8). Fingernail clams were the only other dominant taxa present in Sik Sik Lake (15.3%) and Willow Lake (24.5%). The following two taxa were identified only in Sik Sik Lake: Endochironomus sp. and Callibaetis sp. (Attachment X.V, Table X.V-10).

Lower Lake Sub-Basin

2007

Benthic invertebrate density in the Lower Lake sub-basin ranged from 198 to 6,853 organisms/m^2. Lower Lake had the highest benthic invertebrate density (3,578 to 6,853 organisms/m^2) of any lake sampled within the sub-basin.

Lowest level taxonomic richness values in the Lower Lake sub-basin ranged from a minimum of six taxa (Andrew Lake) to a maximum of 21 taxa (Lower Lake; Table 7.2-3). The SDI values in lakes of the Lower Lake sub-basin ranged from 0.11 (Shack Lake) to 0.68 (Andrew Lake) (Table 7.2-3). The relatively low SDI value in Shack Lake (0.11) is reflective of a high abundance of chironomids of the genus *Paratanytarsus*. In addition, sediments were predominantly coarse and fine sands in Shack Lake. Lower density and diversity is typically associated with higher proportions of sand.

Chironomids were a dominant taxon in all lakes within this sub-basin (Lower Lake 65.4%; Shack Lake 65.2%; Andrew Lake 49.5%; and End Grid Lake 89.1%). Fingernail clams were also dominant taxa in Shack Lake (28.0%), but were present in low numbers or absent from samples collected in the remaining three lakes within this sub-basin. In Andrew Lake, Ceratopogonidae (biting midges) and Enchytraeidae (oligochaete worms) comprised 27.9% and 19.4% of the benthic invertebrate community, respectively, but were absent from samples collected in the other three lakes within this sub-basin. The following taxa were identified as unique to the Lower Lake sub-basin (Attachment X.V, Table X.V-2):

- *Lepidurus* sp.(End Grid Lake);
- *Limnophora* sp. (Andrew Lake);
- *Tipula* sp.(Andrew Lake); and
- *Mystacides* sp. (Lower lake).

2008

The Lower Lake sub-basin had the most extreme variation in benthic invertebrate density, ranging from 940 organisms/m^2 (Lunch Lake) to 68,552 organisms/m^2 (Andrew Lake; Table 7.2-3). The remaining lakes within this sub-basin had benthic invertebrate densities ranging from 2,560 organisms/m^2 (End Grid Lake) to 37,259 organisms/m^2 (Cigar Lake).

Lakes within the Lower Lake sub-basin had taxonomic richness ranging from a minimum of nine taxa (Andrew Lake) to a maximum of 22 (Mushroom Lake; Table 7.2-3). In the Lower Lake watershed, the SDI values ranged from 0.01 (Shack Lake) to 0.72 (Lunch Lake). The very low SDI value observed in Shack Lake (0.01) was the result of the high abundance of chironomid genus, *Paratanytarsus* sp., and the low SDI value in Andrew Lake (0.05) was the result of the high abundance of one chironomid genus, *Dicrotendipes* sp. These two lakes also had a higher proportion of coarse and fine sands in the sediment particle size composition (refer to Section 5.2.2), which typically results in lower benthic invertebrate density and diversity (Table 7.2-3).

Chironomids were the dominant taxa in the majority of lakes (78.1 to 99.5%), with the exception of Lunch Lake, where chironomids comprised only 22.0% of the benthic invertebrate community. In Lunch Lake, fingernail clams and tubificid worms accounted for 43.1% and 15.6% of the benthic invertebrate community composition, respectively. Fingernail clams were only present in one other lake within this sub-basin, specifically Cigar Lake, but the proportion of this taxon was low (4.0%). *Stempellinella* sp. (chironomid) was identified only in Mushroom Lake: and an unidentified chironomid (i.e., species 1) was identified only within Lower Lake.

2009

Andrew Lake was the only lake sampled in the Lower Lake sub-basin in 2009. Density within Andrew Lake was 2,897 organisms/m^2 (Table 7.2-3). Lowest level richness in Andrew Lake was 9 taxa, while the SDI value was 0.55 (Table 7.2-3).

Chironomidae was the most dominant family present in Andrew Lake (52.1%) and Ceratopoginae (41.1%) contributed to the remaining taxa present (Attachment X.V, Table X.V-8). The chironomid family was mainly comprised of Bezzia species and Dictotendipes species. No unique taxa were identified in Andrew Lake (Attachment X.V, Table X.V-10).

Caribou Lake Sub-Basin

2007

In 2007, benthic invertebrate density ranged from 534 organisms/m^2 in Crash Lake to 112,224 organisms/m^2 in Cirque Lake (Table 7.2-3). Within this sub-basin, Cirque Lake (Station 2) had the highest density of 112,224 organisms/m^2, followed by Fox Lake, which had a density of 12,259 organisms/m^2. Cirque Lake had the highest benthic invertebrate density of the lakes sampled in the mine site Local Study Area.

Within the Caribou Lake sub-basin, lowest level taxonomic richness varied from a minimum of 6 taxa (Crash Lake) to a maximum of 17 taxa (Ridge Lake) (Table 7.2-3). The SDI values ranged from a low of 0.06 (Cirque Lake) to a high of 0.74 (Fox Lake) (Table 7.2-3). The very low SDI value observed in Cirque Lake (0.06) was a result of a very high abundance of one species of chironomid genus *Corynocera*.

Fingernail clams were the dominant taxa in Fox Lake (47.6%), with chironomids also accounting for a relatively large proportion (27%) of the benthic invertebrate community. Chironomids were the dominant taxa in Crash Lake (55.6%), Cirque Lake (77.5%) and Ridge Lake (36.9%). Fingernail clams were also dominant taxa in Cirque Lake (26.5%) and Ridge Lake (57.7%), but were absent from samples collected in Crash Lake. Tubificid worms were dominant taxa in Crash Lake (41.2%). No unique taxa were identified in the Caribou Lake sub-basin.

2008

In the Caribou Lake sub-basin, benthic invertebrate density ranged from 1,957 organisms/m^2 (Calf Lake) to 16,414 organisms/m^2 (Fox Lake) (Table 7.2-3).

Lowest taxonomic richness values in the Caribou Lake sub-basin ranged from a minimum of 11 (Calf and Cirque lakes) to a maximum of 20 (Fox Lake) (Table 7.2-3). The SDI values ranged from 0.13 (Crash and Calf lakes) to 0.66 (Caribou Lake). These SDI values were similar to those observed in lakes within the LSA.

Chironomids (25.0 to 93.2%) and fingernail clams (17.8 to 46.3%) were the dominant taxa in the majority of lakes in this sub-basin, with the exception of Crash Lake and Calf Lake, where fingernail clams were not observed. Seed shrimp also dominated the benthic invertebrate community within Cirque Lake (53.9%), but this taxon was present in low proportions in Ridge Lake (7.4%) and Fox Lake (0.2%) and was absent from the other lakes. Two taxa (*Parametriocemus* sp. [chironomid] and *Agrypnia* sp. [Phryganeidae – caddiflies]) were identified only in Crash Lake, while *Endochironomus* sp. (chironomid) was identified only within Caribou Lake.

2009

No lakes were sampled in the Caribou Lake sub-basin in 2009.

Judge Sissons Lake Sub-Basin

2008

Judge Sissions Lake was the largest and deepest lake sampled within the LSA in 2008. Benthic invertebrate density ranged from 1,586 to 14,370 organisms/m^2 in Judge Sissons Lake. The wide range likely reflects the difference in basin morphometry and substrate at the different sampling stations in Judge Sissions Lake.

The lowest level taxonomic richness was variable, ranging from 9 to 23 taxa (Table 7.2-3). The SDI for the five stations in Judge Sissons Lake ranged from 0.14 to 0.77, with a mean SDI of 0.39 (Table 7.2-3).

The benthic community was dominated by chironomids (73.5%), with fingernail clams comprising the next most abundant taxa (11.6%). The following five taxa were identified only within Judge Sissons Lake:

- Potthastia longimanus (chironomid);
- Euryhapsis sp. (chironomid);
- Clinocera sp. (Empididae - dance flies);
- Nemoura sp. (Nemouridae - stoneflies); and
- Hydra sp. (hydra) (Attachment X.V, Table X.V-4).

2009

Judge Sissions Lake remained the largest and deepest lake sampled in 2009. Benthic invertebrate density ranged from 2,897 to 24,474 organisms/m^2, reflecting differences in basin morphometry and substrate at each sampling station.

Lowest level taxonomic richness was variable among stations, ranging from 13 to 39 taxa (Table 7.2-3). In 2009 the SDI values for Judge Sissons Lake varied from 0.39 to 0.79 (Table 7.2-3).

The BIC was dominated by chironomids at all stations in Judge Sissons Lake. Chironomid values ranging from 28.9 to 76.2% (Attachment X.V, Table X.V-8) between sampling stations, with a mean value of 61.2%. Fingernail clams were the second most dominant taxa, ranging from 0 to 44.6% between sampling stations (lake mean of 18.9%). Valvatidae comprised the remaining taxa, ranging from 0.3% to 18.5% (lake mean of 9.2%).

The following taxa were identified only in Judge Sissons Lake (Attachment X.V, Table X.V-10):

- *Abiskomyia* sp. (chironomid);
- *Apatania* sp. (Climnephilidae);
- *Clinocera* sp. (Empididae);
- *Clintotnypus* sp. (Tanypodinae);
- *Corynoneura* sp. (chironomid);
- *Hydra* sp. (hydra);
- *Limnophyes* sp. (Orthocladiinae);
- *Mystacides* sp. (Leptoceridae);
- *Procladius* sp. (Tanypodinae);
- *Stempellinella* sp. (Tanytarsini); and
- *Stilocladius* sp. (Orthocladiinae).

Siamese Lake Sub-Basin

Benthic invertebrate sampling stations were located in both basins of Siamese Lake in 2008. Benthic invertebrate density ranged from 5,974 to 18,747 organisms/m^2 in Siamese Lake. The lowest level taxonomic richness ranged from 16 to 17 taxa in Siamese Lake (Table 7.2-3). As observed in Judge

Sissons Lake, the only other large lake sampled within the Project area, the BIC was dominated by chironomids (83.2%), with fingernail clams the next most abundant taxa (12.1%). The SDI value ranges from 0.17 to 0.39, which was a smaller range in values compared to Judge Sissons Lake.

7.2.2.2 Streams in the Mine Site Local Study Area

Detailed taxonomic results for the 2008 benthic invertebrate community data for stream in the mine site Local Study Area are presented in Attachment V, Table X.V-6 and Table X.V-7. Detailed taxonomic results for the 2009 BIC data for Project area streams are presented in Attachment X.V, Table X.V-12 and Table X.V-13.

Willow Lake Sub-Basin

2008

In the Willow Lake sub-basin, benthic invertebrate density ranged from 1,550 organisms/m^2 in the Northeast Inflow of Pointer Lake to 11,446 organisms/m^2 in the Rock/Willow Stream (Table 7.2-4). Lowest level taxonomic richness in this sub-basin ranged from a minimum of 16 taxa (Northeast Inflow of Pointer Lake) to a maximum of 37 taxa (Northwest Inflow of Pointer Lake). SDI values ranged from 0.39 (Willow/Judge Sissons Stream) to 0.69 (Pointer/Rock Stream) (Table 7.2-4).

Table 7.2-4 Summary of Benthic Invertebrate Community Data for Streams in the Kiggavik Project Area, 2008 and 2009

Sub-Basin	Watercourse	2008			2009		
		Lowest Level Taxonomic Richness (# of Taxa)	Density (#/m^2)	Simpson's Diversity Index	Lowest Level Taxonomic Richness (# of Taxa)	Density (#/m^2)	Simpson's Diversity Index
Local Study Area							
Willow Lake	Northeast Inflow of Pointer Lake	16	1,550	0.63	34	2,508	0.46
	Northwest Inflow of Pointer Lake	37	2,732	0.43	-	-	-
	Pointer/Rock Stream	26	9,458	0.69	-	-	-
	Rock/Willow Stream	25	11,446	0.46	33	12,864	0.67
	Willow/Judge Sissons Stream	20	5,348	0.39	37	11,084	0.48
Lower Lake	Mushroom/End Grid Stream	24	2,778	0.39	-	-	-
	End Grid/Shack Stream	26	10,088	0.25	-	-	-

Table 7.2-4 Summary of Benthic Invertebrate Community Data for Streams in the Kiggavik Project Area, 2008 and 2009

Sub-Basin	Watercourse	2008			2009		
		Lowest Level Taxonomic Richness (# of Taxa)	Density (#/m²)	Simpson's Diversity Index	Lowest Level Taxonomic Richness (# of Taxa)	Density (#/m²)	Simpson's Diversity Index
	Cigar/Lunch Stream	28	7,672	0.39	-	-	-
	Knee/Lunch Stream	24	2,394	0.37	-	-	-
	Lunch/Andrew Stream	25	2,580	0.57	-	-	-
	Andrew/Shack Stream	23	5,460	0.24	-	-	-
	Shack/Lower Stream	26	16,818	0.43	-	-	-
	Lower/Judge Sissons Stream	27	15,304	0.1	-	-	-
Caribou Lake	Ridge/Crash Stream	14	2,028	0.55	-	-	-
	Cirque/Crash Stream	20	1,880	0.43	-	-	-
	Crash/Fox Stream	32	6,856	0.14	-	-	-
	Fox/Caribou Stream	26	5,576	0.3	-	-	-
	Caribou/Calf Stream	29	18,112	0.64	-	-	-
	Calf/Judge Sissons Stream	26	12,546	0.43	-	-	-
Aniguq River	Aniguq River	-	-	-	36	8,752	0.74
		-	-	-	30	4,494	0.35

= number; $\#/m^2$ = number of organisms per square metre; - = not applicable.

Chironomids were the dominant taxa (48.0 to 77.1%). Streams with lower proportions of chironomids had relatively high proportions of seed shrimp (Northeast Inflow of Pointer Lake 18.1% and Pointer/Rock Stream 19.5%). *Hydra* sp. was also relatively abundant in Pointer/Rock Stream (19.5%) and Rock/Willow Stream (16.8%). The following taxa were identified only in streams within the Willow Lake sub-basin (Attachment X.V, Table X.V-6):

- *Paratendipes* sp. (chironomid) – Northwest Inflow of Pointer Lake;
- *Heterotrissocladius* sp. (Orthocladiinae or non-biting midge) – Northwest Inflow of Pointer Lake;
- *Pseudosmittia* sp. (Orthocladiinae or non-biting midge) - Northwest Inflow of Pointer Lake;
- *Thienemanniella* sp. (Orthocladiinae or non-biting midge) – Rock/Willow Stream; and
- *Hemerodromia* sp. (Empididae or dance flies) – Pointer/Rock Stream.

2009

Density in streams within the Willow Lake sub-basin varied from 2,508 organisms/m^2 in the Northeast Inflow to Pointer Lake to 12,864 organisms/m^2 in Rock/Willow Stream (Table 7.2-4).

Lowest level taxonomic richness within the Willow Lake sub-basin was similar among sampling stations in 2009 (Table 7.2-4). Richness values varied from 34 taxa (Northeast Inflow to Pointer Lake) to 37 taxa (Willow/Judge Sissons Stream). The Willow Lake sub-basin had SDI values ranging from 0.46 (Northeast Inflow of Pointer lake) to 0.67 (Rock/Willow Stream).

Within all streams of the Willow Lake sub-basin chironomids dominated the BIC (47.3% to 77.1%) (Attachment X.V, Table X.V-9). Hydridae was a relatively abundant family in the Rock/Willow Stream (29.9%) and Ostracoda (seed shrimp) were also present in both Rock/Willow and Willow/Judge Sissons Streams (10.9% and 17.0%).

The following taxa were identified only within streams within the Willow Lake sub-basin (Attachment X.V, Table X.V-12):

- *Bezzia* sp. (Willow/Judge Sissons Stream);
- *Brachycentrus* sp. (Rock/Willow Stream);
- *Capnia* sp. (Northeast Inflow of Pointer Lake);
- *Chironomus* sp. (Willow/Judge Sissons Stream);
- *Dsayhelea* sp. (Northeast Inflow of Pointer Lake);
- *Glyptotendipes* sp. (Rock/Willow Stream);
- *Halipus* sp. (Northeast Inflow of Pointer Lake);
- *Limnophilla* sp. ((Northeast Inflow of Pointer Lake);
- *Limnophyes* sp. (Northeast Inflow of Pointer Lake);
- *Metricnemus* sp. (Northeast Inflow of Pointer Lake);
- *Parachironomus* sp. (Willow/Judge Sissons Lake);
- *Probezzia* sp. (Northeast Inflow of Pointer Lake); and
- *Rhyacophila* sp. (Rock/Willow Stream).

Lower Lake Sub-Basin

2008

In the Lower Lake sub-basin, benthic invertebrate density in streams ranged from 2,394 organisms/m^2 in the Knee/Lunch Stream to 16,818 organisms/m^2 in the Shack/Lower Stream (Table 7.2-4).

Lowest level taxonomic richness in the Lower Lake sub-basin exhibited the least variability between streams, ranging from a minimum of 23 taxa (Andrew/Shack Stream) to a maximum of 28 taxa (Cigar/Lunch Stream). The SDI values in the Lower Lake sub-basin ranged from 0.10 (Lower/Judge Sissons Stream) to 0.57 (Lunch/Andrew stream). The low SDI value in Lower/Judge Sissons Stream (0.10) was the result of a high abundance of one chironomid genus, *Paratanytarsus* sp.

Chironomids were consistently the dominant taxa (61.5% to 94.9%) in all streams within this sub-basin. *Hydra* sp. was relatively abundant in Lunch/Andrew Stream (20.5%) and Shack/Lower Stream (20.3%), but was present in low proportions (0.4 to 3.8%) in the remaining streams within this sub-basin. *Agabus* sp. (Dytiscidae or predacious diving beetle) was identified only within the Mushroom/End Grid Stream.

2009

No streams were sampled in the Lower Lake sub-basin in 2009.

Caribou Lake Sub-Basin

2008

In 2008, benthic invertebrate density in streams within the Caribou Lake sub-basin ranged from 1,880 organism/m^2 in Cirque/Crash Stream to 18,112 organisms/m^2 in Caribou/Calf Stream (Table 7.2-4). Lowest level taxonomic richness ranged from a minimum of 14 taxa (Ridge/Crash Stream) to a maximum of 32 taxa (Crash/Fox Stream). The SDI values ranged from 0.14 (Crash/Fox Stream) to 0.64 (Caribou/Calf Stream). The lower SDI value in Crash/Fox Stream (0.14) was the result of a high abundance of one chironomid genus, *Tanytarsus* sp.

Chironomids were the dominant taxa in the majority of the steams within this sub-basin (73.8 to 92.7%), with the exception of Ridge/Crash Stream and Caribou/Calf Stream, where chironomids accounted for lower proportions of 33.9% and 39.6%, respectively. The benthic invertebrate community in Ridge/Crash Stream was dominated by Enchytraeidae (oligochaete worms), while Caribou/Calf Stream was primarily dominated by Hydridae (43.7%).

2009

No streams were sampled in the Caribou Lake sub-basin in 2009.

Aniguq River Sub-Basin

2008

The Aniguq River was not sampled for benthic invertebrates in 2008.

2009

In 2009, densities at the two sampling stations in the Aniguq River ranged from 4,494 to 8,752 organisms/m^2 (Table 7.2-4). Lowest level taxonomic richness was similar between the Aniguq River stations (33 and 37). SDI values for the Aniguq River ranged from 0.35 to 0.74, reflecting the differences observed in the density and richness values.

Although chironomids dominated the BIC at both sampling stations, the relative density of this taxa varied from 37.5 % to 79.8% (Attachment X.V, Table X.V-9). Other taxa present at the Aniguq River Station 1 were Hydridae (28.0%) and Enchytraeidae (16.6%).

The following three taxa were identified only within streams within the Aniguq River (Attachment X.V, Table X.V-12):

- *Saetheria* sp. (Chironominae);
- *Sergentia* sp. (Chironominae); and
- *Monodiamesa* sp (Prodiamesinae).

7.2.2.3 Lakes in the Site Access Local Study Area

Baker Lake Sub-Basin

2008

Benthic invertebrates were sampled at the same five stations in Baker Lake used for water and sediment analysis, and results were pooled for the three replicates collected at each station. Community characteristics are summarized in Table 7.2-5. Mean density ranged from 821 organisms/m^2 at Station 2 to 2,058 organisms/m^2 at Station 3, indicating variability even at the three stations with the most similar habitat conditions (see Section 4.2.2.3.1 for a description of locations). Taxon richness at the family level ranged from five taxa at Station 3 (which also had the highest abundance), to ten taxa at Station 4. SDI ranged from 0.61 to 0.79 and was similar among the five stations. SEI ranged from 0.26 at Station 2 to 0.51 at Station 1.

Table 7-1 Benthic Invertebrate Community Characteristics, Baker Lake, September 2008

Station	Variable or Descriptor			
	Density (#/m^2)±SD	Taxon Richness	Simpson's Evenness Index	Simpson's Diversity Index
1	1,787±98	7	0.51	0.72
2	821±52	8	0.26	0.61
3	2,058±73	5	0.31	0.64
4	1,135±22	10	0.43	0.79
5	1,609±55	9	0.29	0.61

Note: Three replicates per site.
#/m^2 = number of organisms per square metre; SD = standard deviation.

A total of 36 taxa (lowest practical taxonomic level) in 16 families was identified in the Baker Lake samples. Taxonomic composition varied among stations. Four groups comprised 75% to 98% of the organisms at stations 1, 2, 3, and 4. These included Chironomidae (midges), Nematoda (roundworms), Enchytraeidae (Oligochaeta worms), and Naididae (Oligochaeta worms). These taxa are common in lake sediment (Wetzel 2001). Composition differed at Station 5, where Nematoda and Chironomidae comprised 85% of the organisms and there were few Oligochaeta; sediment at Station 5 also had a higher proportion of silt than the other sites (Section 5.2.2.2.2).

2009

No benthic sampling was conducted in Baker Lake in 2009.

7.3 Summary

7.3.1 Lakes

Benthic invertebrate communities in lakes within the Project area were characterized by low to moderate density and diversity. In general, SDI values across all lakes sampled ranged from low to moderate, indicating benthic invertebrate communities of moderate richness with a few dominant taxa present, and abundance unequally distributed among taxa.

Chironomids were consistently the most abundant taxa in all lakes sampled within the Project area. Taxonomic groups that were also abundant included fingernail clams, oligochaete worms, and ostracods; however, their abundance was less consistent among sites and years. Several unique taxa were identified within individual lakes within the Project area (Attachment X.V, Table X.V-8). None of these taxa are federally or territorially listed species.

7.3.2 Streams

Benthic invertebrate densities varied considerably within streams of each sub-basin; however, the overall ranges of densities were similar among the sub-basins. Stream communities in the Project area streams were dominated by chironomids. Hydra species, seed shrimp and oligochaete worms were also often abundant, but their predominance was less consistent among sites. Unlike density, lowest level taxonomic richness varied among each sub-basin, but the ranges were similar within sub-basins. Several unique taxa were identified within individual streams within the project area (Attachment X.V, Table X.V-6 and Table X.V-12). None of these taxa are federally or territorially listed species.

8 Aquatic Macrophytes

Aquatic macrophytes are an important component of aquatic systems, providing habitat for fish and invertebrates, offering protection against currents and predators, and forming a substrate for the deposition of eggs. As primary producers, macrophytes represent an important food resource for aquatic and non-aquatic organisms and they also play a significant role in the oxygen balance and nutrient cycle of many watercourses. Aquatic macrophytes can also be used as an indicator of the health of the aquatic ecosystem.

Macrophytes are used in the monitoring of metals in the aquatic environment (Prasad 2009). Prasad (2009) identified *Carex juncell* and *C. rostrata* for use in the biomonitoring of trace elements of chromium, cobalt, copper, lead, molybdenum, nickel, uranium, and zinc. *Carex* sp. have been used for monitoring metals such as cadmium, iron, lead, and manganese (Prasad 2009).

8.1 Overview of Studies

8.1.1 Historical Summary 1979 to 1991

There was no historical information documenting the aquatic vegetation in the waterbodies in the Local Study Area.

8.1.2 Recent Sampling Period 2009

8.1.2.1 Sample Collection Methods

Macrophyte samples were only collected in the Willow Lake and Judge Sissons Lake sub-basins (Table 8.1-1; Attachment X.I, Figure X.I-1, Table X.I-6). Lakes in these sub-basins were selected as they were identified in the project description as potential pathways for effluent discharge.

Samples were collected by hand from three sampling stations within each waterbody. These stations were spread along the edge of the lakes to maximize sampling coverage.

Table 8.1-1 Summary of Macrophyte Sampling in the Kiggavik Project Area, 2009

Sub-Basin	Waterbody
Willow Lake	Pointer Lake
	Sik Sik Lake
	Rock Lake
	Willow Lake
Judge Sissons Lake	Judge Sissons Lake

Carex spp. were selected as the target macrophyte species, as they were available in all waterbodies sampled. Three sub-samples of submerged *Carex* spp. were collected from each station. Sample weight consisted of at least 500 grams (g) of raw material to obtain low detection limit during subsequent chemical analysis. Supporting information was also recorded at each station:

- general site description;
- limnology surface measurements (i.e., dissolved oxygen, water temperature, specific conductivity and pH); and
- weather conditions.

Macrophyte samples were kept submerged and covered until they were processed (i.e., they were not allowed to desiccate). At each station, plants were separated into roots and shoots. All materials were washed in lake water to remove undesirable materials (e.g., sediment and insects). Root and shoot samples were double bagged and a waterproof paper label was inserted between the bags. The outer bag was labelled with waterproof marker with the appropriate information. Samples were kept cool and shaded until they were brought back to camp.

At camp, sample bags were weighed to ensure the appropriate quantity of material had been collected. Samples were frozen and shipped in sealed coolers to Golder's Saskatoon office prior to submission to Saskatchewan Research Council (SRC) Laboratories for analysis.

8.1.2.2 Laboratory Analysis

Macrophyte chemistry samples were analyzed for the following parameters:

- percent moisture;
- for total metals including aluminum (Al), antimony (Sb), arsenic (As), barium (Ba), beryllium (Be), boron (B), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), molybdenum (Mo), nickel (Ni), selenium (Se), silver

(Ag), strontium (Sr), thallium (Tl), tin (Sn), titanium (Ti), uranium (U), vanadium (V), and zinc (Zn), analyzed by ICP Mass Spectrometry Scan (ICP-MS Scan); and
- radionuclides including lead-210 (Pb-210), polonium-210 (Po-210), radium-226 (Ra-226), thorium-228 (Th-228), thorium-230 (Th-230), and thorium-232 (Th-232).

All results were reported on a dry weight basis. The radionuclide detection limits for macrophytes were variable, depending upon mass of sample available and the exact amounts taken for each analysis. Additionally, some radionuclides were analysed using ashed vegetation and the results were converted back to a dry weight basis. The percent ash factor can also affect the detection limit. The detection limits reported were the lowest attainable for the submitted samples.

8.1.2.3 Data Entry and Data Analysis

Macrophyte chemistry electronic data received from SRC Laboratories were imported into a Golder Saskatoon's electronic database (emLine™) along with all supporting data. Macrophyte chemistry for roots and shoots was compared between roots and shoots in the same lake, among sampling stations in the same lake, and among lakes from upstream to downstream.

8.1.2.4 Quality Assurance/Quality Control

Detailed specific work instructions outlining each field task were provided to field personnel prior to the field program to support program and sampling success. Samples were collected by experienced personnel, and were collected, labelled, preserved, and shipped according to laboratory protocols. Detailed field notes were recorded in waterproof field notebooks and on pre-printed waterproof field data sheets. All double-bagged sediment samples were labelled with waterproof ink and a waterproof label was inserted between the two bags.

Data collected during the field program underwent a variety of individual quality assurance/quality control (QA/QC) checks. Field data sheets were checked at the end of each day for completeness and accuracy. Chain of custody forms were used to track sample shipment from the field to Golder's Saskatoon office. SRC Laboratories Analytical Request Forms were submitted with the macrophyte samples. A visual QA/QC check for obvious errors was conducted on the electronic chemistry data. Data entered into emLine™ underwent a 100% transcription check by a second person not involved in the initial data entry process. All datasets generated by the database and all summary tables underwent an additional QA/QC screening.

8.2 Results

The 2009 macrophyte chemistry data are presented in Attachment X.VI. Data for roots is presented in Attachment X.VI, Table X.VI-1 and shoots in Attachment X.VI, Table X.VI-2.

In general, variation between roots and shoots were observed throughout the five lakes sampled in 2009. Percent moisture was higher in roots (ranging from 76.75% to 84.98%) than in shoots (ranging from 65.79% to 77.24%; Attachment X.VI, Tables X.VI-1 and X.VI-2). The concentrations of most metals and radionuclides were higher in the roots than shoots. The concentration of metals in shoots samples were near or below detection limits for most metals and radionuclides. Concentrations of boron, manganese, molybdenum, and strontium were similar or slightly lower in the roots compared to the shoots. Concentrations of antimony were all below detection limits, excepted for one root sample from Judge Sissons Lake that was at detection limits. The concentration of selenium in roots from plants in Rock Lake, silver in roots from Willow Lake, and thallium in roots from Judge Sissons Lake were all below detection limits. Concentrations of barium, zinc, and copper were similar between roots and shoots with occasional spikes on both sides. Concentrations of tin were above detection limits in the roots collected from Pointer Lake and in shoots from Rock Lake (Attachment X.VI, Tables X.VI-1 and X.VI-2).

8.2.1 Willow Lake Sub-Basin

8.2.1.1 Pointer Lake

Concentrations of cadmium in roots and shoots of *Carex* spp. in Pointer Lake ranged from 0.01 to 0.71 micrograms per gram (µg/g) dry weight (dw), with higher values occurring in roots (Table 8.2-1). Concentrations of chromium ranged from less than 0.5 to 3.8 µg/g dw in the roots and was below detection limits in the shoots. Concentrations of cobalt ranged from 0.03 to 5.0 µg/g dw, with the highest value from a root sample. Concentrations of iron in roots (15,700 to 17,300 µg/g dw) were more than one hundred fold higher than the values in the shoots (70 to 130 µg/g dw). Concentrations of lead ranged from 0.04 to 7.2 µg/g dw, with higher values in the roots. Concentrations of manganese ranged from 160 to 320 µg/g dw, with lowest and highest values in the shoots. Concentrations of molybdenum ranged from 0.4 to 1.2 µg/g dw and values were similar in roots and shoots. Concentrations of nickel ranged from 0.24 to 5.7 µg/g dw, with higher values in the roots. Concentrations of uranium ranged from less than 0.01 to 0.61 µg/g dw, with values below or at detection limit in the shoots. Concentrations of zinc ranged from 19 to 36 µg/g dw and values were similar in roots and shoots.

Concentration of radionuclides ranged from 0.019 to 0.16 Becquerels per gram (Bq/g) dw for Pb-210; 0.013 to 0.084 Bq/g dw for Po-210; 0.002 to 0.017 Bq/g dw for Ra-226, 0.002 to 0.041 Bq/g dw for Th-228, less than 0.0009 to 0.008 Bq/g dw for Th-230, and less than 0.0009 to 0.009 Bq/g dw for Th-232. Concentrations of all radionuclides analysed in *Carex* sp from Pointer Lake were higher in roots compared to the shoots (Table 8.2-1).

8.2.1.2 Sik Sik Lake

Concentrations of cadmium in roots and shoots of *Carex* spp. in Sik Sik Lake ranged from less than 0.01 to 0.17 µg/g dw, with concentrations below or at detection limit in the shoots (Table 8.2-2). Concentrations of chromium ranged from less than 0.5 to 5.3 µg/g dw; with all concentrations in the shoots below detection limits. Concentrations of cobalt ranged from 0.04 to 2.2 µg/g dw, with the highest value from a root sample. The highest concentration of iron in roots (13,6000 µg/g dw) was more than one hundred fold higher than the lowest value in the shoots (130 µg/g dw). Concentrations of lead ranged from 0.04 to 1.7 µg/g dw, with higher concentrations present in the roots. Concentrations of manganese ranged from 70 to 290 µg/g dw, with the lowest and highest concentrations in the roots. Concentrations of molybdenum ranged from 0.1 to 1.1 µg/g dw and concentrations were similar in roots and shoots. Concentrations of nickel ranged from 0.28 to 4.9 µg/g dw, with higher concentrations in the roots. Concentrations of uranium ranged from less than 0.01 to 0.28 µg/g dw, with the highest concentrations in the roots. Concentrations of zinc ranged from 13 to 44 µg/g dw, with lowest and highest concentrations occurring in the roots.

All radionuclides included in the analysis were above detection limits in the root samples. With the exception of Th-230 and Th-232, radionuclides were detectable in shoot samples. Concentration of radionuclides in roots and shoots of *Carex* sp. ranged from 0.024 to 0.30 Bq/g dw for Pb-210; 0.018 to 0.16 Bq/g dw for Po-210; 0.0014 to 0.013 Bq/g dw for Ra-226; 0.001 to 0.021 Bq/g dw for Th-228; less than 0.0009 to 0.007 Bq/g dw for Th-230; and less than 0.0009 to 0.01 Bq/g dw for Th-232. Concentrations of all radionuclides analysed in Carex spp. from Sik Sik Lake were higher in roots compared to the shoots (Table 8.2-2).

8.2.1.3 Rock Lake

Concentrations of cadmium in roots and shoots of *Carex* spp. in Rock Lake ranged from 0.02 to 0.45 µg/g dw, with the highest concentrations occurring in the roots (Table 8.2-3). Concentrations of chromium ranged from less than 0.5 to 1.0 µg/g dw, with the majority of samples below detection limits. Concentrations of cobalt ranged from 0.06 to 0.87 µg/g dw, with higher concentrations in roots. The highest concentration of iron in roots (5,300 µg/g dw) was more than forty fold higher than the lowest value in the shoots (130 µg/g dw). Concentrations of lead ranged from 0.05 to 2.5 µg/g dw, with higher concentrations in the roots. Both manganese and molybdenum were in higher concentrations in the shoot samples. Concentrations of manganese ranged from 110 to 340 µg/g dw and molybdenum ranged from 0.3 to 1.2 µg/g dw. Concentrations of nickel ranged from 0.60 to 1.7 µg/g dw, with similar concentrations in roots and shoots. Concentrations of uranium ranged from less than 0.01 to 0.17 µg/g dw, with the highest concentrations occurring in the roots. Concentrations of zinc ranged from 16 to 31 µg/g dw, with lowest and highest concentrations in the shoots. Selenium was below detection limits in both the root and shoot samples.

All radionuclides included in the analysis were above detection limits in the root and shoot samples. Concentration of Pb-210 ranged from 0.018 to 0.088 Bq/g dw; Ra-226 ranged from 0.001 to 0.006 Bq/g dw; and Th-230 ranged from less than 0.0009 to 0.002 Bq/g dw. Concentrations of most radionuclides (i.e., Po-210, Th-228, and Th-232) analysed in Carex spp. from Rock Lake were higher in roots compared to the shoots (Table 8.2-3).

8.2.1.4 Willow Lake

Concentrations of cadmium in roots and shoots of *Carex* spp. in Willow Lake ranged from 0.01 to 0.24 µg/g dw, with higher concentrations present in roots (Table 8.2-4). Concentrations of chromium ranged from less than 0.5 to 1.4 µg/g dw, with most values below detection limits. Concentrations of cobalt ranged from less than 0.01 to 1.5 µg/g dw, with higher concentrations in the roots. The highest concentration of iron in roots (9,100 µg/g dw) was more than one hundred fold higher than the lowest value in the shoots (90 µg/g dw). Concentrations of lead ranged from 0.03 to 2.3 µg/g dw, with higher concentrations in the roots. Concentrations of manganese ranged from 100 to 350 µg/g dw, with lowest and highest concentrations in the shoots. Concentrations of molybdenum ranged from 0.2 to 1.7 µg/g dw, with similar concentrations in both roots and shoots. Concentrations of nickel ranged from 0.20 to 2.2 µg/g dw, with higher concentrations in roots. Concentrations of uranium ranged from less than 0.01 to 0.23 µg/g dw, with concentrations below detection limits in the shoots. Concentrations of zinc ranged from 11 to 30 µg/g dw, with similar concentrations in roots and shoots.

All radionuclides included in the analysis were above detection limits in the root and shoot samples, except for Th-230 and Th-232, which were at or below detection limits in shoot samples (Attachment X.VI, Tables X.VI-2). Concentrations of most radionuclides (i.e., Pb-210, Po-210, Ra-226, Th-228, and Th-232) analysed in *Carex* spp. from Willow Lake were higher in roots compared to the shoots (Table 8.2-4).

8.2.2 Judge Sissons Lake Sub-Basin

8.2.2.1 Judge Sissons Lake

Concentrations of cadmium in roots and shoots of *Carex* spp. in Judge Sissons Lake ranged from 0.02 to 0.29 µg/g dw, with higher concentrations in roots (Table 8.2-5). Concentrations of chromium ranged from less than 0.5 to 5.3 µg/g dw, with concentrations below detection limits in the shoots. Concentrations of cobalt ranged from 0.10 to 2.2 µg/g dw, with higher concentrations in the roots. The highest concentration of iron in roots (11,400 µg/g dw) was more than seventy-five fold higher than the lowest value in the shoots (150 µg/g dw). Concentrations of lead ranged from 0.01 to 2.3 µg/g dw, with higher concentrations in the roots. The concentrations of manganese and molybdenum were higher in the shoots than the roots. Concentrations of manganese ranged from 80 to 650 µg/g dw and the concentration of molybdenum ranged from 0.2 to 2.3 µg/g dw. Concentrations of nickel ranged from 0.95 to 5.2 µg/g dw, with the lowest and highest concentrations occurring in the roots.

Concentrations of uranium ranged from less than 0.01 to 0.86 µg/g dw, with concentrations below detection limits in the shoots. Concentrations of zinc ranged from 19 to 50 µg/g dw, with higher concentrations in shoots.

All radionuclides included in the analysis were above detection limits for both the root and shoot samples. Concentrations of all radionuclides analysed in *Carex* spp. from Judge Sissons Lake were higher in roots compared to the shoots (Table 8.2-5). Concentration of Pb-210 ranged from 0.013 to 0.17 Bq/g dw; Po-210 from 0.012 to 0.097 Bq/g dw; Ra-226 from 0.002 to 0.047 Bq/g dw; Th-228 from less than 0.001 to 0.024 Bq/g dw; Th-230 from less than 0.001 to 0.006 Bq/g dw. Concentration of Th-232 from less than 0.001 to 0.002 and was below detection limits in all the shoot samples.

8.3 Summary

Carex spp. were used to assess metal and radionuclide background concentrations in macrophytes, as these plants have been successfully used in the past to monitor various metals. Macrophytes were only sampled in 2009. In general, concentrations in roots and shoots differed, with percent moisture and concentrations of most metals and radionuclides higher in the roots than shoots. Concentrations in shoots were near or below detection limits for most metals and radionuclides.

Table 8.2-1 Summary of Chemistry Results for Roots and Shoots of *Carex* spp. Collected in Pointer Lake, August 2009

Parameter	Unit	Roots							Shoots						
		n	Mean	Median	SD	SE	Min	Max	n	Mean	Median	SD	SE	Min	Max
Physical Properties															
Moisture	%	3	84.59	84.67	0.4409	0.2546	84.11	84.98	3	67.42	66.90	0.9943	0.5741	66.80	68.57
Metals															
Aluminum	µg/g dw	3	573	420	469	271	200	1,100	3	12	4.5	13	7.6	3.8	27
Antimony	µg/g dw	3	-	-	-	-	<0.1	<0.1	3	-	-	-	-	<0.1	<0.1
Arsenic	µg/g dw	3	22	17	8.1	4.7	17	31	3	0.07	0.07	0.02	0.009	0.06	0.09
Barium	µg/g dw	3	140	130	36.1	20.8	110	180	3	86	79	22	13	68	110
Beryllium	µg/g dw	3	0.1	0.09	0.03	0.02	0.09	0.14	3	-	-	-	-	<0.01	<0.01
Boron	µg/g dw	3	2	2	0.6	0.3	2	3	3	4	4	0	0	4	4
Cadmium	µg/g dw	3	0.46	0.47	0.25	0.14	0.21	0.71	3	0.02	0.02	0.006	0.003	0.01	0.02
Chromium	µg/g dw	3	2	1	2	1	<0.5	3.8	3	-	-	-	-	<0.5	<0.5
Cobalt	µg/g dw	3	3.6	3.2	1.2	0.70	2.7	5.0	3	0.05	0.04	0.03	0.02	0.03	0.08
Copper	µg/g dw	3	12	5.7	13	7.4	3.8	27	3	3.7	3.8	1.2	0.69	2.5	4.9
Iron	µg/g dw	3	16,467	16,400	802	463	15,700	17,300	3	93.3	80.0	32.1	18.6	70	130
Lead	µg/g dw	3	4.4	4.5	2.9	1.7	1.4	7.2	3	0.07	0.07	0.03	0.01	0.04	0.09
Manganese	µg/g dw	3	257	250	20.8	12.0	240	280	3	253	280	83.3	48.1	160	320
Molybdenum	µg/g dw	3	0.6	0.5	0.3	0.2	0.4	1.0	3	0.9	0.9	0.4	0.2	0.5	1.2
Nickel	µg/g dw	3	3.8	3.3	1.7	0.98	2.4	5.7	3	0.89	0.63	0.81	0.47	0.24	1.8
Selenium	µg/g dw	3	0.09	0.07	0.08	0.05	<0.05	0.18	3	-	-	-	-	<0.05	<0.05
Silver	µg/g dw	3	0.02	0.01	0.01	0.01	<0.01	0.03	3	-	-	-	-	<0.01	<0.01
Strontium	µg/g dw	3	12	7.7	8.7	5.0	6.4	22	3	20	19	2.1	1.2	18	22
Thallium	µg/g dw	3	0.1	0.09	0.07	0.04	0.06	0.19	3	-	-	-	-	<0.05	<0.05
Tin	µg/g dw	3	0.06	0.06	0.04	0.02	<0.05	0.10	3	-	-	-	-	<0.05	<0.05
Titanium	µg/g dw	3	19	9.8	21	12	4.4	44	3	0.2	0.1	0.1	0.06	0.08	0.29
Uranium	µg/g dw	3	0.39	0.35	0.20	0.12	0.21	0.61	3	-	-	-	-	<0.01	0.01
Vanadium	µg/g dw	3	4.8	3.4	3.6	2.1	2.1	8.8	3	-	-	-	-	<0.1	<0.1
Zinc	µg/g dw	3	29	27	6.2	3.6	24	36	3	22	20	3.8	2.2	19	26
Radionuclides															
Lead-210	Bq/g dw	3	0.11	0.12	0.049	0.028	0.063	0.16	3	0.026	0.027	0.0070	0.0041	0.019	0.033

Table 8.2-1 Summary of Chemistry Results for Roots and Shoots of *Carex* spp. Collected in Pointer Lake, August 2009

Parameter	Unit	Roots							Shoots						
		n	Mean	Median	SD	SE	Min	Max	n	Mean	Median	SD	SE	Min	Max
Polonium-210	Bq/g dw	3	0.082	0.084	0.0029	0.0017	0.079	0.084	3	0.015	0.014	0.0032	0.0019	0.013	0.019
Radium-226	Bq/g dw	3	0.013	0.013	0.0035	0.0020	0.010	0.017	3	0.002	0.002	0.0005	0.0003	0.002	0.003
Thorium-228	Bq/g dw	3	0.025	0.018	0.014	0.0082	0.015	0.041	3	0.002	0.002	0.0006	0.0003	0.002	0.003
Thorium-230	Bq/g dw	3	0.005	0.005	0.003	0.002	0.002	0.008	3	-	-	-	-	<0.0009	<0.001
Thorium-232	Bq/g dw	3	0.005	0.004	0.003	0.002	0.003	0.009	3	-	-	-	-	<0.0009	<0.001

Notes: When results were less than detection limit, summary statistics were calculated using half the detection limit.
If detection frequency was ≥50%, then non-detect values were replaced with one half the detection limit to calculate summary statistics.
If detection frequency was <50%, then only minimum and maximum values are presented.
Moisture = moisture content by percent weight.
µg/g dw = micrograms per gram dry weight; Bq/g dw = Becquerels per gram dry weight; % = percent; n = number of samples; SD = standard deviation; SE = standard error; Min = minimum; Max = maximum; < = less than; - = not applicable; ≥ = equal to or greater than.

Table 8.2-2 Summary of Chemistry Results for Roots and Shoots of Carex spp. Collected in Sik Sik Lake, August 2009

		Roots							Shoots						
Parameter	**Unit**	**n**	**Mean**	**Median**	**SD**	**SE**	**Min**	**Max**	**n**	**Mean**	**Median**	**SD**	**SE**	**Min**	**Max**
Physical Properties															
Moisture	%	3	78.74	79.50	1.739	1.004	76.75	79.97	3	71.95	73.27	3.065	1.770	68.45	74.14
Metals															
Aluminum	µg/g dw	3	1,267	740	1,444	834	160	2,900	3	32	30	12	7.0	21	45
Antimony	µg/g dw	3	-	-	-	-	<0.1	<0.1	3	-	-	-	-	<0.1	<0.1
Arsenic	µg/g dw	3	11	15	8.0	4.6	1.7	16	3	0.1	0.07	0.1	0.06	0.05	0.23
Barium	µg/g dw	3	99	110	27.6	15.9	68	120	3	54	52	11	6.2	45	66
Beryllium	µg/g dw	3	0.1	0.07	0.1	0.07	0.04	0.25	3	-	-	-	-	<0.01	<0.01
Boron	µg/g dw	3	2	2	0.6	0.3	2	3	3	3	3	0.6	0.3	3	4
Cadmium	µg/g dw	3	0.1	0.2	0.06	0.04	0.06	0.17	3	-	-	-	-	<0.01	0.01
Chromium	µg/g dw	3	2	2	3	2	<0.5	5.3	3	-	-	-	-	<0.5	<0.5
Cobalt	µg/g dw	3	1.4	1.7	0.94	0.54	0.38	2.2	3	0.06	0.06	0.03	0.01	0.04	0.09
Copper	µg/g dw	3	4.9	5.7	2.4	1.4	2.2	6.8	3	2.9	2.4	1.0	0.60	2.2	4.1
Iron	µg/g dw	3	9,100	9,700	4,828	2,787	4,000	13,600	3	397	180	419	242	130	880
Lead	µg/g dw	3	1.3	1.3	0.40	0.23	0.90	1.7	3	0.07	0.04	0.05	0.03	0.04	0.13
Manganese	µg/g dw	3	163	130	114	65.7	70	290	3	103	110	11.5	6.67	90	110
Molybdenum	µg/g dw	3	0.3	0.2	0.2	0.1	0.1	0.5	3	0.6	0.6	0.5	0.3	0.2	1.1
Nickel	µg/g dw	3	2.5	1.5	2.1	1.2	1.2	4.9	3	0.38	0.38	0.11	0.061	0.28	0.49
Selenium	µg/g dw	3	0.05	0.05	0.02	0.01	<0.05	0.07	3	-	-	-	-	<0.05	<0.05
Silver	µg/g dw	3	-	-	-	-	<0.01	0.02	3	-	-	-	-	<0.01	<0.01
Strontium	µg/g dw	3	7.8	7.5	2.1	1.2	5.9	10	3	16	15	4.2	2.4	13	21
Thallium	µg/g dw	3	0.09	0.05	0.08	0.05	<0.05	0.2	3	-	-	-	-	<0.05	<0.05
Tin	µg/g dw	3	-	-	-	-	<0.05	<0.05	3	-	-	-	-	<0.05	<0.05
Titanium	µg/g dw	3	40	19	50	29	3.0	97	3	0.67	0.58	0.30	0.17	0.42	1.0
Uranium	µg/g dw	3	0.1	0.09	0.1	0.08	0.02	0.28	3	0.02	0.01	0.02	0.01	<0.01	0.04
Vanadium	µg/g dw	3	3.5	1.9	2.9	1.7	1.8	6.8	3	-	-	-	-	<0.1	0.2
Zinc	µg/g dw	3	28	27	16	9.0	13	44	3	29	34	10	5.8	17	35
Radionuclides															

Table 8.2-2 Summary of Chemistry Results for Roots and Shoots of Carex spp. Collected in Sik Sik Lake, August 2009

Parameter	Unit	Roots							Shoots						
		n	Mean	Median	SD	SE	Min	Max	n	Mean	Median	SD	SE	Min	Max
Lead-210	Bq/g dw	3	0.20	0.18	0.096	0.055	0.11	0.30	3	0.029	0.031	0.0040	0.0023	0.024	0.031
Polonium-210	Bq/g dw	3	0.13	0.15	0.045	0.026	0.077	0.16	3	0.020	0.021	0.0021	0.0012	0.018	0.022
Radium-226	Bq/g dw	3	0.009	0.007	0.004	0.002	0.006	0.013	3	0.0018	0.0014	0.0006	0.00037	0.0014	0.0025
Thorium-228	Bq/g dw	3	0.017	0.020	0.0061	0.0035	0.010	0.021	3	0.002	0.002	0.0006	0.0003	0.001	0.002
Thorium-230	Bq/g dw	3	0.005	0.004	0.002	0.001	0.003	0.007	3	-	-	-	-	<0.0009	<0.0009
Thorium-232	Bq/g dw	3	0.007	0.006	0.003	0.002	0.004	0.01	3	-	-	-	-	<0.0009	<0.0009

Notes: When results were less than detection limit summary statistics were calculated using half the detection limit.
If detection frequency was ≥50%, then non-detect values were replaced with one half the detection limit to calculate summary statistics.
If detection frequency was <50%, then only minimum and maximum values are presented.
Moisture = moisture content by percent weight.
µg/g dw = micrograms per gram dry weight; Bq/g dw = Becquerels per gram dry weight; % = percent; n = number of samples; SD = standard deviation; SE = standard error; Min = minimum; Max = maximum; < = less than; - = not applicable; ≥ = equal to or greater than.

Table 8.2-3 Summary of Chemistry Results for Roots and Shoots of Carex spp. Collected in Rock Lake, August 2009

Parameter	Unit	Roots							Shoots						
		n	Mean	Median	SD	SE	Min	Max	n	Mean	Median	SD	SE	Min	Max
Physical Properties															
Moisture	%	3	79.80	79.36	1.503	0.8680	78.56	81.47	3	75.05	75.15	0.8690	0.5017	74.14	75.87
Metals															
Aluminum	µg/g dw	3	216	110	203	117	87	450	3	69	34	80	46	12	160
Antimony	µg/g dw	3	-	-	-	-	<0.1	<0.1	3	-	-	-	-	<0.1	<0.1
Arsenic	µg/g dw	3	2.2	1.1	2.3	1.3	0.64	4.8	3	0.2	0.2	0.09	0.05	0.06	0.24
Barium	µg/g dw	3	66	64	4.9	2.8	63	72	3	73	72	4.6	2.6	69	78
Beryllium	µg/g dw	3	0.04	0.04	0.02	0.01	0.02	0.06	3	-	-	-	-	<0.01	0.01
Boron	µg/g dw	3	2	2	0.6	0.3	2	3	3	4	4	0	0	4	4
Cadmium	µg/g dw	3	0.2	0.1	0.2	0.1	0.08	0.45	3	0.02	0.02	0.006	0.003	0.02	0.03
Chromium	µg/g dw	3	-	-	-	-	<0.5	1.0	3	-	-	-	-	<0.5	0.6
Cobalt	µg/g dw	3	0.83	0.83	0.040	0.023	0.79	0.87	3	0.1	0.1	0.06	0.03	0.06	0.17
Copper	µg/g dw	3	7.7	8.1	3.6	2.1	3.9	11	3	3.6	4.0	0.72	0.42	2.8	4.1
Iron	µg/g dw	3	4,033	3,600	1,115	643.8	3,200	5,300	3	393	150	439	253	130	900
Lead	µg/g dw	3	1.4	1.4	1.0	0.60	0.44	2.5	3	0.1	0.09	0.1	0.06	0.05	0.25
Manganese	µg/g dw	3	130	130	20.0	11.5	110	150	3	250	240	85	49	170	340
Molybdenum	µg/g dw	3	0.3	0.3	0	0	0.3	0.3	3	1.1	1.0	0.12	0.067	1.0	1.2
Nickel	µg/g dw	3	1.2	0.95	0.44	0.25	0.93	1.7	3	0.92	0.96	0.30	0.17	0.60	1.2
Selenium	µg/g dw	3	-	-	-	-	<0.05	<0.05	3	-	-	-	-	<0.05	<0.05
Silver	µg/g dw	3	-	-	-	-	<0.01	0.01	3	-	-	-	-	<0.01	<0.01
Strontium	µg/g dw	3	7.7	7.5	1.2	0.67	6.6	8.9	3	14	14	0.58	0.33	13	14
Thallium	µg/g dw	3	0.07	0.07	0.01	0.006	0.06	0.08	3	-	-	-	-	<0.05	<0.05
Tin	µg/g dw	3	-	-	-	-	<0.05	<0.05	3	0.07	0.07	0.01	0.006	0.06	0.08
Titanium	µg/g dw	3	6.3	3.7	5.9	3.4	2.2	13	3	2.1	0.96	2.5	1.4	0.34	4.9
Uranium	µg/g dw	3	0.1	0.1	0.06	0.03	0.06	0.17	3	-	-	-	-	<0.01	0.05
Vanadium	µg/g dw	3	2	2	1	0.6	0.5	2.6	3	-	-	-	-	<0.1	0.4
Zinc	µg/g dw	3	26	26	1.5	0.88	25	28	3	22	19	7.9	4.6	16	31
Radionuclides															

Table 8.2-3 Summary of Chemistry Results for Roots and Shoots of Carex spp. Collected in Rock Lake, August 2009

Parameter	Unit	Roots							Shoots						
		n	Mean	Median	SD	SE	Min	Max	n	Mean	Median	SD	SE	Min	Max
Lead-210	Bq/g dw	3	0.063	0.063	0.025	0.014	0.038	0.088	3	0.032	0.018	0.024	0.014	0.018	0.059
Polonium-210	Bq/g dw	3	0.068	0.054	0.028	0.016	0.049	0.10	3	0.021	0.015	0.012	0.007	0.014	0.035
Radium-226	Bq/g dw	3	0.005	0.006	0.001	0.0007	0.004	0.006	3	0.002	0.001	0.002	0.0009	0.001	0.004
Thorium-228	Bq/g dw	3	0.009	0.008	0.002	0.001	0.007	0.011	3	0.003	0.002	0.002	0.001	0.001	0.005
Thorium-230	Bq/g dw	3	0.002	0.002	0.0009	0.0005	<0.001	0.002	3	-	-	-	-	<0.0009	0.001
Thorium-232	Bq/g dw	3	0.002	0.002	0.0006	0.0003	0.002	0.003	3	-	-	-	-	<0.0009	0.001

Notes: When results were less than detection limit summary statistics were calculated using half the detection limit.
If detection frequency was ≥50%, then non-detect values were replaced with one half the detection limit to calculate summary statistics.
If detection frequency was <50%, then only minimum and maximum values are presented.
Moisture = moisture content by percent weight.
µg/g dw = micrograms per gram dry weight; Bq/g dw = Becquerels per gram dry weight; % = percent; n = number of samples; SD = standard deviation; SE = standard error; Min = minimum; Max = maximum; < = less than; - = not applicable; ≥ = equal to or greater than.

Table 8.2-4 Summary of Chemistry Results for Roots and Shoots of Carex spp. Collected in Willow Lake, August 2009

Parameter	Unit	Roots							Shoots						
		n	Mean	Median	SD	SE	Min	Max	n	Mean	Median	SD	SE	Min	Max
Physical Properties															
Moisture	%	3	80.18	79.60	1.719	0.9925	78.82	82.11	3	70.73	70.60	2.193	1.266	68.60	72.98
Metals															
Aluminum	µg/g dw	3	293	180	196	113	180	520	3	22	20	10	5.6	14	33
Antimony	µg/g dw	3	-	-	-	-	<0.1	<0.1	3	-	-	-	-	<0.1	<0.1
Arsenic	µg/g dw	3	4.5	3.8	1.2	0.70	3.8	5.9	3	0.07	0.08	0.04	0.02	<0.05	0.10
Barium	µg/g dw	3	82	87	9.5	5.5	71	88	3	81.0	67.0	25.1	14.5	66	110
Beryllium	µg/g dw	3	0.06	0.05	0.04	0.02	0.03	0.10	3	-	-	-	-	<0.01	<0.01
Boron	µg/g dw	3	3	2	1	0.7	2	4	3	4	4	1	0.6	3	5
Cadmium	µg/g dw	3	0.2	0.2	0.08	0.05	0.08	0.24	3	0.02	0.03	0.01	0.007	0.01	0.03
Chromium	µg/g dw	3	-	-	-	-	<0.5	1.4	3	-	-	-	-	<0.5	<0.5
Cobalt	µg/g dw	3	1.1	0.98	0.39	0.23	0.73	1.5	3	0.04	0.04	0.03	0.02	<0.01	0.06
Copper	µg/g dw	3	6.8	5.7	2.7	1.5	4.8	9.8	3	3.2	3.4	0.40	0.23	2.7	3.4
Iron	µg/g dw	3	6,200	6,200	2,900	1,674	3,300	9,100	3	130	110	52.9	30.6	90	190
Lead	µg/g dw	3	1.4	1.3	0.86	0.50	0.59	2.3	3	0.05	0.04	0.03	0.02	0.03	0.08
Manganese	µg/g dw	3	207	170	119	68.9	110	340	3	232	245	126	72.5	100	350
Molybdenum	µg/g dw	3	0.7	0.3	0.7	0.4	0.2	1.5	3	1	2	0.6	0.3	0.7	1.7
Nickel	µg/g dw	3	1.5	1.2	0.61	0.35	1.1	2.2	3	0.25	0.23	0.068	0.039	0.20	0.33
Selenium	µg/g dw	3	-	-	-	-	<0.05	0.05	3	-	-	-	-	<0.05	<0.05
Silver	µg/g dw	3	-	-	-	-	<0.01	<0.01	3	-	-	-	-	<0.01	<0.01
Strontium	µg/g dw	3	7.6	7.4	0.92	0.53	6.8	8.6	3	20	19	7.0	4.1	13	27
Thallium	µg/g dw	3	0.07	0.08	0.04	0.02	<0.05	0.10	3	-	-	-	-	<0.05	<0.05
Tin	µg/g dw	3	-	-	-	-	<0.05	<0.05	3	-	-	-	-	<0.05	<0.05
Titanium	µg/g dw	3	10	4.6	10	5.6	4.0	21	3	0.75	0.55	0.49	0.28	0.39	1.3
Uranium	µg/g dw	3	0.1	0.1	0.08	0.04	0.08	0.23	3	-	-	-	-	<0.01	<0.01
Vanadium	µg/g dw	3	3	2	2	1	0.9	5.4	3	-	-	-	-	<0.1	<0.1
Zinc	µg/g dw	3	27	30	4.6	2.7	22	30	3	17	18	6.0	3.5	11	23
Radionuclides															

Table 8.2-4 Summary of Chemistry Results for Roots and Shoots of Carex spp. Collected in Willow Lake, August 2009

Parameter	Unit	Roots							Shoots						
		n	Mean	Median	SD	SE	Min	Max	n	Mean	Median	SD	SE	Min	Max
Lead-210	Bq/g dw	3	0.059	0.052	0.021	0.012	0.042	0.083	3	0.033	0.036	0.0093	0.0054	0.023	0.041
Polonium-210	Bq/g dw	3	0.041	0.038	0.014	0.0082	0.028	0.056	3	0.019	0.020	0.0061	0.0035	0.012	0.024
Radium-226	Bq/g dw	3	0.006	0.005	0.002	0.001	0.004	0.008	3	0.003	0.003	0.001	0.0006	0.002	0.004
Thorium-228	Bq/g dw	3	0.01	0.01	0.008	0.005	0.005	0.021	3	0.003	0.003	0.0006	0.0003	0.002	0.003
Thorium-230	Bq/g dw	3	0.002	0.002	0.0006	0.0003	0.001	0.002	3	-	-	-	-	<0.001	0.001
Thorium-232	Bq/g dw	3	0.002	0.002	0.0006	0.0003	0.001	0.002	3	-	-	-	-	<0.001	<0.001

Notes: When results were less than detection limit summary statistics were calculated using half the detection limit.
If detection frequency was ≥50%, then non-detect values were replaced with one half the detection limit to calculate summary statistics.
If detection frequency was <50%, then only minimum and maximum values are presented.
Moisture = moisture content by percent weight.

µg/g dw = micrograms per gram dry weight; Bq/g dw = Becquerels per gram dry weight; % = percent; n = number of samples; SD = standard deviation; SE = standard error; Min = minimum; Max = maximum; < = less than; - = not applicable; ≥ = equal to or greater than.

Table 8.2-5 Summary of Chemistry Results for Roots and Shoots of Carex spp. Collected in Judge Sissons Lake, August 2009

Parameter	Unit	Roots							Shoots						
		n	Mean	Median	SD	SE	Min	Max	n	Mean	Median	SD	SE	Min	Max
Physical Properties															
Moisture	%	3	80.66	80.96	1.557	0.8991	78.97	82.04	3	71.10	70.28	5.769	3.331	65.79	77.24
Metals															
Aluminum	µg/g dw	3	1,337	1,700	901.7	520.6	310	2,000	3	21	28	14	8.2	5.0	31
Antimony	µg/g dw	3	-	-	-	-	<0.1	0.1	3	-	-	-	-	<0.1	<0.1
Arsenic	µg/g dw	3	7.0	6.6	2.2	1.3	5.0	9.4	3	0.07	0.07	0.04	0.02	<0.05	0.11
Barium	µg/g dw	3	137	130	90.2	52.1	50	230	3	74	79	9.5	5.5	63	80
Beryllium	µg/g dw	3	0.2	0.2	0.09	0.05	0.06	0.22	3	-	-	-	-	<0.01	0.01
Boron	µg/g dw	3	5	4	3	2	3	8	3	4	4	0.6	0.3	4	5
Cadmium	µg/g dw	3	0.19	0.17	0.10	0.055	0.10	0.29	3	0.03	0.03	0.02	0.009	0.02	0.05
Chromium	µg/g dw	3	3	4	2	1	0.8	5.3	3	-	-	-	-	<0.5	<0.5
Cobalt	µg/g dw	3	1.3	0.98	0.75	0.43	0.84	2.2	3	0.18	0.21	0.070	0.040	0.10	0.23
Copper	µg/g dw	3	11	8.1	7.9	4.5	5.1	20	3	4.8	5.1	1.3	0.77	3.3	5.9
Iron	µg/g dw	3	9,133.3	10,900	3,501.9	2,021.8	5,100	11,400	3	217	250	57.7	33.3	150	250
Lead	µg/g dw	3	1.5	1.1	0.73	0.42	0.99	2.3	3	0.03	0.03	0.02	0.01	0.01	0.04
Manganese	µg/g dw	3	120	120	40.0	23.1	80	160	3	517	511	130.1	75.1	390	650
Molybdenum	µg/g dw	3	0.4	0.3	0.2	0.1	0.2	0.6	3	1	1	0.9	0.5	0.7	2.3
Nickel	µg/g dw	3	3.5	4.3	2.2	1.3	0.95	5.2	3	1.6	1.6	0.55	0.32	1.0	2.1
Selenium	µg/g dw	3	0.1	0.1	0.06	0.03	0.07	0.19	3	-	-	-	-	<0.05	<0.05
Silver	µg/g dw	3	0.02	0.02	0.009	0.005	<0.01	0.02	3	-	-	-	-	<0.01	<0.01
Strontium	µg/g dw	3	11	9.9	4.2	2.4	6.6	15	3	17	17	2.0	1.2	15	19
Thallium	µg/g dw	3	-	-	-	-	<0.05	<0.05	3	-	-	-	-	<0.05	<0.05
Tin	µg/g dw	3	-	-	-	-	<0.05	<0.05	3	-	-	-	-	<0.05	<0.05
Titanium	µg/g dw	3	30	40	21	12	6.2	45	3	0.41	0.50	0.22	0.13	0.16	0.57
Uranium	µg/g dw	3	0.49	0.37	0.33	0.19	0.24	0.86	3	-	-	-	-	<0.01	<0.01
Vanadium	µg/g dw	3	5.3	5.9	2.1	1.2	3.0	7.0	3	-	-	-	-	<0.1	<0.1
Zinc	µg/g dw	3	22	19	4.6	2.7	19	27	3	42	39	7.0	4.0	37	50
Radionuclides															

Table 8.2-5 Summary of Chemistry Results for Roots and Shoots of Carex spp. Collected in Judge Sissons Lake, August 2009

Parameter	Unit	Roots							Shoots						
		n	Mean	Median	SD	SE	Min	Max	n	Mean	Median	SD	SE	Min	Max
Lead-210	Bq/g dw	3	0.12	0.12	0.051	0.029	0.068	0.17	3	0.025	0.028	0.011	0.0062	0.013	0.034
Polonium-210	Bq/g dw	3	0.077	0.083	0.023	0.013	0.052	0.097	3	0.021	0.023	0.0078	0.0045	0.012	0.027
Radium-226	Bq/g dw	3	0.02	0.007	0.02	0.01	0.006	0.047	3	0.003	0.003	0.001	0.0006	0.002	0.004
Thorium-228	Bq/g dw	3	0.02	0.02	0.002	0.001	0.02	0.024	3	-	-	-	-	<0.001	0.002
Thorium-230	Bq/g dw	3	0.004	0.003	0.002	0.001	0.003	0.006	3	0.001	0.001	0.0008	0.0004	<0.001	0.002
Thorium-232	Bq/g dw	3	0.002	0.002	0.0006	0.0003	0.002	<0.006	3	-	-	-	-	<0.001	<0.001

Notes: When results were less than detection limit summary statistics were calculated using half the detection limit.
If detection frequency was ≥50%, then non-detect values were replaced with one half the detection limit to calculate summary statistics.
If detection frequency was <50%, then only minimum and maximum values are presented.
Moisture = moisture content by percent weight.

µg/g dw = micrograms per gram dry weight; Bq/g dw = Becquerels per gram dry weight; % = percent; n = number of samples; SD = standard deviation; SE = standard error; Min = minimum; Max = maximum; < = less than; - = not applicable; ≥ = equal to or greater than.

9 Plankton and Periphyton Communities

The term “plankton” is a general term referring to small, usually microscopic, organisms that live suspended in open water. For the purpose of the Project, the term “phytoplankton” refers to the open-water, algal component (i.e., non-vascular, photosynthetic plants) and includes the following seven major taxonomic groups:

- Cyanobacteria (blue-green algae);
- Chlorophyta (green algae);
- Chrysophyta (golden-brown algae);
- Cryptophyta (cryptomonads);
- Bacillariophyta (diatoms);
- Pyrrophyta (dinoflagellates); and
- Other taxa (which includes Xanthophyta and Haptophyta).

Chlorophyll *a* is the primary photosynthetic pigment contained in phytoplankton, although there are a number of secondary pigments (e.g., chlorophyll *b*, chlorophyll *c*, carotenoids) (Wetzel 2001). Chlorophyll *a* concentration has been used to provide a practical and economical alternative to full taxonomic analysis of the phytoplankton community, and has been widely used as a measure of the trophic status (i.e., nutrient status and productivity) of lakes. Chlorophyll *a* concentrations can range from less than 8 micrograms per litre (µg/L) in unproductive waters to greater than 75 µg/L in highly productive waters (Mitchell and Prepas 1990). Chlorophyll *a* concentrations are known to vary seasonally and taxonomically (Wetzel 2001), which results in uncertainty in the use of chlorophyll *a* as a measure of phytoplankton biomass.

The term “zooplankton” refers to microscopic animals that float, drift or swim weakly, and includes crustaceans (i.e., Cladocera [cladocerans], Calanoida, and Cyclopoida) and rotifers. Cyclopoid and calanoid copepods are considered separately because of taxonomic differences, but also because Calanoida are almost exclusively planktonic, while Cyclopoida are dominated by littoral species (Wetzel 2001). However, the few planktonic species of Cyclopoida can account for a major component of the plankton community (Wetzel 2001).

Periphyton consists of a biofilm of algae, bacteria, fungi, protozoa and associated non-cellular material that surround solid surfaces in aquatic systems (Lock et al. 1984). For the purpose of this study, the term ‘periphyton’ refers only to the algal component as opposed to the entire biofilm. Periphyton is the term used to describe the algal community that grows attached to the substrate (generally rocks) in streams and lakes. They are a primary producer, similar to phytoplankton; however, periphyton is attached to the substrate where as phytoplankton is suspended in the water column.

The periphytic algal community is often monitored or assessed because of the following:

- periphytic algae form part of the lower trophic food chain level (i.e., convert sunlight into biological tissues); upon which other aquatic life forms depend;
- minimal sampling effort is required; and
- algae are numerically abundant, diverse, and identifiable.

Plankton community surveys were carried out in the Kiggavik study area between 1979 and 1991. More recent studies were conducted between 2008 and 2009 to expand and complement the existing baseline information. There are differences in sampling methods between the historical (1979 to 1991) and recent (2008 and 2009) field surveys. Table 9.0-1 provides a summary of the plankton sampling locations between 1979 and 2009.

Periphyton community surveys were completed only in 2008 and 2009; therefore, no historical periphyton data was available for comparison. Table 9.0-2 provides a summary of the periphyton sampling locations between 2008 and 2009.

9.1 Overview of Studies

9.1.1 Historical Summary 1979 to 1991

9.1.1.1 Phytoplankton Sampling Methods

Phytoplankton samples were collected from five lakes in the Project area (Jaeger, Pointer, Ridge, Cirque, and Judge Sissons lakes) in August 1989 (BEAK 1990). Samples were collected from lake outlets in 1989. Samples were preserved in Lugol's solution.

In August 1990, phytoplankton samples were collected from five lakes in the Lower Lake sub-basin: Mushroom Lake, Cigar Lake, Andrew Lake, Bear Island Lake, and Lower Lake (BEAK 1992a). Samples were collected as subsurface grabs from lake outlets and preserved in Lugol's solution (BEAK 1992a).

Table 9.0-1 Summary of Phytoplankton and Zooplankton Sampling in Lakes and Streams in the Kiggavik Project Area, 1979 to 2009

Watershed	Sub-Basin	Waterbody	BEAK 1990		BEAK 1992a		Golder		Nunami Stantec
			1979	1989	1990	1991	2008	2009	2008
Aniguq River	Willow Lake	Scotch Lake	ZP	-	-	-	-	-	-
		Jaeger Lake	ZP	PP, ZP	-	-	-	-	-
		Pointer Lake	ZP	PP, ZP	-	ZP	PP, ZP	-	-
		Pointer Lake Outfall	-	-	-	PP	-	-	-
		Sik Sik Lake	-	-	-	-	-	PP, ZP	-
		Rock Lake	-	-	-	-	-	PP, ZP	-
		Willow Lake	-	-	-	-	-	PP, ZP	-
	Lower Lake	Mushroom Lake	-	-	PP, ZP	PP, ZP	PP, ZP	-	-
		Cigar Lake	-	-	PP, ZP	PP, ZP	-	-	-
		Andrew Lake	-	-	-		-	PP, ZP	-
		Andrew Lake Outfall	-	-	PP	PP	-	-	-
		Shack Lake	-	-	ZP	-	-	-	-
		Bear Island Lake	-	-	ZP	-	-	-	-
		Bear Island Lake Outfall	-	-	PP	-	-	-	-
		Lower Lake	-	-	ZP	-	PP, ZP	-	-
		Lower Lake Outfall	-	-	PP	-	-	-	-
	Caribou Lake	Ridge Lake	-	PP, ZP	-	PP	-	-	-
		Cirque Lake	-	PP, ZP	-	-	-	-	-
		Fox Lake	-	-	-	-	PP, ZP	-	-
		Caribou Lake	-	-	-	-	PP, ZP	-	-
	Judge Sissons Lake	Judge Sissons Lake	ZP	PP, ZP	-	PP, ZP	PP, ZP	PP, ZP	-
		Judge Sissons Outfall	-	-	-	PP	-	-	-
Baker Lake	Baker Lake	Baker Lake	-	-	-	-	-	-	ZP

- = not collected; PP = phytoplankton; ZP = zooplankton.

Table 9.0-2 Summary of Periphyton Sampling in Streams in the Kiggavik Project Area, 2008 to 2009

Watershed	Sub-Basin	Watercourse	Golder 2008	Golder 2009
Aniguq River	Willow Lake	Northeast Inflow of Pointer Lake	X	X
		Northwest Inflow of Pointer Lake	X	-
		Pointer/Rock Stream	X	-
		Sik Sik/Rock Stream	[a]	[a]
		Rock/Willow Stream	X	X
		Willow/Judge Sissons Stream	X	X
	Lower Lake	Mushroom/End Grid Stream	X	-
		End Grid/Shack Stream	X	-
		Cigar/Lunch Stream	X	-
		Knee/Lunch Stream	X	-
		Lunch/Andrew Stream	X	-
		Andrew/Shack Stream	X	-
		Shack/Lower Stream	X	-
		Lower/Judge Sissons Stream	X	-
	Caribou Lake	Ridge/Crash Stream	X	-
		Cirque/Crash Stream	X	-
		Crash/Fox Stream	X	-
		Fox/Caribou Stream	X	-
		Caribou/Calf Stream	X	-
		Calf/Judge Sissons Stream	X	-
	Aniguq River	Aniguq River	-	X

[a] Sampling was not completed at this station due to inappropriate substrate type.
\- = not collected.

During the winter sampling in March of 1991, phytoplankton communities were collected at Ridge Lake and Judge Sissons Lake. Samples were collected as subsurface grabs through the ice within the deep basin of each lake (BEAK 1992a). In June 1991, phytoplankton samples were collected as subsurface grabs from the outlets of Pointer Lake, Cigar Lake, Andrew Lake, and Judge Sissons

Lake. Subsurface grab samples were collected from the deep basins of Pointer Lake, Mushroom Lake, and Judge Sissons Lake in July of 1991.

For all samples, biomass was determined by measuring the cell dimensions to calculate cell volumes, which were then used to calculate biomass based on an assumed density of 1 gram per cubic centimetre (g/cm^3) (BEAK 1990, 1992a). Phytoplankton taxa were identified and enumerated using an inverted microscope following the Utermohl technique (BEAK 1990, 1992a).

9.1.1.2 Zooplankton Sampling Methods

During the 1979 ice-free season, zooplankton were sampled nine times in Pointer Lake, three times in Judge Sissons Lake, once in each of Scotch and Jaeger lakes (BEAK 1990). In 1979, zooplankton samples were collected by vertical haul using a 60 micrometre (µm) mesh Wisconsin net. In August 1989, zooplankton were sampled in Jaeger, Pointer, Ridge, Cirque, and Judge Sissons lakes. Samples were collected by filtering a measured volume through a 60 µm mesh plankton net at a stationary location in lake outlet streams (BEAK 1990).

Zooplankton samples were collected from the outlet streams in Cigar, Shack, Bear Island, Mushroom and Lower lakes in August 1990. In July 1991, zooplankton samples were collected from the deep basins in Judge Sissons Lake, Pointer Lake, Cigar Lake and Mushroom Lake. During both years, samples were collected by filtering a measured volume through a 60 µm mesh net.

9.1.2 Recent Sampling Period 2008 to 2009

9.1.2.1 Sample Collection Method

Phytoplankton, chlorophyll *a*, zooplankton and periphyton samples were collected concurrently with summer 2008 water quality sampling (Section 4.0). Plankton samples and chlorophyll *a* were also collected concurrently with the fall 2008 water quality (Section 4.0), sediment quality (Section 5.0), and benthic invertebrate community samples (Section 7.0).

Phytoplankton, chlorophyll a and zooplankton samples were collected from six lakes and periphyton samples were collected from 19 streams within the mine site LSA in 2008 (Table 9.0-1). Phytoplankton, chlorophyll *a* and zooplankton samples were collected from five lakes and periphyton samples were collected from 3 streams and a river within the mine site LSA in 2009 (Table 9.0-1). Information regarding the location of each sampling station can be found in Attachment X.I, Figures X.I-1 and X.I-2,Tables X.I-7 to X.I-9.

Phytoplankton

A single phytoplankton community sample was collected within the photic zone (i.e., the depth at which light is sufficient to allow photosynthesis by phytoplankton) at each sampling station (Attachment X.I, Figure X.I-1,Table X.I-7). Secchi depth was measured and recorded prior to sampling because the depth of the photic zone was estimated at twice the Secchi depth. Phytoplankton community samples were collected following Golder's *Aquatic Technical Procedure 8.7-1: Phytoplankton and Zooplankton Sampling* (unpublished file information). A 2.2 litre (L) Kemmerer water sampler was used to collect water at 2 metre (m) intervals throughout the photic zone, which was combined into a composite sample in a clean carboy. A sub-sample of the composite water was poured into an individual, pre-labelled 250 millilitre (mL) amber plastic Nalgene bottle to prevent degradation from exposure to light. All phytoplankton samples were preserved with 10 mL of DaFano's solution and 10 mL of Lugol's solution, and kept cool (not frozen) and in the dark prior to shipment to Golder's Saskatoon office. The samples were then submitted to Bio-Limno Research and Consulting, Inc. (Bio-Limno) in Halifax, Nova Scotia, for analysis.

Chlorophyll a

Two chlorophyll *a* samples were collected from each lake sampling location. These samples were collected from remaining water collected for the phytoplankton community samples. Chlorophyll *a* samples are generally not sampled in streams due to the downstream drift from lakes; however, chlorophyll *a* was included as a general water quality parameter in the 2009 sampling. Between 150 and 600 mL of water was filtered through a 47 millimetre (mm) glass fibre filter. Each filter was folder in half, wrapped in tin foil to prevent degradation from light penetration, labelled and frozen prior to shipment. Samples were shipped in sealed coolers to Golder's Saskatoon office prior to submission to Saskatchewan Research Council Laboratories (SRC) for analysis.

Zooplankton

Local Study Area Lakes

A single zooplankton community sample was collected from each sampling station (Attachment X.I, Figure X.I-1, Table X.I-8). Zooplankton community samples were collected following Golder's *Aquatic Technical Procedure 8.7-1: Phytoplankton and Zooplankton Sampling* (unpublished file information). Zooplankton community samples were collected using a 30 centimetres (cm) diameter, 1.25 m long, 63 µm Nytex mesh Wisconsin plankton net, with a detachable Dolphin bucket.

In waterbodies with a maximum depth less than 3 m, samples were collected using horizontal net tows. In waterbodies with a maximum depth between 3 and 5 m, samples were collected using a single vertical net tow. In waterbodies where the maximum depth was greater than 5 m, samples were collected using two vertical net tows. Vertical net tows consisted of lowering the plankton net until the bottom of the Dolphin bucket was about 1 m above the lake bottom and towed vertically to the surface at a rate of about 0.5 metres per second (m/s). Horizontal net tows consisted of towing the plankton net behind a boat, at a speed that kept the net just below the lake surface for a distance of 25 to 50 m.

Each sample was transferred from the detachable Dolphin bucket to an individual, pre-labelled 1 L plastic Nalgene bottle. One-half an Alka-Seltzer tablet was added to each zooplankton community sample, to anaesthetize the zooplankton and prevent them from contorting and making identification difficult. Each sample was then preserved with 10% buffered formalin to a final concentration of 4%. Zooplankton community samples were kept cool (not frozen) and in the dark prior to shipment to Golder's Saskatoon office. These samples were submitted to Bio-Limno in Halifax, Nova Scotia for analysis.

Baker Lake

Zooplankton sampling was undertaken at Baker Lake by Nunami Stantec to characterize abundance and diversity at the end of the growing season. One zooplankton sample was collected at each of the five stations on Baker Lake using a 64 µm plankton net (0.0113 square metres [m^2] opening area) deployed from a boat. The net was hauled vertically through the water column at a constant rate of approximately 0.5 m/s beginning from the depth where the deepest water sample was taken (i.e., from a depth of 1 to 6.5 m). At the surface, the outside of the net was rinsed with de-ionized water to wash any adhered plankton down into the cod-end. The sample in the cod-end was then decanted into a pre-labelled 500 mL wide-mouth plastic jar, preserved with 10% buffered formalin, and stored in a cooler until sent to Biologica Environmental Services Ltd. (Victoria, BC) for identification and enumeration. The net was rinsed between samples with de-ionized water.

Field quality assurance/quality control (QA/QC) measures were based on *Guidelines for Monitoring Benthos in Freshwater Environments* (Gibbons et al. 1993) and ensured adequate training for all personnel; consistent sampling methods; correct collection, labelling, and preservation of samples; proper cleaning of equipment; keeping of detailed field notes; use of chain-of-custody forms; and safe shipping and storage methods.

Periphyton

In 2008, three replicate periphyton samples, were collected at each stream sampling station and analyzed. In 2009, two replicate periphyton samples were analyzed and one sample was archived for possible future analysis. Location of stream sampling stations is provided in Attachment X.I, Figure X.I-2, Table X.I-9. Each replicate sample consisted of five sub-samples. Periphyton samples were collected following Golder's *Aquatic Technical Procedure 8.9-1: Benthic Algae Sampling* (unpublished file information). Sampling locations within each stream were selected by choosing a flat area and gently placing a 40 cm ruler to mark the area that was to be sampled. Rocks were scraped with the edge of a scalpel blade. Five rock scrapings, each with an area of 5 square centimetres (cm^2), were combined into one composite sample (total sample area per replicate = 25 cm^2). Samples were placed into glass scintillation vials and preserved with a mixture of Lugol's solution and 10% buffered formalin to a final concentration of 2%. Samples were shipped in sealed coolers to Golder's Saskatoon office prior to submission to TC-Ecologic, Spokane, Washington (USA) for analysis.

Supporting Information

The following supporting environmental information was collected during the plankton and periphyton surveys:

- waterbody and station code;
- sampling date and time;
- ambient weather and wind conditions;
- Universal Transverse Mercator (UTM) coordinates;
- detailed habitat description;
- Secchi depth (when applicable);
- maximum water depth;
- photic zone interval depths (when applicable);
- water volume per depth collected (when applicable);
- total water volume collected (when applicable);
- distance of horizontal tow (when applicable);
- sampling depth (both horizontal and vertical net tows); and
- in situ water measurements (i.e., water temperature, dissolved oxygen, specific conductivity and pH) (Section 6: Limnology).

9.1.2.2 Laboratory Analysis

Phytoplankton

Aliquots of the phytoplankton community samples were allowed to settle overnight in sedimentation chambers following the procedure of Lund et al. (1958). Algal units were counted from randomly selected transects on a Zeiss Axiovert 40 CFL (inverted) microscope. Counting units were individual cells, filaments, or colonies depending on the organization of the algae. A minimum of 400 units were counted for each sample. The bulk of the counts were made at 500X magnification, with initial scanning for large and rare organisms (e.g., *Ceratium*) completed at 250X magnification. Taxonomic identifications were based primarily on Geitler (1932), Skuja (1949), Anton and Duthie (1981), Findlay and Kling (1976), Huber-Pestalozzi (1961, 1972, 1982, 1983), Tikkanen (1986), Geitler (1932), Prescott (1982), Whitford and Schumacher (1984), Starmach (1985), Krammer and Lange-

Bertalot (1986, 1988, 1991a,b), Komarek and Anagnostidis (1998, 2005), and Wehr and Sheath (2003).

Wet weight biomass was calculated from recorded abundance and specific biovolume estimates, based on geometric solids (Rott 1981), assuming unit specific gravity. The biovolume (cubic millimetre per cubic metre [mm^3/m^3] wet weight) of each species was estimated from the average dimensions of 10 to 15 individuals. The biovolumes of colonial taxa were based on the number of individuals in a colony. All calculations for cell concentration and biomass were performed with Hamilton's (1990) computer program.

Chlorophyll a

Chlorophyll a samples were analyzed using acetone extraction according to the *Standard_Methods for the Examination of Water and Wastewater* (WEF 2005). Samples were analyzed on a spectrophotometer and final chlorophyll a concentrations were calculated and expressed as µg/L.

Zooplankton

Three 1 to 5 mL sub-samples were removed from each zooplankton community sample for identification and enumeration. Exact volume of each sub-sample was dependent on the amount of particulate material present in the sample. Macro-zooplankton (i.e., Cladocera, Cyclopoida, and Calanoida) were identified and enumerated using a dissecting microscope at magnifications of 12 to 50X. An inverted microscope at magnification 200 to 400X was used to identify and enumerate rotifers and copepod nauplii. Sub-samples for rotifers and nauplii were allowed to settle for 24 hours prior to counting. Taxonomic identifications were based primarily on Brooks (1957), Edmondson (1966), Chengalath et al. (1971), Grothe and Grothe (1977), Pennak (1978), Stemberger (1979), Clifford (1991), and Thorp and Covich (1991).

Zooplankton lengths were determined directly on the microscope fitted with a micrometer inside the ocular lens. In general, lengths were measured on a minimum of 40 to 50 individuals of each species or genus encountered within a representative subset of samples. Length measurements were recorded for rare taxa or those that occurred in low numbers as they were encountered. Wet weight biomass was calculated for each sample, based on published length-weight regressions cited in Botterell et al. (1976), Downing and Rigler (1984), and Stemberger and Gilbert (1987). For each sample, mean individual weights for each species were calculated by averaging estimated weights. Total biomass for each group (species or developmental stage) was calculated as the product of its abundance and estimated mean individual weight.

Periphyton

Periphyton samples were transferred to 400 mL beakers and clean, filtered water was added to bring the samples up to a known volume of either 40 or 50 mL. The majority of samples contained dense mats of periphyton, which were broken up by agitation and use of scissors. Once the mats were sufficiently broken up and well dispersed within the beaker, 1/8th of the sample volume was drawn off and placed into a clean scintillation vial. This fraction was then set aside for soft bodied algal identification and enumeration. The remaining 7/8th of the sample was prepared for acid digestion for diatom identification and enumeration.

Acid digestion involved the addition of concentrated nitric acid (70%) to the samples in a ratio of one part acid to two parts water. The samples were then heated to near boiling for two hours. At the end of the acid digestion, potassium dichromate was added to catalyze the reaction and ensure complete digestion of organic matter. After the samples were cool, additional water was added to fill the beakers to the original volume of 40 or 50 mL, respectively. The samples were allowed to settle for a minimum of eight hours. After the samples had settled, the liquid was siphoned off taking care to leave the diatom frustules and inorganic sediment undisturbed on the bottom of the beakers. After the liquid had been siphoned off, the samples were again refilled with filtered water. The settling and siphoning process was repeated six times or until the pH approached neutrality. The samples were then transferred into centrifuge tubes.

‘Permanent-mount’ diatom slides were created using the acid digested samples by removing an aliquot of the well mixed acid digested sample and placing that on a microscope cover slip. The aliquot volume varied depending on the density of the original sample; this was necessary to produce slides that would be countable and not occluded by high densities of sediment and frustules. Once the optimal density for enumeration was achieved, the water/diatom mixture was allowed to dry. After drying the sample was mounted to a microscope slide using Zyrax mounting medium and allowed to set prior to counting and enumeration of the diatoms. Slides of periphytic diatoms were enumerated at 700X magnification using a Zeiss Inverted phase-contrast microscope. Approximately 300 to 350 cells (600 to 700 frustules) were enumerated from each slide. Taxonomy was based on Patrick and Reimer (1966), Stockner and Costella (1980), Canter-Lund and Lund (1995), Camburn and Charles (2000); and Wehr and Sheath (2003).

Lugol’s solution was added to the portion of each periphyton sample retained for soft-bodied algal analysis, to attain ample staining and preservation. A known aliquot of the sample was put into 25 mL Utermohl chambers and allowed to settle for two hours. The periphyton taxa were then identified and enumerated using an Olympus Inverted microscope at 600X magnification. Taxonomy was based on Prescott (1982), and Wehr and Sheath (2003).

The data from both the diatom and soft-bodied algal counts were entered into a database for calculation of density in cells per square centimetre (cells/cm^2) and biovolume per square centimetre (biovolume/cm^2). Biovolume estimates for each taxa were determined using average literature values and professional judgment based on microscopic measurements for all taxa present in these samples.

9.1.2.3 Data Analysis

Phytoplankton and Zooplankton

Raw phytoplankton and zooplankton data were received from the taxonomist in an electronic format stored electronically as an Excel file in emLine™. Supporting plankton survey data from the field was entered directly into emLine™. Phytoplankton and zooplankton data were analyzed separately, but the same methods were used to group data as follows:

- Density and biomass data were divided into groups based on taxonomic results. Phytoplankton groups included cyanobacteria, chlorophytes, chrysophytes, cryptophytes, dinoflagellates, diatoms and "other taxa". Zooplankton groups included cladocerans, calanoid copepods (calanoids), cyclopoid copepods (cyclopoids), and rotifers.
- For both phytoplankton and zooplankton, the relative proportion accounted for by each group (based on both density and biomass) was calculated separately for each lake and for each sampling event to evaluate temporal and spatial variability in community structure.
- The phytoplankton and zooplankton data sets were separated into two seasons for 2008 (i.e., summer and fall). Comparisons of density and biomass were completed on a seasonal basis.

Chlorophyll a

Chlorophyll *a* data were received from SRC in electronic format and the data was imported into emLine™. Data was then exported from emLine™ to Excel. Supporting plankton survey data from the field were entered into emLine™. A qualitative review of these data was completed (i.e., no statistical analyses were performed).

Periphyton

Periphyton taxanomic data were received in electronic format from the taxonomist and stored electronically in emLine™. Supporting periphyton survey data from the field were entered into emLine™. Abundance and biomass data were divided into groups based on taxonomic results. Periphyton groups included cyanobacteria, chlorophytes, chrysophytes and cryptophytes, diatoms and dinoflagellates. The relative proportion accounted for by each group (based on both abundance and biomass) was calculated separately for each station to evaluate temporal and spatial variability in periphyton community structure.

9.1.2.4 Quality Assurance/Quality Control

Detailed specific work instructions outlining each field task were provided to field personnel prior to the field program. Samples were collected, labelled, preserved, and shipped according to Golder's *Aquatic Technical Procedure 8.7-1: Phytoplankton and Zooplankton Sampling* (unpublished file information), Golder's *Aquatic Technical Procedure 8.9-1: Benthic Algae Sampling* (unpublished file information) and laboratory protocols. Detailed field notes were recorded in waterproof field notebooks and on pre-printed waterproof field data sheets. Sample bottles were pre-labelled in waterproof ink, and a second waterproof label was inserted into each jar.

Data collected during the field program underwent a variety of individual quality assurance (QA) checks. Field data sheets and the portable emLine™ database were checked at the end of each day for completeness and accuracy. Chain-of-custody (COC) forms were used to track sample shipment from the field, to Golder's Saskatoon office. A copy of the COC forms was used to track phytoplankton, zooplankton, and periphyton sample shipments to the respective taxonomists. SRC analytical request forms were submitted with the chlorophyll *a* samples.

Ten percent of both the phytoplankton and zooplankton samples were re-counted by Bio-Limno to verify counting efficiency. Samples were reanalyzed if 10% or more of these samples were counted incorrectly. The inherent variability associated with the plankton samples prevents the establishment of a quality control (QC) threshold value. Instead, the proportion of each taxon was calculated and the occurrence of dominant species were compared between the field samples and those analyzed for QC purposes.

The electronic taxonomy data underwent a visual QA/QC check for obvious errors. Data entered into emLine™ underwent a 100% transcription check by a second person not involved in the initial data entry process. All datasets generated by the database and all summary tables underwent an additional QA/QC screening.

9.2 Results

9.2.1 Phytoplankton Community

9.2.1.1 Historical Summary 1989 to 1991

In August 1989, phytoplankton communities in the Project area lakes exhibited characteristics typical of unproductive Canadian Shield lakes (BEAK 1990). In general, total phytoplankton biomass was low in all lakes, generally ranging between 100 mg/m^3 and 300 mg/m^3 (BEAK 1990). The phytoplankton community biomass in all lakes was dominated by chrysophytes, with the exception of Ridge Lake, where the diatom, *Tabellaria flocculosa*, was the dominant taxon. Chlorophytes and cryptophytes were the next most predominant taxonomic groups in all lakes. Species richness ranged from 23 taxa (Cirque Lake) to 43 taxa (Ridge Lake) (Table 9.2-1). In general, the phytoplankton biomass and community composition were consistent with the communities of lakes within the Experimental Lakes Area on the Canadian Shield in northwestern Ontario (BEAK 1990).

In August 1990, high inter-lake variability was observed for phytoplankton biomass, which ranged from 65 mg/m^3 (Andrew Lake outfall) to 783 mg/m^3 (Lower Lake outfall) (Table 9.2-1). All phytoplankton samples were collected from lake outlets rather than deep basins, and the community composition exhibited a slight reflection of the habitats from where they were collected (BEAK 1992a). Chrysophytes were the dominant taxa in Mushroom Lake and Lower Lake outfall, and were also abundant within Cigar Lake. However, Cigar Lake was dominated by the chlorophyte, *Euastrum*, which is not normally planktonic and may be indicative of the sampling location within the littoral area at the Cigar Lake outflow (BEAK 1992a). Diatoms were also abundant in Mushroom Lake (BEAK 1992a). Bear Island Lake outfall was dominated by cyanobacteria, chlorophytes and chrysophytes, which may reflect a slightly higher trophic status in this lake compared to the other lakes sampled in August 1990. In addition, the species assemblage in Bear Island Lake outfall reflected differences in water depth and level of wind mixing. Despite these differences between waterbodies, overall species richness tended to be high and consisted of species typical of shallow tundra pond habitats (BEAK 1992a). Species richness ranged from 36 taxa (Mushroom Lake and Andrew Lake outfall) to 50 taxa (Cigar Lake) (Table 9.2-1).

In March 1991, under-ice phytoplankton community samples were collected from Ridge and Judge Sissons lakes (BEAK 1992a). Diatoms were the dominant taxa in both waterbodies; however, the phytoplankton biomass in Judge Sissons Lake (9 mg/m^3) was almost one order of magnitude lower than in Ridge Lake (77 mg/m^3) (Table 9.2-1). Species richness ranged from 20 taxa (Judge Sissons Lake) to 33 taxa (Ridge Lake) (Table 9.2-1).

In June 1991, biomass ranged from 7 mg/m^3 at the Andrew Lake outfall to 158 mg/m^3 in Cigar Lake (Table 9.2-1). Species richness ranged from 12 taxa (Pointer Lake outfall) to 26 taxa (Cigar Lake) (Table 9.2-1). No single major taxonomic group consistently dominated the phytoplankton communities across the four waterbodies sampled at this time. The dominant taxa in June 1991 included *Dinobryon sertularia*, *Rhodomonas minuta*, *Cryptomonas erosa, Pseudoanabaena constricta*, and *Gymnodinium ordinaturm* (BEAK 1992a). The overall diversity was lower in the June 1991 samples collected in Judge Sissons Lake compared to samples collected in March 1991, which may reflect the rapid dilution of the community resulting from spring runoff (BEAK 1992a).

Table 9.2-1 Phytoplankton Density, Biomass, Dominant Taxonomic Group and Richness in Lakes and Streams within the Kiggavik Project Area, 1989 to 1991

Date	Waterbody	Density (cells/L)	Biomass (mg/m3)	Dominant Taxonomic Group	Lowest Taxonomic Level Richness
August 1989	Jaeger Lake	1,055,700	118	chrysophyte	40
	Pointer Lake	1,243,800	138	chrysophyte	37
	Ridge Lake	815,850	269	diatom	43
	Cirque Lake	892,650	198	chrysophyte	24
	Judge Sissons Lake	1,078,500	119	chrysophyte	32
August 1990	Mushroom Lake	1,692,650	110	chrysophyte	36
	Cigar Lake	1,322,100	223	chlorophyte	50
	Andrew Lake Outfall	218,480	65	chlorophyte	36
	Bear Island Lake Outfall	1,235,057	350	cyanobacteria	46
	Lower Lake Outfall	4,790,175	783	chrysophyte	43
March 1991	Ridge Lake	256,076	77	diatom	33
	Judge Sissons Lake	44,240	9	diatom	20
June 1991	Pointer Lake Outfall	163,799	32	cyanobacteria	12
	Cigar Lake	1,484,646	158	chrysophyte	26
	Andrew Lake Outfall[(a)]	33,344	7	chlorophyte	19
	Judge Sissons Lake Outfall	199,497	23	cryptophytes	18
July 1991	Pointer Lake	257,367	93	chlorophyte	26
	Mushroom Lake	801,879	70	cryptophytes	26
	Judge Sissons Lake Outfall	499,845	118	chrysophyte	28

Source: BEAK 1990, 1992.
(a) What was referred to as the Andrew LSA = Andrew Lake Study Area
cells/L = cells per litre; mg/m^3 = milligrams per cubic metre; n/a = not available.

In July 1991, biomass ranged from 70 mg/m^3 in Mushroom Lake to 118 mg/m^3 in Judge Sissons Lake outfall (Table 9.2-1). Species richness was consistent at 28 taxa in Judge Sissons Lake and 26 taxa in the remaining two lakes sampled (Table 9.2-1). No single major taxonomic group consistently dominated the phytoplankton communities across the three waterbodies sampled at this time. The dominant taxa identified in July 1991 included *Aphanocapsa delicatissima*, *Dinobryon bavaricum*, *Chromulina* sp., *Ochromonas* sp., and *Rhodomonas minuta* (BEAK 1992a). These communities exhibited characteristics typical of unproductive tundra lakes and ponds as known in general from the Canadian Arctic; specific assemblages appeared to be affected by lake depth (BEAK 1992a).

9.2.1.2 Recent Sampling Period 2008 to 2009

Detailed taxonomic results (density and biomass) for the 2008 and 2009 phytoplankton community from the Project area are presented in Attachment X.VII. The 2008 data is found in Attachment X.VII, Table X.VII-2 and the 2009 data in Attachment X.VII, Table X.VII-3.

Density

Summer 2008 total phytoplankton density ranged from 1,701,655 cells/L (Lower Lake) to 7,424,224 cells/L (Pointer Lake) (Attachment X.VII, Table X.VII-2). In fall 2008, the range in density was less, ranging from 1,926,292 cells/L (Fox Lake) to 3,165,122 cells/L (Lower Lake). Chrysophytes were consistently the most abundant taxa in all lakes, ranging from 42.0% (Fox Lake) to 87.0% (Pointer Lake) in the summer, and 53.9% (Pointer Lake) to 89.8% (Mushroom Lake) in the fall (Figure 9.2-1). The density of chlorophytes was variable among the lakes sampled, but accounted for more than 25% of the phytoplankton communities in Fox Lake and Caribou Lake. The remaining major taxonomic groups were typically present at low relative densities (Figure 9.2-1).

In fall 2009, total phytoplankton density was lower than the previous year. Density values ranged from 1,400,212 cells/L (Rock Lake) to 3,733,965 cells/L (Andrew Lake) (Attachment X.VII, Table X.VII-3). Chrysophytes were the most abundant taxa in all lakes for 2009, with values ranging from 37.2% (Sik Sik Lake) to 84.9% (Willow Lake) (Figure 9.2-2). Chlorophytes were typically the next most predominant taxa, with the exception of Sik Sik Lake where cyanobacteria accounted for 45.9% of the phytoplankton community density (Figure 9.2-2).

Biomass

Summer 2008 total phytoplankton biomass ranged from 293.54 µg/m^3 (Judge Sissons Lake [mean biomass]) to 1776.75 µg/m^3 (Pointer Lake) (Attachment X.VII, Table X.VII-2). Chrysophytes dominated the summer phytoplankton community biomass in Mushroom Lake (56.6%), Caribou Lake (81.3%), and Judge Sissons (61.3%) (Figure 9.2-3). Mushroom Lake also had a large proportion of cryptophyte biomass (32.6%), but this taxonomic group accounted for low biomass in the remaining lakes (1.0 to 12.1%). Chlorophytes (45.9%) and chrysophytes (38.1%) co-dominated the phytoplankton community biomass in Pointer Lake. Chlorophytes were the dominant taxa in Fox Lake (51.3%), although cyanobacteria accounted for 30.0% of the community biomass. Lower Lake had relatively similar proportions of cyanobacteria (20.9%), chrysophytes (27.5%), and dinoflagellates (25.2%). Diatom biomass was low in all lakes sampled, ranging from 0.55 to 7.7%.

The biomass of “Other Taxa” accounted for less than 1% of the phytoplankton communities in all lakes.

Fall 2008 total phytoplankton biomass increased in all lakes, ranging from 493.24 µg/m^3 (Lower Lake) to 2048.89 µg/m^3 (Pointer Lake) (Attachment X.VII, Table X.VII-2). Chrysophytes remained the dominant taxonomic group in Mushroom Lake (43.0%) and Caribou Lake (61.3%) (Figure 9.2-3). The proportion of chrysophyte biomass increased in Lower Lake (57.6%) and also formed the dominant taxa within that lake. The biomass of chlorophytes increased in the fall in both Pointer Lake (74.8%) and Judge Sissons Lake (56.3%). Cyanobacteria biomass remained low in all lakes (1.0 to 11.9%), with the exception of Fox Lake, where this taxonomic group accounted for 54.3% of the phytoplankton community biomass. The proportion of dinoflagellate biomass also increased in the fall in Mushroom Lake (24.5%), but this taxonomic group was absent in the summer sample from this lake. Diatom biomass remained low in all lakes sampled within the Project area, ranging from 0.2 to 5.0%. The biomass of “Other Taxa” continued to account for less than 1% of the phytoplankton communities in all lakes.

Fall 2009 total phytoplankton biomass ranged from 403.95 µg/m^3 (Willow Lake) to 1,643.96 µg/m^3 (Sik Sik Lake) (Attachment Table X.VII-3). This range is similar to what was observed in fall 2008. Chrysophytes were the most dominant taxa group in Judge Sissons Lake (43.3%), Rock Lake (44.3%), and Willow Lake (59.8%); whereas, cyanobacteria were the most dominant taxa present in Andrew Lake (40.0%) and Sik Sik Lake (65.7%) (Figure 9.2-4). Dinoflagellates were absent from the Andrew Lake and Sik Sik Lake communities. The biomass of “Other Taxa” was absent from all lakes with the exception of Rock Lake where it accounted for less than 1% of the phytoplankton community.

Richness

In 2008, lowest level taxonomic richness ranged from 24 taxa (Mushroom Lake) to 58 taxa (Judge Sissons Lake) in the summer, and 28 taxa (Mushroom Lake) to 69 taxa (Judge Sissons Lake) in the fall. In general, chlorophytes and chrysophytes exhibited the greatest species diversity, while diatoms, dinoflagellates and cryptophytes were represented by only a few species (Table 9.2-2). Several taxa were identified as being unique to only one lake within the Project area in 2008 (Table 9.2-3).

In 2009, the lowest taxonomic richness was observed in Willow Lake (29 taxa) while Judge Sissons Lake had the highest taxonomic richness (73 taxa). In all lakes, chrysophytes and chlorophytes exhibited the greatest species diversity (Table 9.2-2). Several taxa were identified as being unique to only one lake within the Project area in (Table 9.2-4).

Table 9.2-2 Lowest Level Taxonomic Richness of the Phytoplankton Communities in Lakes within the Kiggavik Project Area, 2008 and 2009

Sub-Basin	Waterbody	Cyanobacteria	Chlorophyte	Chrysophyte	Cryptophyte	Dinoflagellate	Diatom	Other Taxa	Total
Summer 2008									
Willow Lake	Pointer Lake	2	12	11	2	2	1	1	31
Lower Lake	Mushroom Lake	0	7	10	3	0	4	0	24
	Lower Lake	3	15	10	5	3	3	0	39
Caribou Lake	Fox Lake	8	12	9	3	1	3	1	37
	Caribou Lake	3	14	8	3	2	1	1	32
Judge Sissons Lake	Judge Sissons Lake	3	24	17	6	1	6	1	58
Fall 2008									
Willow Lake	Pointer Lake	4	21	16	2	3	4	1	51
Lower Lake	Mushroom Lake	1	6	11	4	2	3	1	28
	Lower Lake	4	8	12	2	1	2	1	30
Caribou Lake	Fox Lake	3	14	11	2	1	1	0	32
	Caribou Lake	2	12	17	2	2	3	1	39
Judge Sissons Lake	Judge Sissons Lake	7	25	21	5	2	8	1	69
Fall 2009									
Willow Lake	Rock Lake	3	13	6	5	3	6	1	37
	Sik Sik Lake	12	15	10	4	0	2	0	43
	Willow Lake	2	11	9	2	3	2	0	29
Lower Lake	Andrew Lake	8	14	13	3	0	3	0	41
Judge Sissons Lake	Judge Sissons Lake	5	27	24	5	4	8	0	73

Table 9.2-3 Phytoplankton Taxa Unique to Individual Lakes within the Kiggavik Project Area, 2008

Sub-Basin	Waterbody	Taxa	Season
Willow Lake	Pointer Lake	*Snowella lacustris* (cyanobacteria)	summer and fall
		Dictyosphaerium ehrenbergianum (chlorophyte)	fall
		Oocystis gigas (chlorophyte)	summer
		Glrenodinium sp. (dinoflagellate)	fall
		Pseudokephyrion minutissimum (chrysophyte)	fall
Lower Lake	Mushroom Lake	*Chlamydomonas globosa* (chlorophyte)	fall
		Tetraedron trigonum (chlorophyte)	summer
		Glrenodinium paradoxum (dinoflagellate)	fall
		Diatoma sp. (diatom)	summer
		Neidium sp. (diatom)	fall
		Cryptomonas tenuis (chrysophyte)	fall
	Lower Lake	*Cosmarium meneghinii* (chlorophyte)	summer
		Cosmarium sp. (chlorophyte)	summer
		Monoraphidium pusillum (chlorophyte)	summer
		Isthmochloron trispinatum (chlorophyte)	summer
		Tetraedron sp. (chlorophyte)	summer
Caribou Lake	Fox Lake	*Merismopedia glauca* (cyanobacteria)	summer
		Microcystis ichthyoblabe (cyanobacteria)	summer
		Coelastrum cambricum (chlorophyte)	summer
		Cosmarium phaseolus (chlorophyte)	fall
		Monoraphidium sp. (chlorophyte)	summer
		Sphaeroctystis Schroeteri (chlorophyte)	fall
		Peridinium sp. (dinoflagellate)	fall
		Bitrichia ollula (chrysophyte)	summer
	Caribou Lake	*Ankistrodesmus bernardii* (chlorophyte)	fall
		Monoraphidium minutum (chlorophyte)	summer and fall
		Bicosoeca kenaiensis (chrysophyte)	fall
		Synura sp. (chrysophyte)	summer and fall

Table 9.2-3 Phytoplankton Taxa Unique to Individual Lakes within the Kiggavik Project Area, 2008

Sub-Basin	Waterbody	Taxa	Season
Judge Sissons Lake	Judge Sissons Lake	*Limnothrix redekei* (cyanobacteria)	summer
		Ankistrodesmus spiralis (chlorophyte)	summer
		Ankistrodesmus triangularis (chlorophyte)	summer
		Choricystis sp. (chlorophyte)	summer
		Cosmarium ochthodes var amoebum (chlorophyte)	summer
		Dictyosphaerium subsolitarium (chlorophyte)	summer
		Eudorina elegans (chlorophyte)	summer
		Eudorina sp. (chlorophyte)	summer
		Monoraphidium circinale (chlorophyte)	summer
		Spondylosium planum (chlorophyte)	summer and fall
		Tetraedron caudatum (chlorophyte)	summer and fall
		Achnanthes minutissima (diatom)	summer
		Ophiocytium parvulum (xanthophyte)	summer
		Chrysolykos skuja (chrysophyte)	summer and fall
		Mallomonas pseudocoronata (chrysophyte)	summer
		Pedinella sp. (chrysophyte)	summer
		Spiniferomonas sp. (chrysophyte)	summer
		Cryptomonas erosa (chrysophyte)	summer and fall
		Cryptomonas reflexa (chrysophyte)	summer

Table 9.2-4 Phytoplankton Taxa Unique to Individual Lakes within the Kiggavik Project Area, Fall 2009

Sub-Basin	Waterbody	Taxa
Willow Lake	Sik Sik Lake	*Anabaena inaequalis* (Kuetzing) Bornet & Flahault
		Phormidium sp
		Pseudanabaena limnetica Komarek
		Microcystis ichthyoblabe Kuetzing
		Cosmaruim bioculatum Brebisson
		Quadrigula closteriodes (Bohlin) Printz
		Scenedesmus arcuatus var. platydisca G. M. Smith
		Spondylosium planum (Wolle) W. and G.S. West
		Unidentified naked Chrysophyte sp (*Ochromonas/Chromulina*)-large
		Unidentified naked Chrysophyte sp (*Ochromonas/Chromulina*)-small
	Rock Lake	*Ankistrodesmus falcatus* (Corda) Ralfs
		Euastrum insulare (Wittrock) Roy
		Cymbella minuta var. silesiaca (Bleisch ex. Rabenhorst) C.W. Reimer
		Cymbella sp.
		Navicula sp.
		Haptophyte
	Willow Lake	*Cosmarium regnesii* Reinsch
		Limnothrix redekei (Van Goor) Meffert
		Monoraphidium minutum (Nag.) Komarkova-Legenerova
		Stichogloea doederleinii (Schmidle) Wille
Lower Lake	Andrew Lake	*Anabaenopsis* sp.
		Woronichinia sp.
		Dispora sp.
		Euastrum sp.
		Franceia Droescheri (Lemm.) G.M. Smith

Table 9.2-4 Phytoplankton Taxa Unique to Individual Lakes within the Kiggavik Project Area, Fall 2009

Sub-Basin	Waterbody	Taxa
Judge Sissons Lake	Judge Sissons Lake	*Aphanothece clathrata* W & G.S. West
		Ankistrodesmus bernardii Komarek
		Ankistrodesmus falcatus var. mirabilis West
		Ankistrodesmus fusiformis Corda
		Botryococcus sudeticus Lemmermann
		Chamydomonas frigida Skuja
		Coenocystis sp.
		Crucegenia crucifera (Wolle) Collins
		Eudorina sp.
		Elakatothrix gelatinosa Wille
		Microspora sp.
		Scenedesmus sp.
		Tetraedron minimum (A. Braun) Hansgirg
		Pediastrum boryanum (Turpin) Meneghini
		Dinobryon dilatatum Hillard
		Uroglena sp.
		Spiniferomonas sp.
		Amphidinium sp.
		Gymnodinium lantzschii Utermohl
		Cyclotella/Stephanodiscus (4 µm)
		Synedra sp.

µm = micrometre; sp. = species singular.

9.2.2 Chlorophyll *a*

Within lakes sampled within the Project area in 2008, chlorophyll *a* concentrations ranged from 0.70 to 1.80 µg/L in the summer and less than 0.1 to 0.85 µg/L in the fall (Table 9.2-5). These concentrations are within the range specified for oligotrophic lakes (0.3 to 4.5 µg/L) (Wetzel 2001). In general, higher chlorophyll *a* concentrations were observed in the summer and were lower in the fall, with the exception of Judge Sissons Lake, where mean chlorophyll *a* concentrations remained relatively consistent between summer (0.71 µg/L) and fall (0.78 µg/L) (Table 9.2-5). This pattern is inconsistent with that observed for phytoplankton biomass, which increased in most lakes in the fall. This suggests that seasonal and taxonomic variation may be affecting overall chlorophyll *a* concentrations.

Table 9.2-5 Mean Chlorophyll *a* Concentrations in Lakes within the Kiggavik Project Area, 2008 and 2009

		Summer 2008	Fall 2008	Fall 2009
Sub Basin	**Waterbody**	**Chlorophyll-*a* (µg/L)**	**Chlorophyll-*a* (µg/L)**	**Chlorophyll-*a* (µg/L)**
Willow Lake	Pointer Lake	1.8	0.6	-
	Sik Sik Lake	-	-	4.6
	Rock Lake	-	-	3.4
	Willow Lake	-	-	2.4
Lower Lake	Mushroom Lake	1.65	0.85	-
	Lower Lake	0.7	0.35	-
	Andrew Lake	-	-	3.1
Caribou Lake	Fox Lake	1.05	<0.1	-
	Caribou Lake	1.1	0.55	-
Judge Sissons Lake	Judge Sissons Lake[(a)]	0.71	0.78	1.9

(a) Chlorophyll *a* concentrations in Judge Sissons Lake are mean concentrations calculated from five sampling locations.
µg/L = micrograms per litre; < = less than; - = not sampled.

In fall 2009, chlorophyll *a* concentrations ranged from 1.9 to 4.6 µg/L (Table 9.2-5). These results are consistent with chlorophyll *a* concentrations within oligotrophic lakes (Wetzel 2001). Seasonal variation in chlorophyll *a* concentrations could not be assessed in 2009 as there was only one season of sampling.

9.2.3 Zooplankton Community

Detailed zooplankton data has been included in Attachment X.VII. Historical data summary is found in Attachment X.VII, Table X.VII-4. The 2008 data has been summarized in Attachment X.VII, Table X.VII-5 and the 2009 data in Attachment X.VII, Table X.VII-6.

9.2.3.1 Historical Summary 1979 to 1991

Zooplankton communities sampled in 1979 and 1989 were found to be extremely variable in terms of species composition and number of organisms (BEAK 1992a). In 1979, crustacean zooplankton densities in Scotch, Jaeger, Pointer, and Judge Sissons lakes ranged between 0.4 and 9.2 organisms per litre (organisms/L) (Attachment X.VII, Table X.VII-4). The range of crustacean densities was greater in 1989 (0.04 to 20.5 organisms/L) (Attachment X.VII, Table X.VII-4). Copepods (either calanoid or cyclopoid) were the dominant taxa, with the exception of Jaeger Lake (1989), Pointer Lake (1989) and Cirque Lake (1989) where cladocerans dominated the zooplankton communities (Table 9.2-6). In both years, the following species were common in most lakes sampled: *Bosmina longirostris*; *Chydorus sphaericus; Daphnia longiremis*; cyclopoid copepodids (larval cyclopoid copepods); and calanoid copepodids (larval calanoid copepods) (BEAK 1989). Overall, the densities of crustacean zooplankton were low relative to other Shield lakes, which is reflective of the relatively low biological productivity of lakes within the Project area (BEAK 1989). Biomass data was unavailable for the 1979 and 1989 zooplankton community results; therefore, these results could not be assessed.

Rotifers were analyzed in 1989, but were not analyzed in the 1979 samples (BEAK 1989). This group is commonly overlooked in aquatic biological inventories; however, these organisms form a significant portion of the zooplankton community (Wetzel 2001). *Keratella* sp., *Lepadella ovalis*, and *Kellicottia longispina* were common species present in most of the lakes sampled in 1989 (BEAK 1989).

In addition, during the summer months in both 1979 and 1989, the fairy shrimp, *Brachinecta* sp., was observed in abundance in fishless lakes such as Sik Sik Lake and Meadow Lake (BEAK 1989). No fairy shrimp were observed in deeper lakes, which would provide over-wintering habitat for fish and fairy shrimp would be susceptible to fish predation (BEAK 1990).

During the July 1990 sampling events, crustacean zooplankton densities in Mushroom, Cigar, Shack, Bear Island, and Lower lakes ranged from 0.04 to 0.8 organisms/L (Table 9.2-6). Zooplankton density was higher in July 1991, ranging between 2.9 and 8.4 organisms/L (Table 9.2-6). In general, cladocerans were the dominant taxonomic group in the lakes sampled in both years. However, calanoid copepods dominated the zooplankton communities in Bear Island Lake (1990), Pointer Lake (1991), and Cigar Lake (1991); cyclopoid copepods were the dominant taxa in Judge Sissons Lake in July 1991. In both years, the following species were common in most lakes sampled: *Bosmina* *logirostris*; *Chydorus sphaericus; Daphnia longiremis*; *Holopedium gibberum*; *Epishura lacustris*; cyclopoid copepodids (larval cyclopoid copepods); and calanoid copepodids (larval calanoid copepods) (BEAK 1992a).

Rotifers were identified as being abundant, common or rare in both 1990 and 1991 (BEAK 1992a). In July 1990, there were no rotifer species common to all lakes sampled. However, *Conochilus* sp. was abundant in both Cigar Lake and Lower Lake; *Kellicottia* sp., *Synchaeta* sp., and *Gastropus* sp. also were abundant rotifers in Lower Lake (BEAK 1992a). *Testudinella* sp. was only present in Mushroom Lake where it was also classified as abundant (BEAK 1992a). In July 1991, *Kellicottia* sp. and *Conochilus* sp. were abundant in all lakes sampled, with the exception of Cigar Lake, where these two taxa were classified as rare (BEAK 1992a). All other rotifer species identified in both July 1990 and July 1991 were classified as either common or rare in the lakes within the Project area (BEAK 1992a).

Table 9.2-6 Zooplankton Density, Dominant Taxonomic Group and Richness in Lakes within the Kiggavik Project Area, 1979 to 1991

Date	Waterbody	Density[c] (organisms/L)	Dominant Taxonomic Group	Lowest Taxonomic Level Richness[c]
July 1979	Pointer Lake[a]	2.97	calanoid	10
August 1979	Scotch Lake	3.84	calanoid	11
	Jaeger Lake	2.87	calanoid	12
	Pointer Lake[b]	0.812	calanoid	10
	Judge Sissons Lake[b]	7.73	cyclopoid	9
August 1989	Jaeger Lake	0.05	cladoceran	2
	Pointer Lake	0.18	cladoceran	2
	Ridge Lake	20.5	calanoid	5
	Cirque Lake	1.57	cladoceran	5
	Judge Sissons Lake	0.40	calanoid	8
July 1990	Mushroom Lake	0.04	cladoceran	8
	Cigar Lake	0.80	cladoceran	20
	Shack Lake	0.05	cladoceran	8
	Bear Island Lake	0.78	calanoid	13
	Lower Lake	0.06	cladoceran	12

Table 9.2-6 Zooplankton Density, Dominant Taxonomic Group and Richness in Lakes within the Kiggavik Project Area, 1979 to 1991

Date	Waterbody	Density[(c)] (organisms/L)	Dominant Taxonomic Group	Lowest Taxonomic Level Richness[(c)]
July 1991	Pointer Lake	8.24	calanoid	14
	Mushroom Lake	8.40	cyclopoid	9
	Cigar Lake	2.92	calanoid	8
	Judge Sissons Lake	3.26	cyclopoid	11

Source: BEAK 1990, 1992.
(a) Data is based on a calculated mean from six sampling events.
(b) Data is based on a calculated mean from three sampling events.
(c) Result only include crustacean zooplankton (i.e., rotifers were excluded from results).
organisms/L = number of organisms per litre.

Variation observed in the lowest taxonomic level richness (for crustacean zooplankton only) is likely a reflection of differences in sampling locations and methods. In 1979 and 1991, samples were collected using vertical net tows in the deep basin of each lake. In 1989 and 1990, a measured volume was filtered through a plankton net at a stationary location in the outlet streams. The high number of Chydoridae (chydorid) species identified in 1990, particularly in Cigar Lake, may be a reflection of sampling littoral habitat as chydorids are primarily found in these areas (Wetzel 2001).

9.2.3.2 Recent Sampling Period 2008 and 2009

Density

Summer 2008 total zooplankton density ranged between 63,892 organisms/m^3 (Fox Lake) and 247,737 organisms/m^3 (Mushroom Lake) (Attachment X.VII, Table X.VII-5). In fall 2008, total zooplankton density ranged between 48,861 organisms/m^3 (Fox Lake) and 450,681 organisms/m^3 (Pointer Lake) (Attachment X.VII, Table X.VII-5). Total zooplankton density decreased in the fall in most lakes, which is a typical seasonal pattern related to cooler water temperatures and reduced phytoplankton availability (Wetzel 2001). However, total zooplankton density increased in the fall in both Pointer Lake and Caribou Lake. In Pointer Lake, this increase was primarily related to a large increase in the cladocerans *Bosmina longirostris* and *Chydorus sphaericus*, as well as a 3.6 fold increase in total rotifer biomass. In Caribou Lake, the increase in total zooplankton density was less and was related to a 1.5 fold increase in total rotifer biomass.

Overall, rotifers were the most abundant taxonomic group in all of the lakes sampled within the Project area in 2008 and this was a consistent pattern in both the spring (64.7 to 93.8%) and fall

(73.6 to 99.2%). Calanoid and cyclopoid copepods, as well as cladocerans, were present in all of the lakes, but the overall densities of these taxa were low (Figure 9.2-5).

Fall 2009 total zooplankton density ranged between 16,854 organisms/m^3 (Sik Sik Lake) and 88,876 organisms/m^3 (Judge Sissons Lake) (Attachment X.VII, Table X.VII-6). Rotifers remained the most abundant taxonomic group in the five lakes sampled within the Project area in 2009, ranging from 46.9% (Sik Sik Lake) to 91.3% (Andrew Lake) of the total zooplankton community (Figure 9.2-6). Calaniods were also a dominant taxa in Sik Sik Lake (44.2%).

Biomass

Summer 2008 total zooplankton biomass ranged between 124,028.70 µg/m^3 (Pointer Lake) and 422,184.39 µg/m^3 (Fox Lake) (Attachment X.VII, Table X.VII-5). Fall 2008 total zooplankton biomass ranged between 79,367.67 µg/m^3 (Lower Lake) and 364,775.70 µg/m^3 (Pointer Lake) (Attachment X.VII, Table X.VII-5). Total zooplankton biomass followed a similar pattern of decrease between summer and fall in all lakes sampled within the Project area, with the exception of Pointer Lake and Caribou Lake. The increase in biomass in these two lakes was related to the same taxa responsible for the increase in total zooplankton density (see above).

Rotifers dominated the zooplankton community biomass in the majority of lakes sampled within the Project area in both the summer (48.6 to 85.9%) and fall (65.4 to 98.0%), with the exception of Fox Lake (spring = 7.3%; fall = 31.0%) (Figure 9.2-7). In Fox Lake, cladocerans were the predominant taxonomic group, comprising 77.6% of the summer zooplankton biomass and 56.9% of the fall zooplankton biomass (Figure 9.2-7); *Daphnia middendorffiana* was the primary cladoceran accounting for the high biomass as it is a large daphniid species. This suggests fish predation is limited in Fox Lake because the large size of *D. middendorffiana* makes it susceptible to visual predators.

Fall 2009 total zooplankton biomass ranged between 64,415.64 µg/m^3 (Andrew Lake) and 214,129.56 µg/m^3 (Sik Sik Lake; Attachment X.VII, Table X.VII-6). As in 2008, rotifers dominated the zooplankton community biomass in the majority of lakes sampled in the Project area (41.9 to 78.8%) (Figure 9.2-8). In 2009, the zooplankton community biomass in Sik Sik Lake was co-dominated by calanoids (55.5%) and cladocerans (42.6%). *Leptodiaptomus sicilis* (calanoid) and *D. middendorffiana* were the predominant species, suggesting fish predation in this lake is limited.

Richness

Lowest level taxonomic richness ranged from 16 taxa (Pointer Lake) to 29 taxa (Judge Sissons Lake) taxa in summer 2008, and 11 (Pointer Lake) to 29 (Judge Sissons Lake) taxa in fall 2008 (Table 9.2-7). In general, rotifers exhibited the greatest diversity (Table 9.2-7). The species assemblages of calanoids, cyclopoids and calanoids were relatively consistent between lakes sampled within the

Project area. Several taxa were identified as being unique to only one lake within the project area (Table 9.2-8). A number of these “unique” species were rotifers and their apparent absence from other lakes may be an artifact of sampling methods.

In 2009, lowest taxonomic richness was observed in Rock Lake (10 taxa) while Judge Sissons Lake had the highest taxonomic richness (32 taxa). Rotifers continued to exhibit the greatest diversity (Table 9.2-7). Several taxa were identified as being unique to Rock, Andrew, and Judge Sissons lakes (Table 9.2-9).

Table 9.2-7 Lowest Level Taxonomic Richness of the Zooplankton Communities in the Kiggavik Project Area, 2008 and 2009

Sub-Basin	Waterbody	Calanoida	Cyclopoida	Cladocera	Rotifera	Total
Summer 2008						
Willow Lake	Pointer Lake	2	3	3	8	16
Lower Lake	Mushroom Lake	3	4	4	9	19
	Lower Lake	1	0	5	13	19
Caribou Lake	Fox Lake	4	2	4	6	18
	Caribou Lake	3	3	3	10	19
Judge Sissons Lake	Judge Sissons Lake	5	5	5	14	29
Fall 2008						
Willow Lake	Pointer Lake	1	2	2	6	11
Lower Lake	Mushroom Lake	2	3	5	11	21
	Lower Lake	1	2	4	13	20
Caribou Lake	Fox Lake	1	3	2	7	13
	Caribou Lake	2	1	3	12	18
Judge Sissons Lake	Judge Sissons Lake	5	5	7	12	29
Fall 2009						
Willow Lake	Rock Lake	3	1	3	3	10
	Sik Sik Lake	3	2	4	9	18
	Willow Lake	3	1	5	8	17
Lower Lake	Andrew Lake	5	1	7	11	24
Judge Sissons Lake	Judge Sissons Lake	4	5	7	16	32

Table 9.2-8 Zooplankton Taxa Unique to Individual Lakes within the Kiggavik Project Area, 2008

Sub-Basin	Waterbody	Taxa	Season
Willow Lake	Pointer Lake	*Trichotria* sp. (rotifer)	summer
Lower Lake	Mushroom Lake	*Monostyla lunaris* (rotifer)	summer
	Lower Lake	*Asplanchna herricki* (rotifer)	fall
		Brachionus angularis (rotifer)	summer
		Lepadella sp. (rotifer)	summer
		Lophocharis sp. (rotifer)	summer
		Monostyla bulla (rotifer)	summer
		Testudinella sp. (rotifer)	summer
		Trichotria sp. (rotifer)	fall
Caribou Lake	Fox Lake	*Heterocope septentrionalis* (calanoid)	summer
		Daphnia middendorffiana (cladoceran)	summer and fall
		Lecane flexilis (rotifer)	summer
	Caribou Lake	*Asplanchna herricki* (rotifer)	summer
		Brachionus angularis (rotifer)	fall
Judge Sissons Lake	Judge Sissons Lake	*Leptodiaptomus sicilis* (calanoid)	fall
		Cyclops scutifer (cyclopoid)	fall
		Gastropus hyptopus (rotifer)	summer
		Filinia terminalis (rotifer)	summer
		Keratella hiemalis (rotifer)	summer
		Keratella serrulata (rotifer)	summer

Table 9.2-9 Zooplankton Taxa Unique to Individual Lakes within the Kiggavik Project Area, Fall 2009

Sub-Basin	Waterbody	Taxa
Willow Lake	Rock Lake	*Encentrum* sp. (rotifer)
		Trichocerca cylindrical (rotifer)
Lower Lake	Andrew Lake	*Testudinella parva*
Judge Sissons Lake	Judge Sissons Lake	*Cyclops scutifer* (cyclopoid)
		Lecane flexilis (rotifer)
		Lepadella sp. (rotifer)
		Monostyla bulla (rotifer)
		Monostyla lunaris (rotifer)
		Polyathra dolicoptera (rotifer)
		Polyathra vulgaris (rotifer)

Baker Lake 2008

Zooplankton data for Baker Lake are provided in Appendix X.VII. Total zooplankton density ranged from 5,047 organisms/m^3 at Station 5 to 227,945 organisms/m^3 at Station 4 (Table 9.2-10). Taxon richness (species and genera) ranged from 15 taxa at Station 5 to 22 taxa at Stations 2 and 4 (Table 9.2-10). Diversity, calculated using the Simpson's diversity index, ranged from 0.43 at Station 1 to 0.79 at Station 4 (Table 9.2-10). The high density (227,945 organisms/m^2), taxon richness (22 taxa) and diversity (0.79) at Station may be due, in part, to its location in a small, protected bay, with freshwater inputs from tributaries. Station 2 also had high taxon richness (22 taxa) and high diversity (0.77).

Table 9.2-10 Baker Lake Zooplankton Community Characteristics, September 2008

Station	Depth of Haul (m)	Index		
		Density (# organisms/m^2)	Taxon Richness	Simpson's Diversity
1	6	10,139	17	0.43
2	6.5	5,047	22	0.77
3	4	12,799	16	0.64
4	2	227,945	22	0.79
5	1	53,228	15	0.64

m = metre; # organisms/m^2 = number of organisms per square metre.

Rotifera (small zooplankton) were predominant (66% to 94% of total) at all five stations (Figure 9.2-9). The rotifer *Kellicottia longispina* was predominant at all five stations, as were *Keratella cochlearis* at Stations 2 and 4. *Keratella cochlearis* was common at Stations 1, 3, and 5. The crustacean Copepoda, comprised mainly of *Leptodiaptomus* spp. and *Limnocalanus macrurus*, were common (12% to 33%) at Stations 1, 2, and 3 and present at Stations 4 and 5 (3.4% and 5.6% respectively). Low numbers of Cladocera, comprised mainly of *Bosmina logirostris*, were present at all five stations (0.2% to 5.6%).

9.2.4 Periphyton Community

Detailed periphyton data has been included in Attachment X.VII. The 2008 data has been summarized in Attachment X.VII, Table X.VII-8 and the 2009 data in Attachment X.VII, Table X.VII-9.

9.2.4.1 Historical Summary

There was no record of previous periphyton sampling in the Project area.

9.2.4.2 Recent Sampling Period 2008 and 2009

Detailed taxonomic results for the 2008 and 2009 periphyton community taxonomic data (density and biomass) from the Project area are presented in Attachment X.VII, Tables X.VII-7 and X.VII-8. Five major taxonomic groups were identified including cyanobacteria, Chlorophyceae (chlorophytes), Bacillariophyceae (diatoms), Chrysophyceae and Cryptophyceae (chrysophytes and cryptophytes), and Dinophyceae (dinoflagellates).

Density

In 2008, total periphyton density within the Willow Lake sub-basin ranged from a mean of 103,138 cells/cm^2 (Pointer/Rock Stream) to 1,174,421 cells/cm^2 (Northeast Inflow of Pointer Lake) (Attachment X.VII, Table X.VII-7). Chlorophyte had the greatest relative abundance in all streams within this sub-basin, ranging from 57.9 to 73.9% (Figure 9.2-10). Diatoms comprised 43.2%, 17.9% and 26.3% of the periphyton community composition (based on density) in Northeast Pointer Lake Stream, Northwest Inflow of Pointer Lake, and Willow/Judge Sissons Stream, respectively; however, the relative abundance of this major taxonomic group was low in Pointer/Rock Stream (1.1%) and Rock/Willow Stream (7.8%) (Figure 9.2-10). The relative density of cyanobacteria was fairly consistent among streams, ranging from 13.8% to 28.6% (Figure 9.2-10). The periphyton communities in streams within the Willow sub-basin had very low proportions of Chrysophytes and Cryptophytes (zero to 0.04%) as well as dinoflagellates (zero to 0.13%).

Streams within the Lower Lake sub-basin exhibited the greatest variability in total periphyton density ranging from a mean of 114,484 cells/cm^2 (Knee Lunch Stream) to 4,025,327 cells/cm^2 (Lower/Judge Sissons Stream) (Attachment X.VII, Table X.VII-7). The relative density of the major taxonomic groups also exhibited more variability in streams sampled within this sub-basin (Figure 9.2-10). Chlorophyte was the dominant taxonomic group in End Grid/Shack Stream (78.1%), Knee/Lunch Stream (63.2%) and Lunch/Andrew Stream (72.4%). In these three streams, cyanobacteria was the next most dominant group, ranging from 17.7 to 32.7%, with diatoms accounting for a small proportion of the periphyton community (2.2 to 4.1%). Andrew/Shack Stream had equal proportions of diatoms (44.2%) and chlorophytes (43.4%), with a lower proportion of cyanobacteria (12.4%). The periphyton communities in the remaining four streams within the Lower Lake sub-basin were dominated by diatoms (62.4 to 81.6%), with chlorophytes (15.0 to 30.0%) and cyanobacteria (4.5 to 10.6%) accounting for lower proportions. In all streams within the Lower sub-basin, chrysophytes and cryptophytes as well as dinoflagellates accounted for less than 1% of the periphyton communities.

Within the Caribou Lake sub-basin, total periphyton density ranged from a mean of 108,509 cells/cm^2 (Cirque/Crash Stream) to 2,716,343 cells/cm^2 (Crash/Fox Stream) (Attachment X.VII, Table X.VII-7). With the exception of Crash/Fox Stream, Chlorophytes has the highest relative abundance (61.7 to 71.9%) (Figure 9.2-10), while the remainder of the periphyton community consisted of diatoms (2.2 to 13.1%) and cyanobacteria (13.7 to 27.3%). The periphyton community in Crash/Fox Stream was dominated by diatoms (63.2%), with Chlorophytes (27.5%) and cyanobacteria (9.2%) present at lower relative density (Figure 9.2-10). Chrysophytes and Cryptophytes as well as dinoflagellates accounted for less than 1% of the periphyton community in all streams sampled within the Caribou sub-basin.

In 2009, total periphyton density within the Willow Lake sub-basin ranged from a mean of 2,350,319 cells/cm^2 (Willow/Judge Sissons Stream) to 905,450 cells/cm^2 (Rock/Willow Stream) (Attachment X.VII, Table X.VII-8). Chlorophytes had the greatest relative density in all streams within this sub-basin, ranging from 74.8% to 99.8% (Figure 9.2-11). Diatoms comprised less than 5% of the periphyton communities within the three streams sampled in 2009. The relative density of cyanobacteria among streams ranged from 0.1% (Willow/Judge Sissons Stream) to 20.5% (Rock/Willow Stream) (Figure 9.2-11). Chrysophytes and Cryptophytes, as well as dinoflagellates, were absent from the periphyton communities in streams within the Willow Lake sub-basin.

In the Aniguq River, total periphyton density varied between the two sampling stations, ranging from a mean of 1,395,260 cells/cm^2 and 2,340,221 cells/cm^2 (Attachment X.VII, Table X.VII-8). Chlorophytes dominated the periphyton community with a relative density of 95.3 to 99.1% (Figure 9.2-11). Cyanophytes comprised 0.4 to 4.3% of the remaining periphyton community. Diatoms, Crysophytes, Cryptophytes and dinoflagelaltes all accounted for less than 1% of the periphyton community within the river.

Biomass

In 2008, total periphyton biomass within the Willow sub-basin ranged from a mean of 151,471 mg/cm^2 (Pointer/Rock Stream) to 416,995 mg/cm^2 (Northeast Inflow of Pointer Lake) (Attachment X.VII, Table X.VII-7). Chlorophyte dominated the periphyton community biomass in Pointer/Rock Stream (91.2%) and Rock/Willow Stream (68.2%), but accounted for a smaller proportion (17.6 to 32.1%) in the remaining streams sampled within this sub-basin (Figure 9.2-12). The relative biomass of cyanobacteria was high in Northwest Pointer Lake Stream (67.4%) and Willow/Judge Sissons Stream (50.8%), and moderate in Northeast Pointer Lake Stream (31.5%) and Rock/Willow Stream (27.0%). This major taxonomic group had a low relative biomass in Pointer/Rock Stream (8.5%). Diatoms were predominant in Northeast Pointer Lake Stream (46.3%), but accounted for a small proportion of the periphyton community biomass (0.3 to 17.1%) in the remaining streams sampled within this sub-basin (Figure 9.2-12). Chrysophytes and Cryptophytes as well as dinoflagellates comprised less than 1% of the periphyton community biomass in all streams sampled within this sub-basin.

As with density, streams within the Lower Lake sub-basin exhibited the greatest variability in total periphyton biomass ranging from a mean of 7.2 mg/cm^2 (Knee/Lunch Stream) to 1,040 mg/cm^2 (Lower/Judge Sissons Stream) (Attachment X.VII, Table X.VII-7). The periphyton community within Andrew/Shack Stream consisted of equal proportions of chlorophytes (49.4%) and diatoms (49.3%), with a small proportion of cyanobacteria (1.2%) (Figure 9.2-12). Chlorophytes dominated the periphyton community biomass in Knee/Lunch Stream (77.7%) and End Grid/Shack Stream (67.4%), but accounted for lower proportions of the biomass in the remaining five streams (13.3 to 30.2%) (Figure 9.2-12). Lunch/Andrew Stream had a high proportion of cyanobacteria biomass (74.7%), but this major taxonomic group had lower proportional biomass (15.4 to 36.0%) in the remaining four streams sampled within the sub-basin (Figure 9.2-12). Diatoms had high proportional biomass in Mushroom/End Grid Stream (65.8%), Cigar/Lunch Stream (50.7%), Shack Lower Stream (59.7%), and Lower/Judge Sissons Stream (54.2%), but only accounted for a low proportion (2.9%) in

Lunch/Andrew Stream (Figure 9.2-12). Chrysophytes and Cryptophytes as well as dinoflagellates comprised less than 1% of the periphyton community biomass in all streams sampled within this sub-basin.

Within the Caribou sub-basin, total periphyton biomass ranged from a mean of 34.3 mg/cm^2 (Fox/Caribou Stream) to 113,900 mg/cm^2 (Caribou/Calf Stream) (Attachment X.VII, Table X.VII-7). Periphyton biomass in Caribou/Calf Stream was almost exclusively chlorophytes (98.0%), with the remaining four major taxonomic groups represented in small proportions (≤1.5%) (Figure 9.2-12). Chlorophytes also accounted for 54.0% of the periphyton community within Calf/Judge Sissons Stream, with relatively equal proportions of diatoms (23.9%) and cyanobacteria (21.9%) represented in the biomass (Figure 9.2-12). Crash/Fox Stream periphyton biomass was dominated by diatoms (61.1%), with lower proportional biomass of cyanobacteria (21.6%) and chlorophytes (17.2%); whereas, the remaining three streams within this sub-basin were dominated by cyanobacteria (47.4 to 69.7%), with Chlorophytes (21.8 to 44.7%) and diatoms (7.9 to 12.4%) comprising comparable proportions of the biomass (Figure 9.2-12). Chrysophytes and Cryptophytes as well as dinoflagellates comprised less than 1% of the periphyton community biomass in all streams sampled within this sub-basin.

In 2009, total periphyton biomass within the Willow sub-basin ranged from a mean of 113 mg/cm^2 (Rock/Willow Stream) to 305 mg/cm^2 (Willow/Judge Sissons Stream) (Attachment X.VII, Table X.VII-8). Chlorophyte dominated the periphyton community biomass in all streams within the sub-basin ranging from a mean biomass of 70.3% (Northeast Pointer Lake Stream) to 96.1% (Willow/Judge Sissons Stream; Figure 9.2-13). The biomass of cyanobacteria was highest in Northeast Pointer Lake Stream (26.4%) and lowest in Willow/Judge Sissons Stream (3.7%). Diatoms biomass was also low in all the streams of the sub-basin, ranging from 0.2% in Willow/Judge Sissons Stream to 6.8% in Rock/Willow Stream (Figure 9.2-13). Chrysophytes and Cryptophytes as well as dinoflagellates were not present in the periphyton community biomass in all streams sampled within this sub-basin.

In the Aniguq River, the total biomass of periphyton was low and the mean ranged from 188 to 294 mg/cm^2, in the upper river station and lower river station, respectively (Attachment X.VII, Table X.VII-8). Chlorophytes were the greatest contributor to the periphyton community biomass composing 90.4% to 98.9% of the relative biomass (Figure 9.2-13). Cyanophytes contributed 8.7% to the total periphyton relative biomass at Station 1. The Aniguq River Station 1 also had low biomass of diatoms (0.9%), Chrysophytes and Cryptophytes (less than 0.1%), Dinophytes (less than 0.1%). Station 2 of the Aniguq River was less diverse and the remaining biomass was comprised of diatoms (0.9 to 1.1%) and cyanobacteria (less than 0.1%). Chrysophytes, Cryptophytes, and Dinophytes were not present in the samples.

Richness

In 2008, mean lowest level taxonomic richness was similar across sub-basins, ranging from 49 to 69 taxa in the Willow sub-basin, 41 to 66 in the Caribou sub-basin, and 34 to 64 in the Lower sub-basin (Table 9.2-11). Within all streams sampled within the Project area, diatom taxa had the greatest number of taxa, followed by chlorophyte and cyanobacteria. Cryptophyte and chrysophyte as well as dinoflagellates were represented by only one or two taxa, where present within the periphyton community. Several taxa were identified as being unique to only one stream within the Project area (Table 9.2-12).

In 2009, mean lowest level taxonomic richness was varied across sub-basins, ranging from 18 to 34 taxa in the Willow sub-basin, and 31 to 43 in the Aniguq River sub-basin (Table 9.2-13). Within all streams sampled within the Project area, diatom taxa had the greatest number of taxa, followed by chlorophyte and cyanobacteria. Cryptophyte and chrysophyte as well as dinoflagellates were only present in the Aniguq River 1 samples. Several taxa were identified as being unique to only one stream within the project area (Table 9.2-14).

Table 9.2-11 Lowest Level Taxonomic Richness of the Periphyton Communities in the Kiggavik Project Area, 2008

Sub-Basin	Watercourse	Cyanobacteria	Chlorophyte	Chrysophyte and Cryptophyte	Dinoflagellate	Diatom	Total
Willow Lake	Northeast Inflow of Pointer Lake	7	14	0	1	27	**49**
	Northwest Inflow of Pointer Lake	7	18	0	2	31	**58**
	Pointer/Rock Stream	6	16	0	1	17	**40**
	Rock/Willow Stream	8	22	0	1	38	**69**
	Willow/Judge Sissons Stream	7	25	1	1	32	**66**
Lower Lake	Mushroom/End Grid Stream	6	15	2	1	31	**55**
	End Grid/Shack Stream	5	19	2	1	37	**64**
	Cigar/Lunch Stream	5	14	1	1	28	**49**
	Knee/Lunch Stream	5	6	2	1	20	**34**
	Lunch/Andrew Stream	7	10	0	0	33	**50**
	Andrew/Shack Stream	7	18	2	1	31	**59**
	Shack/Lower Stream	7	15	0	1	32	**55**
	Lower/Judge Sissons Stream	7	20	1	1	29	**58**
Caribou Lake	Ridge/Crash Stream	5	13	0	1	30	**49**
	Cirque/Crash Stream	5	11	2	0	23	**41**
	Crash/Fox Stream	8	23	1	1	32	**65**
	Fox/Caribou Stream	6	14	0	1	27	**48**
	Caribou/Calf Stream	4	13	1	1	28	**47**
	Calf/Judge Sissons Stream	6	20	1	1	38	**66**

Table 9.2-12 Periphyton Taxa Unique to Individual Streams within the Kiggavik Project Area, 2008

Sub-Basin	Watercourse	Taxa
Willow Lake	Northeast Inflow of Pointer Lake	*Stigonema* sp. (chlorophyte)
	Willow/Judge Sissons Stream	*Neidium affine* (diatom)
		Neidium iridis (diatom)
Lower Lake	Mushroom/End Grid Stream	*Eunotia maior* (diatom)
		Fragilaria construens (diatom)
	End Grid/Shack Stream	*Anomoeneis vitrea* (diatom)
		Gomphonema sp. (diatom)
	Cigar/Lunch Stream	*Spirogyra* sp. (chlorophyte)
		Fragilaria vaucheriae (diatom)
	Knee/Lunch Stream	*Cymbella lunata* (diatom)
	Lunch/Andrew Stream	*Caloneis ventricosa* (diatom)
		Eunotia bigibba (diatom)
	Lower/Judge Sissons Stream	*Coelastrum* sp. (chlorophyte)
Caribou Lake	Ridge/Crash Stream	*Cyclotella perglabra* (diatom)
		Cyclotella radiosa (diatom)
		Meridion circulare (diatom)
	Cirque/Crash Stream	*Asterionella ralfsii* (diatom)
		Peronia herbaudi (diatom)
	Crash/Fox Stream	*Achnanthidium exiguum* (diatom)
		Achnathidium pusilla (diatom)
	Caribou/Calf Stream	*Cyclotella* sp. (diatom)
		Stauroneis anceps (diatom)
	Calf/Judge Sissons Stream	*Diploneis* sp. (diatom)

Table 9.2-13 Lowest Level Taxonomic Richness of the Periphyton Communities in the Kiggavik Project Area, 2009

Sub-Basin	Watercourse	Cyanobacteria	Chlorophyte	Chrysophyte & Cryptophyte	Dinoflagellate	Diatom	Total
Willow Lake	Northeast Inflow of Pointer Lake	6	7	0	0	16	**29**
	Rock/Willow Stream	5	7	0	0	22	**34**
	Willow/Judge Sissons Stream	3	4	0	0	11	**18**
Aniguq River	Aniguq River	7	11	1	1	23	**43**
		1	7	0	0	23	**31**

Table 9.2-14 Periphyton Taxa Unique to Individual Streams within the Kiggavik Project Area, 2009

Sub-Basin	Watercourse	Taxa
Willow Lake	Northeast Inflow of Pointer Lake	*Aulacoseira italica* (Diatom)
		Encocconeis flexella (Diatom)
		Cladophora (Diatom)
		Dichtyosphaerium (Chlorophyte)
		Chroococcus sp. (Cyanophyte)
		Coelosphaeria sp. (Cyanophyte)
	Rock/Willow Stream	*Diploneis elliptica* (Diatom)
		Gomphonema sp. (Small) (Diatom)
		Pleurosigma sp. (Diatom)
		Rhoicosphenia curvata (Diatom)
	Willow/Judge Sissons Stream	None
Aniguq River	Aniguq River	*Achnanthidium exiguum* (Diatom)
		Asterionella formosa (Diatom)
		Cyclotella comta (Diatom)
		Diatoma vulgare (Diatom)

Table 9.2-14 Periphyton Taxa Unique to Individual Streams within the Kiggavik Project Area, 2009

Sub-Basin	Watercourse	Taxa
		Staurosirella leptostauron (Diatom)
		Tabellaria fenestrata (Diatom)
		Botryococcus (Chlorophyte)
		Euastrum (Chlorophyte)
		Oedogonium (Chlorophyte)
		Oocystis sp. (Chlorophyte)
		Spirogyra (Chlorophyte)
		Spondylosium sp. (Chlorophyte)
		Anabaena sp. (Cyanophyte)
		Gymnodinium sp1 (Dinoflagellates)

9.3 Summary

Historical phytoplankton data from 1989 to 1991 were limited. The historical phytoplankton community data indicated some inter-lake variability in phytoplankton biomass, particularly in August 1990. Chrysophytes tended to be the dominant taxonomic group; however, cyanobacteria and diatoms were also identified as dominant taxonomic groups, but this may be related to variation in the timing of sample collection (i.e., under ice versus summer open water conditions). Overall, the historical phytoplankton community data indicated lakes within the Project area exhibited characteristics typical of unproductive Canadian Shield lakes.

In general, chrysophytes were the most abundant taxonomic group in the phytoplankton communities of lakes sampled within the Project area in both 2008 and 2009. In 2008, phytoplankton community biomass was more variable both across lakes and between the two sampling seasons. With the exception of Fox Lake (2008), Andrew Lake (2009) and Sik Sik Lake (2009), cyanobacteria biomass was consistently low in lakes sampled within the Project area. Diatoms and “Other Taxa” were consistently low in abundance and biomass in all lakes. Species richness varied across lakes, with chlorophytes and chrysophytes exhibiting the greatest diversity. Several unique phytoplankton taxa were identified within various waterbodies in both 2008 and 2009; however, none of these are federally or territorially listed taxa.

In 2008 and 2009, chlorophyll *a* concentrations were within the range specified for oligotrophic lakes. In general, higher chlorophyll *a* concentrations in 2008 were observed in the summer and decreased in the fall, which is inconsistent with the pattern observed for phytoplankton biomass. This suggests that seasonal and taxonomical variation may be affecting overall chlorophyll *a* concentrations.

Historical zooplankton data from 1979 to 1991 were limited. Biomass data were absent for this period and while rotifers were identified in 1989, 1990 and 1991 samples, they were not enumerated. This group is ecologically important, but is often overlooked because of their small size. In general, the zooplankton communities were either dominated by cladocerans or calanoid copepods. However, variation in crustacean species richness is likely a reflection of differences in sampling methods (i.e., vertical tows versus stationary sampling) and locations (i.e., deep basin versus outflow areas).

In both 2008 and 2009, rotifers consistently exhibited the highest relative density in all lakes sampled within the Project area. Rotifers also accounted for the majority of the zooplankton biomass, with the exception of Fox Lake (2008) and Sik Sik Lake (2009). In both summer and fall 2008, the zooplankton community within Fox Lake was dominated by cladocerans, specifically by the large sized *Daphnia middendorffiana*. The presence of this species suggests fish predation in this lake is limited. In 2009, the zooplankton community biomass in Sik Sik Lake was co-dominated by calanoids and cladocerans. *Leptodiaptomus sicilis* (calanoid) and *D. middendorffiana* were the predominant species, suggesting fish predation in this lake is limited. Several unique zooplankton taxa were identified within various waterbodies in both 2008 and 2009; however, none of these are federally or territorially listed taxa.

In both 2008 and 2009, chlorophytes had the highest density in the majority of stream periphyton communities within the Project area, although a number of streams within the Lower Lake sub-basin had high densities of diatoms. Cyanobacteria were present in variable numbers within all streams within the Project area. Chlorophytes and cyanobacteria dominated the periphyton community biomass in many of the streams; however, diatom biomass was greater in several of the streams within the Lower Lake sub-basin. Overall, lowest level taxonomic richness in periphytic communities was similar between sub-basins, with diatoms being the most taxonomically rich group within the streams in the Project area, followed by chlorophytes and cyanobacteria. Chrysophytes and cryptophytes as well as dinoflagellates were represented by a small number of taxa and were absent from several of the Project area streams. These three taxonomic groups also contributed a low proportion to the density and biomass of the periphyton community in all streams sampled within the Project area. Several unique periphyton taxa were identified within various waterbodies in both 2008 and 2009; however, none of these are federally or territorially listed taxa.

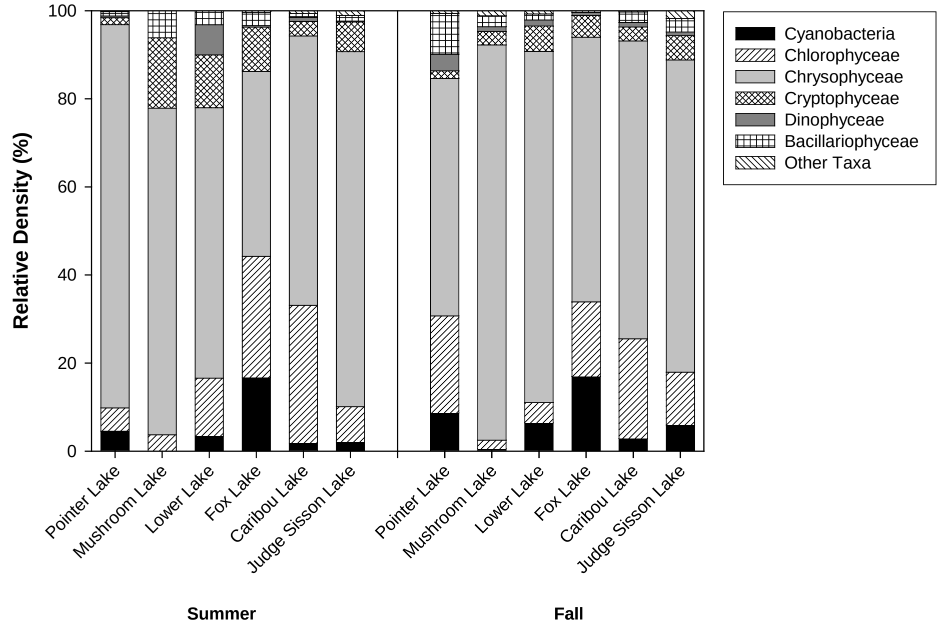


Figure 9.2-1 Phytoplankton Density in Waterbodies within the Kiggavik Project Area, 2008

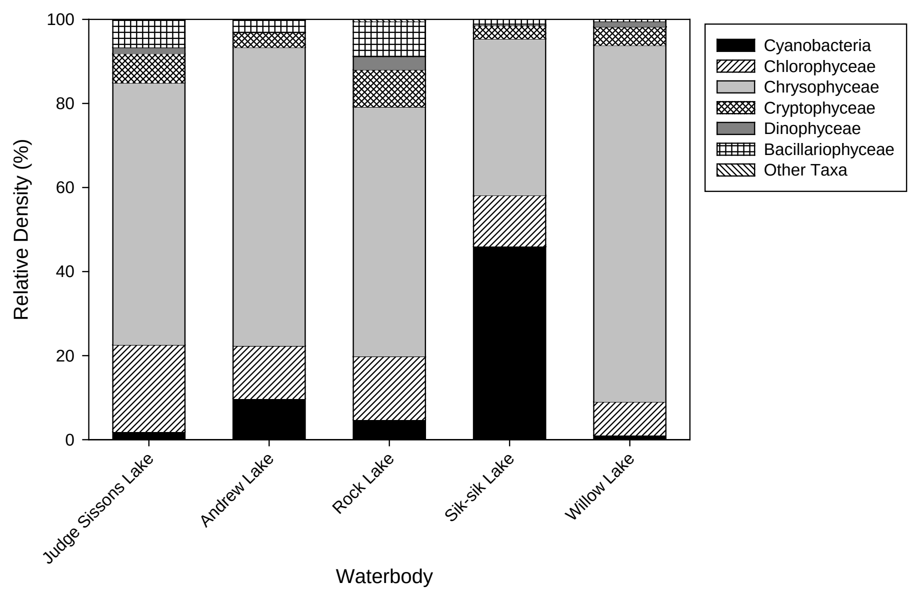


Figure 9.2-2 Phytoplankton Density in Waterbodies within the Kiggavik Project Area, 2009

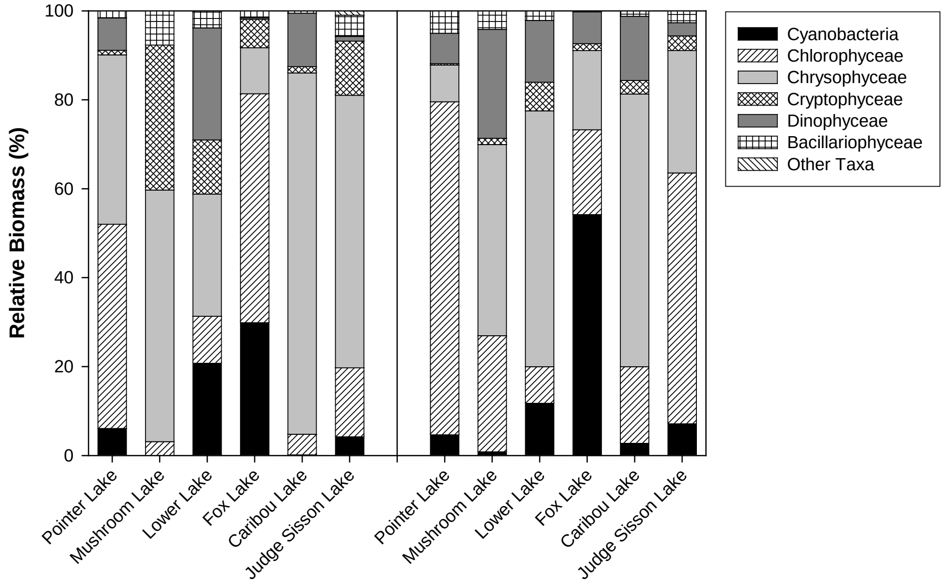


Figure 9.2-3 Phytoplankton Biomass in Waterbodies within the Kiggavik Project Area, 2008

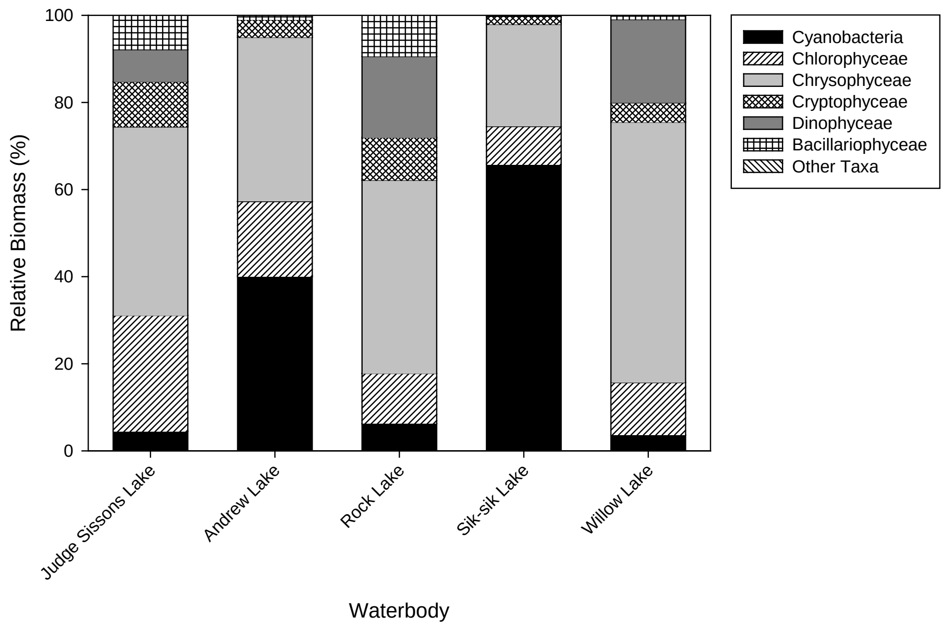


Figure 9.2-4 Phytoplankton Biomass in Waterbodies within the Kiggavik Project Area, 2008

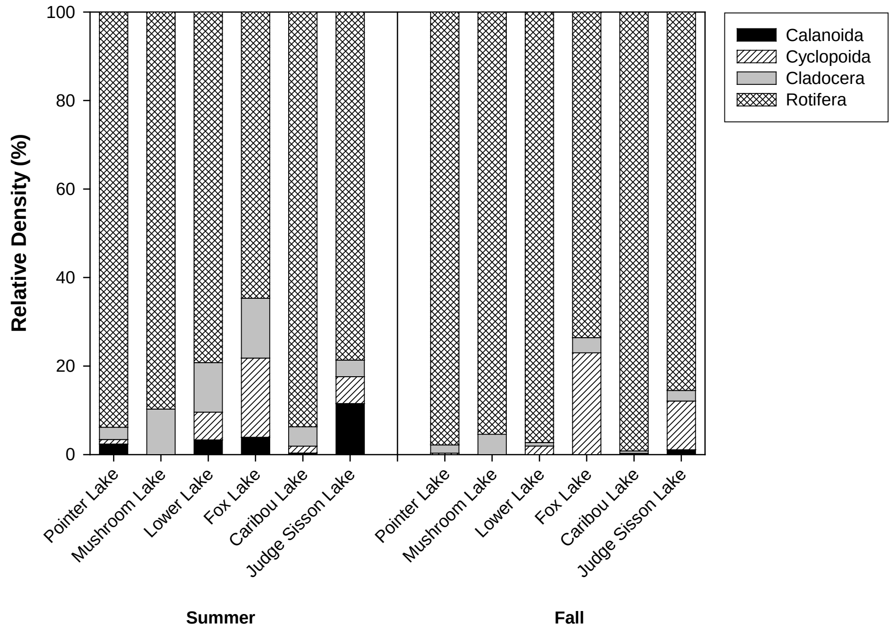


Figure 9.2-5 Zooplankton Density in Waterbodies within the Kiggavik Project Area, 2008

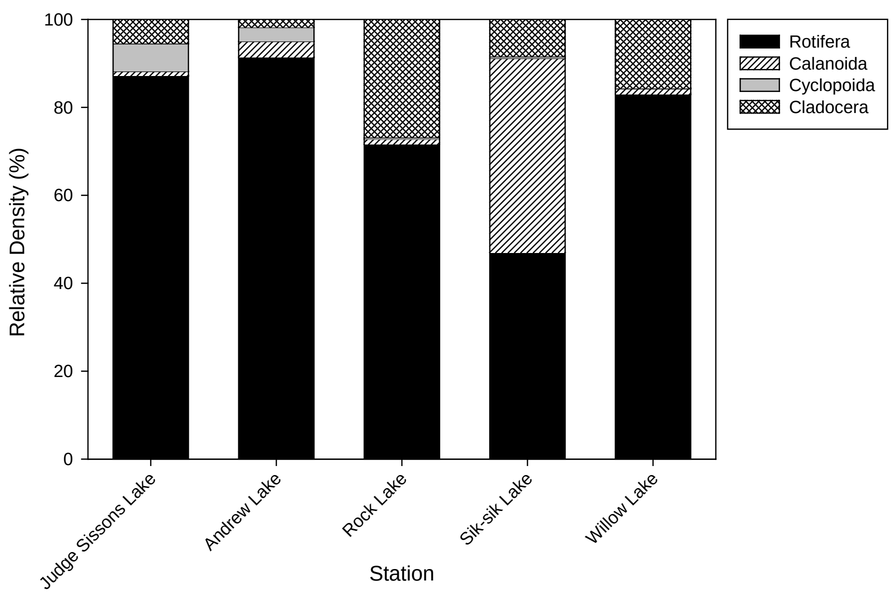


Figure 9.2-6 Zooplankton Density in Waterbodies within the Kiggavik Project Area, 2009

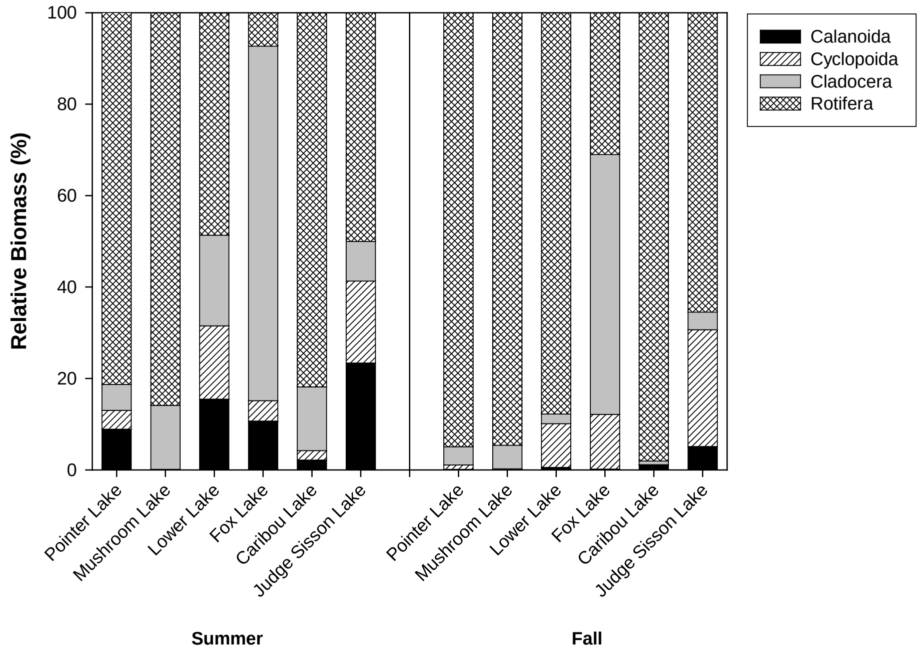


Figure 9.2-7 Zooplankton Biomass in Waterbodies within the Kiggavik Project Area, 2008

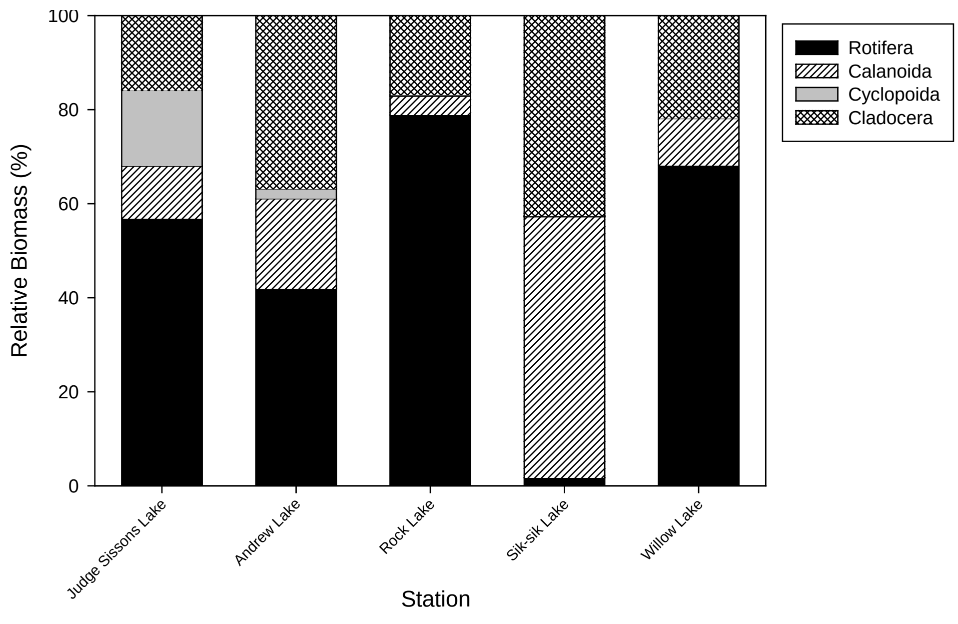


Figure 9.2-8 Zooplankton Biomass in Waterbodies within the Kiggavik Project Area, 2009

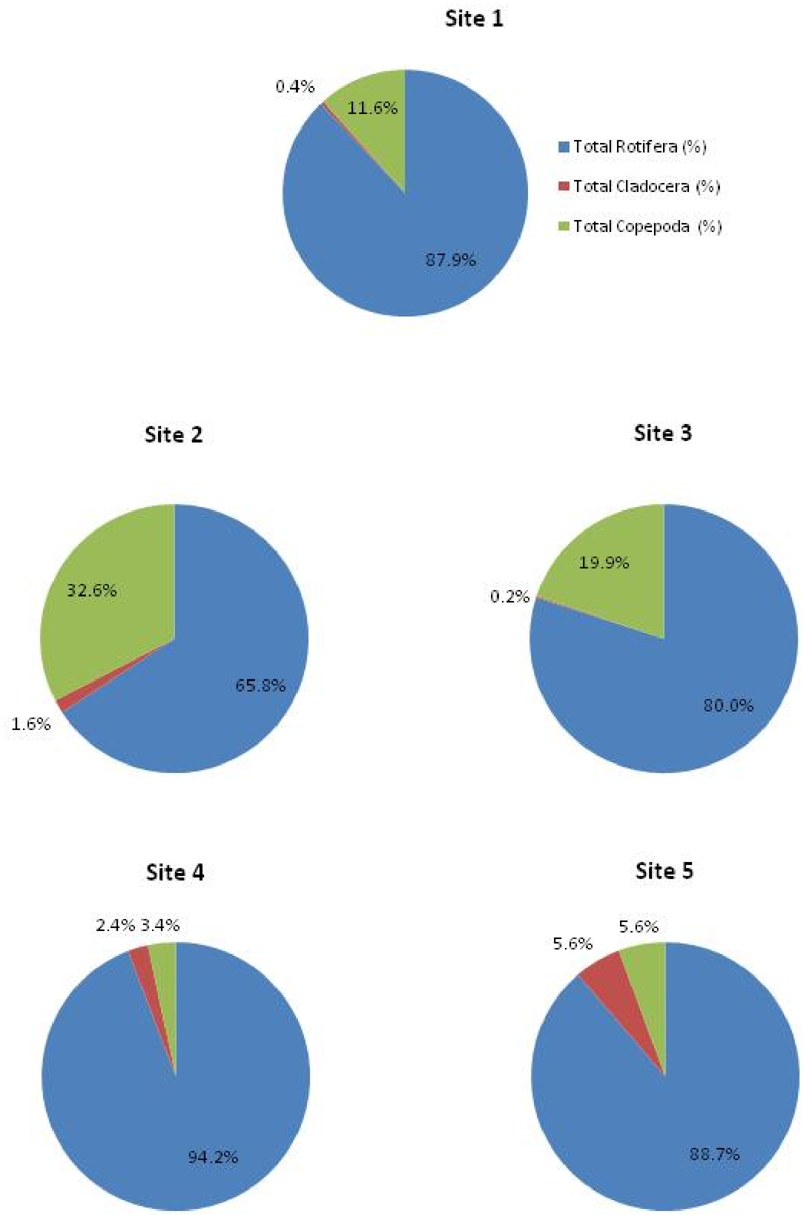


Figure 9.2-9 Zooplankton Composition (expressed as a percent of total) in Baker Lake, September 2008

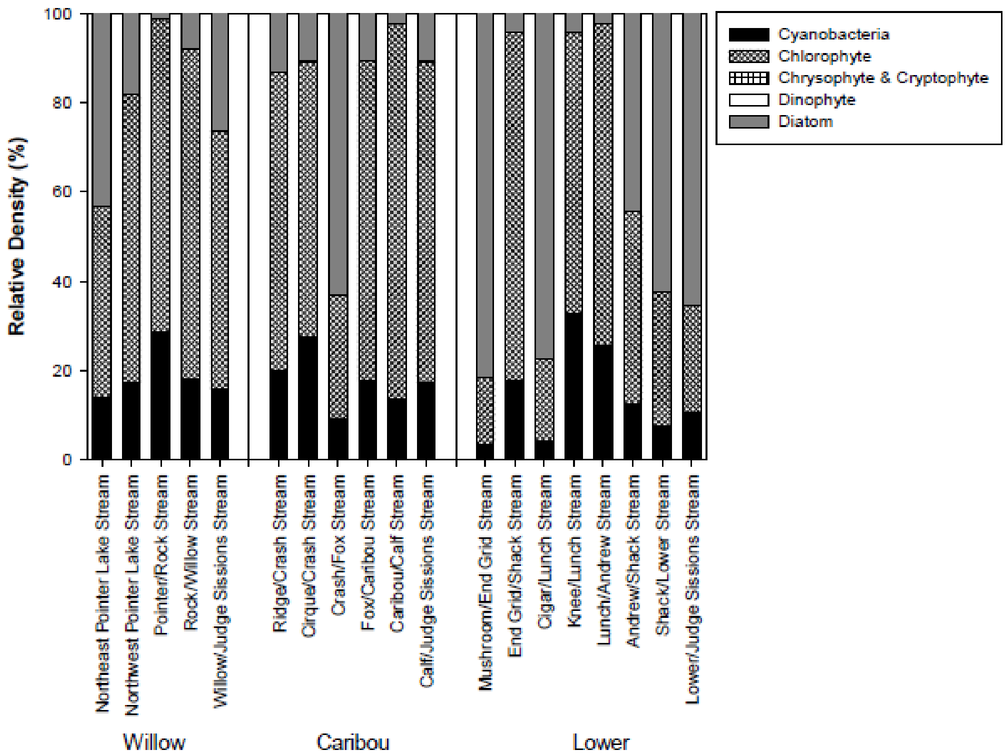


Figure 9.2-10 Relative Periphyton Density in Watercourses in Sub-Basins within the Kiggavik Project Area, 2008

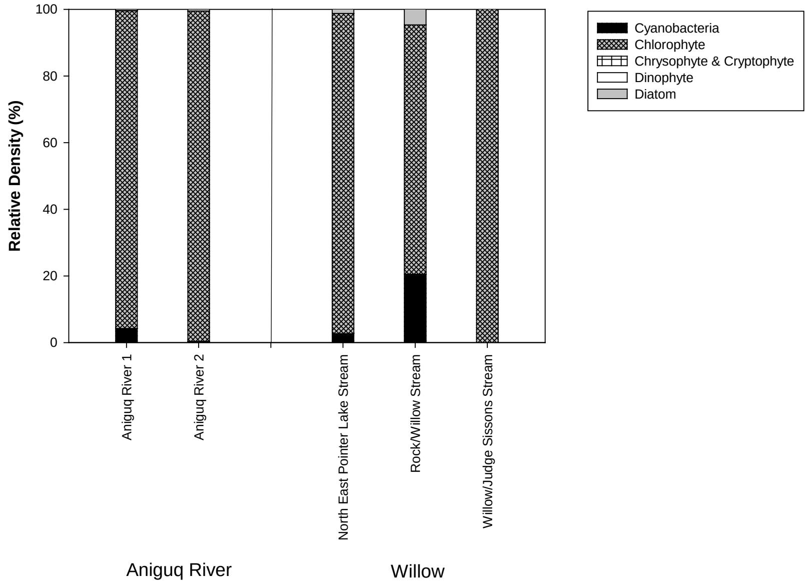


Figure 9.2-11 Relative Periphyton Density in Watercourses in Sub-Basins within the Kiggavik Project Area, 2009

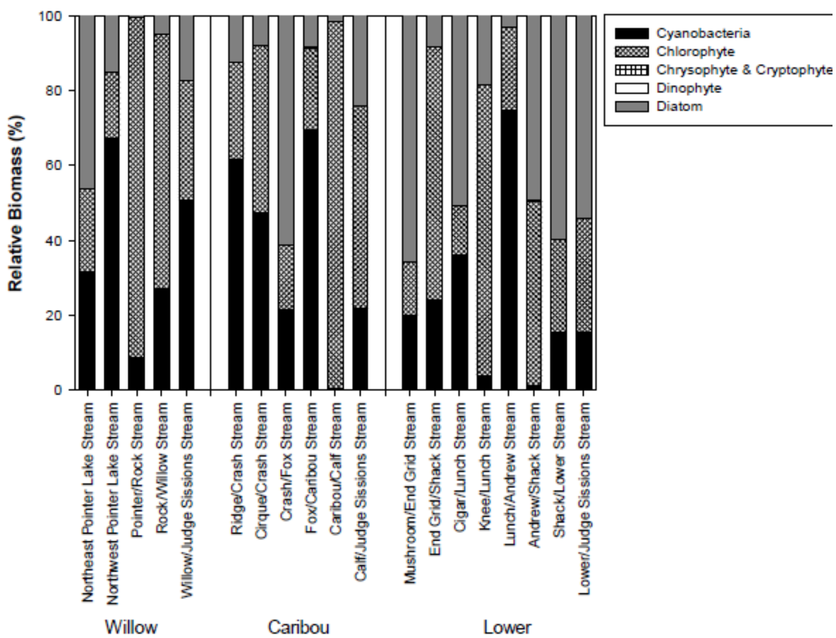


Figure 9.2-12 Relative Periphyton Biomass in Watercourses in Sub-Basins within the Kiggavik Project Area, 2008

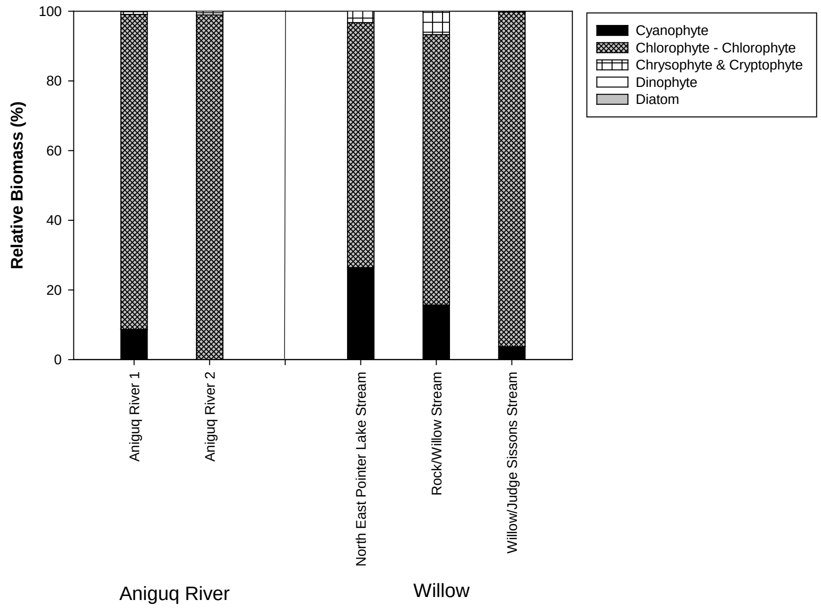


Figure 9.2-13 Relative Periphyton Biomass in Watercourses in Sub-Basins within the Kiggavik Project Area, 2009

10 Fish Habitat

Habitat assessments were carried out to document the lake morphometric measurements and classify the types and distribution of fish habitat within the Project study areas. Historical habitat information was limited to bathymetric maps for some of the lakes in the mine site Local Study Area (LSA) and some qualitative information on lake habitat. The objectives of the 2007 to 2010 study were to reduce the data gaps, to verify the accuracy of the historical bathymetric data, and to gather quantitative and qualitative fish habitat information. Habitat mapping provides an ecologically relevant inventory of the type and diversity of habitats found within the study area. The value of specific habitats to the fish species and various life-stages can then be determined. Important features examined included availability of refuge or cover habitat, over wintering or deeper water habitat, spawning habitat, and foraging habitat.

The mine site and Site Access LSA included lakes and streams presented in Table 10.0-1 and 10.0-2. The assessments conducted in 2007 to 2009, were focussed on the Willow Lake, Lower Lake, Caribou Lake, Judge Sissons Lake, and Siamese Lake sub-basins. Detailed fish habitat assessments were completed in lakes between 2007 and 2009 (Table 10.0-1). In 2008, fish habitat assessments were completed in streams (Table 10.0-2). Habitat assessments were also conducted in 2008 and 2009 in streams crossed by the proposed road corridors. In 2010, several small, isolated ponds in the Lower Lake sub-basin, and a pond and two streams in the Willow Lake sub-basin were sampled.

10.1 Overview of Studies

10.1.1 Historical Summary 1979 to 1991

Limited information regarding the physical habitat in LSA waterbodies was available in the historical documents. Bathymetric maps were available for most lakes in the LSA. These were included with the information collected during the 2007 to 2010 studies. All bathymetric maps have been included in Attachment X.IV. An habitat map for Skinny Lake was available in BEAK (1992b). This map has been included in Attachment X.VIII, Figure X.VIII-30.

10.1.2 Recent Sampling Period 2007 to 2010

The assessment of fish habitat from 2007 to 2010 was completed in accordance with the habitat mapping protocols outlined in the Golder's *Aquatic Technical Procedure 8.19-0 Lake Habitat Mapping* (unpublished file information). The entire shoreline of each waterbody was assessed except for Judge Sissons Lake, for which the habitat assessment was limited to the northern portion of the lake.

Table 10.0-1 Summary of the Lakes and Ponds Assessed for Bathymetry and Aquatic Habitat, Kiggavik Project Area, 1979 to 2010

Watershed	Sub-Basin	Waterbody	Bathymetry Map	Aquatic Habitat Map
Aniguq River	Willow Lake	Meadow Lake	1979-1986	-
		Felsenmeer Lake	1979-1986	-
		Escarpment Lake	1979-1986	-
		Drum Lake	1979-1986	-
		Lin Lake	1979-1986	-
		Scotch Lake	1979-1986	-
		Jaeger Lake	1979-1986	-
		Pointer Pond	2010	2010
		Pointer Lake	1979-1986, 2007	2007
		Sik Sik Lake	1979-1986, 2009	2007, 2009
		Rock Lake	1979-1986, 2008	2008
		Willow Lake	1979-1986	2007
	Lower Lake	Mushroom Lake	1990, 2009	2008
		Pond 1 to Pond 8	2010	2010
		End Grid Lake	2008	2007
		Smoke Lake	1990	-
		Cigar Lake	1990	2008
		Knee Lake	1990	2008
		Lunch Lake	1990	2008
		Andrew Lake	1990, 2009	2007, 2009
		Shack Lake	1990	2007
		Bear Island Lake	1990	-
		Lower Lake	1990-1991	2007
	Caribou Lake	Ridge Lake	1979-1986	2007
		Cirque Lake	1979-1986	2007
		Crash Lake	1979-1986	2007
		Fox Lake	1979-1986	2007
		Caribou Lake	1979-1986	2008

Table 10.0-1 Summary of the Lakes and Ponds Assessed for Bathymetry and Aquatic Habitat, Kiggavik Project Area, 1979 to 2010

Watershed	Sub-Basin	Waterbody	Bathymetry Map	Aquatic Habitat Map
		Calf Lake	2008	2008
	Judge Sissons Lake	Judge Sissons Lake	1979-1986, 2009 (north)	2008 (north)
	Siamese Lake	Siamese Lake	2008	2008
	Skinny Lake	Skinny Lake	1979-1986	1979-1986
	Kavisilik Lake	Kavisilik Lake	1979-1986	-
Thelon River	Squiggly Lake	Squiggly Lake	1979-1986	-
Baker Lake	Baker Lake	Baker Lake	2008, 2009	2008, 2009

Source:BEAK 1987, 1990, 1992a and 1992b presented maps produced between 1979 and 1990; Golder Associates Ltd. conducted the 2007 to 2010 surveys. Nanumi Stantec surveyed Baker Lake in 2008 and 2009.
- = no data.

Table 10.0-2 Summary of the Streams Assessed for Aquatic Habitat, Kiggavik Project Area 2008 to 2010

Watershed	Sub-Basin	Watercourse	Aquatic Habitat
Aniguq River	Willow Lake	Northeast Inflow of Pointer Lake	2008
		Upper Tributary to the Northeast Inflow of Pointer Lake	2010
		Upper Northwest Inflow of Pointer Lake	2010
		Northwest Inflow of Pointer Lake	2008
		Pointer/Rock Stream	2008
		Sik Sik/Rock Stream	2008
		Rock/Willow Stream	2008
		Willow/Judge Sissons Stream	2008
	Lower Lake	Mushroom/End Grid Lake	2008
		End Grid/Shack Stream	2008
		Cigar/Lunch Stream	2008
		Knee/Lunch Stream	2008
		Lunch/Andrew Stream	2008
		Andrew/Shack Stream	2008
		Shack/Lower Stream	2008
		Lower/Judge Sissons Stream	2008
	Caribou Lake	Ridge/Crash Stream	Flight overview only
		Cirque/Crash Stream	Flight overview only
		Crash/Fox Stream	Flight overview only
		Fox/Caribou Stream	2008
		Caribou/Calf Stream	2008
		Calf/Judge Sissons Stream	2008
	Aniguq River	Aniguq River	Flight overview only

Characteristics, such as shoreline substrate type, presence/absence of vegetation, shoreline slope, bank stability, channel units (only applicable to Lower Lake), and water depth at sampling locations were recorded on waterproof field maps. Representative photos were taken within assessed areas of each lake.

Bathymetry mapping was completed in accordance with the Golder's *Aquatic Technical Procedure 8.23-0: Basic Limnology and Bathymetric Procedures* (unpublished file information). Bathymetry measurements were completed using a Garmin GPSmap 178C Sounder. The Global Positioning System (GPS) component provided the position of the boat using satellite triangulation, while the sounding transducer provided the water depth at each location. The sounder was configured to record geo-referenced depths at five second intervals. The field crew traveled in a zigzag pattern throughout the entire lake at speeds ranging between 7 kilometres per hour (km/h) to 10 km/h. The recorded information was then transferred to geographic information system (GIS) to generate a bathymetry map.

In 2008, foreshore habitat of Baker Lake was characterized at each of five selected sites (Attachment X.I, Figure X.I-3) to document environmental values that could be affected by the development of docking facilities and an access road. At each site, two or three distinct habitat zones were identified based on substrate type and vegetation cover: a shoreline zone and one or two backshore zones. Zone lengths were variable and were typically delineated based on substrate type and vegetative cover. Substrate type and relative percentage, as well as vegetation species type and amount, were recorded along variable-length transects perpendicular to the shoreline in each zone.

Littoral habitat was characterized at site 2 (proposed dock site) during the 2009 field program. Six transects, oriented parallel to shore were assessed. Transects were spaced about 20 metres (m) apart and were situated from the shoreline out to about 150 m into the lake. Littoral conditions along each transect were document using an underwater video recorder.

10.1.2.1 Mine Site Local Study Area

Between 2007 and 2010, fish habitat mapping was completed for all lakes of the mine site LSA (Table 10.0-1).

Fish habitat mapping was completed in the following lakes in 2007:

1. Pointer, Sik Sik, and Willow lakes (Willow Lake sub-basin);
2. End Grid, Andrew, Shack, and Lower lakes (Lower Lake sub-basin); and
3. Ridge, Cirque, Crash, and Fox lakes (Caribou Lake sub-basin).

Lakes sampled in 2008 included:

- Rock Lake (Willow Lake sub-basin);
- Mushroom, Cigar, Knee, and Lunch lakes (Lower Lake sub-basin);
- Caribou and Calf lakes (Caribou Lake sub-basin);
- Judge Sissons Lake (Judge Sissons Lake sub-basin); and
- Siamese Lake (Siamese Lake sub-basin).

More detailed assessments of several lakes were completed in 2009 in response to changes in project description. Lakes included:

- Sik Sik Lake (Willow Lake sub-basin); and
- Andrew Lake (Lower Lake sub-basin).

Habitat assessments of several isolated ponds in the vicinity of Andrew Lake (Lower Lake sub-basin) were conducted in 2010. These ponds were in proximity to infrastructure associated with the proposed Andrew Lake pit. Habitat assessment of Pointer Pond located on the Northwest Inflow of Pointer Lake (Willow Lake sub-basin) was also conducted in 2010.

Bathymetry was only completed for specific lakes, primarily those that did not have bathymetry data from previous surveys. Bathymetry mapping was completed for Pointer Lake in 2007, for Rock Lake in 2008, for Sik Sik Lake in 2009, and for Pointer Pond in 2010 in the Willow Lake sub-basin. Bathymetric mapping was completed for Siamese Lake and Calf Lake in 2008. Bathymetry mapping was completed for End Grid Lake in 2008, for Mushroom and Andrew lakes in 2009, and for Andrew Lake Ponds (Pond 1 to Pond 8) in 2010 in the Lower Lake sub-basin.

In the Judge Sissons Lake sub-basin, fish habitat mapping of the northern portion of Judge Sissons Lake was completed in 2008. Bathymetry of the same portion of the lake was conducted in 2009. In addition, aerial video imagery of the Judge Sissons Lake shoreline habitat was recorded in 2008 and used to characterize shoreline habitat.

10.1.3 Stream Assessments

Fish habitat assessments were completed in streams from 2007 to 2010. The assessments were carried out in accordance with the habitat mapping protocols outlined in the Golder's *Aquatic Technical Procedure 8.5-1 Watercourse Habitat Mapping* (unpublished file information).

Using the Stream Habitat Classification and Rating System outlined in Golder's *Aquatic Technical Procedure 8.5-1 Watercourse Habitat Mapping* (unpublished file information), the stream length was separated into channel units (i.e., riffle, run, or pools) depending on the channel characteristics such as flow velocity, water depth, and substrate. For each channel unit, additional characteristics such as wetted and bankful widths, shoreline substrate type, presence/absence of fish cover, shoreline slope, and bank stability were recorded on waterproof field maps and forms. Representative photos were taken within assessed areas. Waypoints (geographic coordinates) were recorded in a GPS for the upper and lower end of each habitat unit.

The entire length of each stream in the Willow Lake, Lower Lake, and Caribou Lake sub-basins was assessed (Table 10.0-2), except for three stream reaches upstream of Fox Lake. For each of the stream crossings along the proposed all-weather and winter road corridors, the habitat was assessed along a portion of stream extending about 100 m upstream to 1000 m downstream of the proposed crossing. The length of channel assessed varied with the stream width.

10.1.4 Data Entry and Data Analysis

Fish habitat information was recorded on field forms and field maps. Fish habitat data and waypoints from the GPS were then transferred to a GIS to create habitat maps.

Bathymetry measurements were transferred from the depth sounder to a field laptop. Data was screened for double depth values recorded at the same Universal Transverse Mercator (UTM) coordinates and locations without depth values. Only one depth per location was kept and locations without depth values were removed from the digital file prior to generating the bathymetry map. The digital data was then uploaded to the GIS.

10.1.5 Quality Assurance/Quality Control

Detailed specific work instructions were provided to Golder field personnel prior to the field programs to help ensure program and sampling success. Fish habitat assessments were conducted according to the Golder's *Aquatic Technical Procedure 8.19-0 Lake Habitat Mapping* (unpublished file information) and *Aquatic Technical Procedure 8.5-1 Watercourse Habitat Mapping* (unpublished file information). Bathymetric surveys were conducted according to Golder's *Aquatic Technical Procedure 8.23-0: Basic Limnology and Bathymetric Procedures* (unpublished file information).

Detailed field notes were recorded in waterproof field notebooks and on pre-printed waterproof lake outline maps. Data collected during the field trip underwent a variety of thorough individual quality assurance/quality control (QA/QC) checks. Field data sheets were verified at the end of each day for completeness and accuracy. Following data entry, all data sets underwent an additional 100% transcriptional QA/QC check.

10.2 Results

The results of the habitat characterization are summarized in the following sections. Bathymetric maps are provided in Attachment X.IV (Limnology). Habitat maps for lakes and streams are provided in Attachments X.VIII. Detailed lake habitat data are provided in Attachment X.VIII, Table X.VIII-1. Detailed stream habitat data are provided in Attachment X.VIII, Table X.VIII-2. The results of the habitat assessments at proposed stream crossing locations are found in Attachment X.VIII, Table X.VIII-3.

10.2.1 Lakes of the Mine Site Local Study Area

A brief summary of the habitat characteristics is provided in the following sections.

10.2.1.1 Willow Lake Sub-Basin

Pointer Pond

Pointer Pond is located on the Northwest Inflow to Pointer Lake, about 2.4 km upstream from Pointer Lake. A complete habitat assessment of Pointer Pond could not be done in the spring 2010 sampling session as ice extended over the north-western shoreline and into the pond. The remaining shoreline habitat and bathymetry information was collected in the fall of 2010. In spring 2010, maximum depth was 4.5 m (Attachment X.IV, Figure X.IV-7). The surface area was 3.09 hectare (ha) and the shoreline perimeter was 815 m (Attachment X.VIII, Table X.VIII-1). Shoreline development index was 1.3, due to the elongated shape of the pond.

The pond is located at the base of a rocky outcrop and the slope along the north and northwest shoreline was flat to moderate near the shore and moderately steep further away from the pond (Attachment X.VIII, Figure X.VIII-1). The slope was moderately high along the northeast and eastern shoreline, becoming flatter toward the south. Shoreline vegetation included grasses and small shrubs, as well as moss on the northwest shoreline. Substrate near the shoreline consisted of a mixture of cobble and boulder with occasional presence of gravel, sand, or silt. Open water substrate consisted primarily of boulder and cobble with patches of sand. Cover habitat consisted largely of interstitial spaces in the coarse substrate and a large area of inundated vegetation along the southwest shoreline of the pond (near the outflow). Emergent and submergent vegetation were also present in the northwest area of the pond.

There was a defined channel and wetland area draining into the lake (refer to the upper reach of the Northwest Inflow of Pointer Lake). There was a defined outlet channel that connected the pond to the lower reach of the Northwest Inflow to Pointer Lake. Given the small size of the pond, it is unlikely that large-bodied fish would overwinter in the pond.

Pointer Lake

Bathymetric data were collected in Pointer Lake during the fall 2007 field program (Attachment X.IV, Figure X.IV-8). At the time of the assessment, the surface area of the lake was 393 ha, the shoreline perimeter was 11,756 m, and the maximum water depth was 3.0 m (Attachment X.VIII, Table X.VIII-1). Pointer Lake has a shoreline development index of 1.7, which is due to the elongated shape of the lake and the presence of bays.

Pointer Lake shoreline substrate consisted primarily of cobble and boulder, with patches of sand (Attachment X.VIII, Figure X.VIII-2). The shoreline slope was predominantly flat. The shoreline vegetation was primarily grasses and low shrubs. Cover habitat consisted primarily of interstitial spaces in the coarse substrate and some areas with emergent vegetation.

Sik Sik Lake

Bathymetric data were collected in Sik Sik Lake during the summer of 2009 field program (Attachment X.IV, Figure X.IV-9). The surface area of Sik Sik Lake was 17.5 ha and the shoreline perimeter was 2,155 m (Attachment X.VIII, Table X.VIII-1). Sik Sik Lake has a shoreline development index of 1.5. Sik Sik Lake has an elongated shape with the deepest area located in mid lake. At the time of the assessment in 2007, the maximum water depth recorded at the sampling stations was 1.7 m. Ice measurements were taken in May 2009 at which time the ice was about 2 m thick and the lake was frozen to the bottom.

Sik Sik Lake shoreline substrate consisted primarily of boulder and cobble (Attachment X.VIII, Figure X.VIII-3). The shoreline slope was predominantly flat. The shoreline vegetation consisted primarily of grasses and low shrubs. Cover habitat consisted primarily of interstitial space in substrates with some inundated vegetation.

Rock Lake

Bathymetric data were collected in Rock Lake during the summer 2008 field program (Attachment X.IV, Figure X.IV-10). At the time of the bathymetry assessment the surface area of the lake was 32.4 ha and the shoreline perimeter was 3,648 m. Rock Lake has a shoreline development index of 1.8, which indicates a more complex shoreline as there are several bays. The maximum water depth was 1.5 m. In May 2009 the ice was about 1.5 m thick and the lake was frozen to the bottom (Attachment X.VIII, Table X.VIII-1).

Rock Lake shoreline substrate consisted primarily of cobble and boulder, with areas of sand, silt, and gravel (Attachment X.VIII, Figure X.VIII-4). The shoreline slope was predominantly flat. The shoreline vegetation was dominated by grass with some patches of low shrubs. Cover habitat consisted primarily of interstitial spaces in substrate, with an area of submergent vegetation.

Willow Lake

Based on the available bathymetric map and the digital NTS map coverage, the surface area of Willow Lake was 54.9 ha and the shoreline perimeter was approximately 4,321 m (Attachment X.IV, Figure X.IV-11). At the time of the assessment the maximum water depth recorded at the sampling stations was 2.0 m (Attachment X.VIII, Table X.VIII-1). Ice thickness measured in May 2009 was about 2 m and the lake was frozen to the bottom. Willow Lake has a shoreline development index of 1.6, which is mainly due to the elongated shape of the lake rather than an abundance of bays.

Willow Lake shoreline substrate consisted primarily of boulder and cobble (Attachment X.VIII; Figure X.VIII-5). The shoreline slope was predominantly flat. The shoreline vegetation consisted primarily of grasses and low shrubs. Cover habitat consisted primarily of interstitial spaces in substrate, with some areas of inundated vegetation.

10.2.1.2 Lower Lake Sub-Basin

Mushroom Lake

Bathymetric data were collected in Mushroom Lake during the summer 2009 field program (Attachment X.IV, Figure X.IV-12). The surface area of Mushroom Lake was 32 ha, the shoreline perimeter was 3,416 m, and a maximum depth of 8.9 m was measured (Attachment X.VIII, Table X.VIII-1). Mushroom Lake has a shoreline development index of 1.7, which is identical to Pointer Lake. Ice thickness in May 2009 was 2 m.

The Mushroom Lake shoreline substrate consisted primarily of cobble and boulder, with areas of sand and gravel located on the northwest and southern shorelines (Attachment X.VIII, Figure X.VIII-6). The shoreline slope was predominantly flat, with an area on the northeast shoreline with a moderate to moderately steep slope. The shoreline vegetation was dominated by grass with some patches of low shrubs and some sand beach areas. Cover habitat consisted primarily of interstitial spaces in substrate.

Andrew Lake Ponds

Several small, isolated ponds are located near Andrew Lake. These ponds were sampled as they would be affected by infrastructure associated with the proposed Andrew Lake pit.

Pond 1

Bathymetric data were collected in Pond 1 during the spring 2010 field program (Attachment X.IV, Figure X.IV-13). The surface area was 9.94 ha and the shoreline perimeter was 1,897 m (Attachment X.VIII, Table X.VIII-1). Shoreline development index was 1.7, due to the elongated shape of the pond and the presence of bays. The maximum water depth was 1.5 m at the time of the survey.

The shoreline slope was flat. The shoreline vegetation was primarily grasses and low shrubs (Attachment X.VIII, Figure X.VIII-7). Substrate near the shoreline consisted primarily of cobble and boulder, with patches of sand. Open water substrate consisted of a mixture of boulder, sand, and cobble areas. Cover habitat consisted of interstitial spaces in the coarse substrate and some areas with emergent vegetation.

There was no defined channel connecting this pond to the mainstem stream in the Lower Lake sub-basin. The shallow nature of the lake, combined with ice thickness, suggests that the pond would not provide overwintering habitat.

Pond 2

The surface area was 6.56 ha and the shoreline perimeter was 1,348 m (Attachment X.VIII, Table X.VIII-1). Shoreline development index was 1.5, due to the elongated shape of the pond and the presence of bays. Maximum depth of Pond 2 was 1.2 m at the time of the survey (Attachment X.IV, Figure X.IV-14).

The shoreline slope was flat. Shoreline vegetation included grasses and low shrubs (Attachment X.VIII, Figure X.VIII-8). Substrate near the shoreline consisted of a mixture of boulder and cobble with areas of sand and silt at the north end of the pond. Open water substrate was predominately sand and boulder. Cover habitat consisted of inundated vegetation, emergent vegetation, and interstitial spaces in the coarse substrate.

There was no defined channel connecting this pond to the mainstem stream in the Lower Lake sub-basin. The shallow nature of the lake, combined with ice thickness, suggests that the pond would not provide overwintering habitat.

Pond 3

The surface area was 0.26 ha and the shoreline perimeter was 245 m (Attachment X.VIII, Table X.VIII-1). Shoreline development index was 1.3, due to the slightly oval shape of the pond and the presence of small bays. The maximum depth of Pond 3 was 0.5 m at the time of the survey (Attachment X.IV, Figure X.IV-15).

Shoreline slope was flat. Shoreline vegetation included grasses and low shrubs (Attachment X.VIII, Figure X.VIII-9). Substrate near the shoreline consisted primarily of silt deposed on ice (i.e., permafrost at 0.5 m deep) or mixed with sand. Cobble and boulder were also present near the shoreline. Open water substrate was a mixture of boulder and cobble with areas of sand and silt. Cover habitat consisted largely of emergent vegetation with some areas of interstitial spaces available in the coarse substrate.

There was no defined channel connecting this pond to the mainstem stream in the Lower Lake sub-basin. The shallow nature of the lake, combined with ice thickness, suggests that the pond would not provide overwintering habitat.

Pond 4

The surface area was 0.67 ha and the shoreline perimeter was 354 m (Attachment X.VIII, Table X.VIII-1). Shoreline development index was 1.2, due to the oval shape of the pond. The maximum depth of Pond 4 was 0.7 m at the time of the survey (Attachment X.IV, Figure X.IV-16).

Shoreline slope was flat. Shoreline vegetation included grasses and low shrubs (Attachment X.VIII, Figure X.VIII-10). Substrate near the western shoreline consisted primarily of cobble, gravel and boulder, with patches of silt and sand. Near the eastern shoreline, substrate consisted primarily of silt and sand substrate with some boulder. Open water substrate consisted of a mixture of cobble, sand, gravel, and boulder. Cover habitat consisted primarily of interstitial spaces in the coarse substrate and some areas with emergent vegetation.

There was no defined channel connecting this pond to the mainstem stream in the Lower Lake sub-basin. The shallow nature of the lake, combined with ice thickness, suggests that the pond would not provide overwintering habitat.

Pond 5

Surface area was 1.62 ha and the shoreline perimeter was 615 m (Attachment X.VIII, Table X.VIII-1). Shoreline development index was 1.4, due to the elongated shape of the pond. The maximum depth of Pond 5 was 1.0 m at the time of the assessment (Attachment X.IV, Figure X.IV-17).

Shoreline slope was flat. Shoreline vegetation included grasses and low shrubs (Attachment X.VIII, Figure X.VIII-11). Substrate consisted of a mixture of cobble with silt, sand or boulder along the northern shore; a mixture of silt with gravel and cobble along the eastern shore; and a mixture of sand with cobble and gravel along the southern shoreline. Silt and sand substrate was dominant throughout the open water area, although there were patches of boulder, cobble and gravel also present. Cover habitat consisted largely of emergent vegetation and inundated vegetation (particularly along the northern shoreline). Interstitial spaces in the coarse substrate were also present along the northern shoreline of the pond.

There was no defined channel connecting this pond to the mainstem stream in the Lower Lake sub-basin. The shallow nature of the lake, combined with ice thickness, suggests that this pond would not provide overwintering habitat.

Pond 6

Surface area was 1.76 ha and the shoreline perimeter was 636 m (Attachment X.VIII, Table X.VIII-1). Shoreline development index was 1.4, due to the presence of a bay on the west side of the lake. Maximum water depth of Pond 6 was 1.2 m at the time of the survey (Attachment X.IV, Figure X.IV-18).

Shoreline slope was flat. Shoreline vegetation included grasses and low shrubs (Attachment X.VIII, Figure X.VIII-12). Substrate in much of Pond 6 consisted of organic material, silt and sand with a patch of cobble, gravel, and boulder along the north shoreline. Open water substrate was primarily silt and sand with some small patches of cobble, gravel, and boulder. Cover habitat consisted primarily of inundated and emergent vegetation. Interstitial spaces in the coarse substrate were also present along the northern shore.

There was no defined channel connecting this pond to the mainstem stream in the Lower Lake sub-basin. The shallow nature of the lake, combined with ice thickness, suggests that this pond would not provide overwintering habitat.

Pond 7

Surface area was 6.53 ha and the shoreline perimeter was 1,102 m (Attachment X.VIII, Table X.VIII-1). Shoreline development index was 1.2, due to the elongated shape of the pond. At the time of the assessment, the maximum depth in Pond 7 was 1.2 m (Attachment X.IV, Figure X.IV-19).

Shoreline slope was flat. Shoreline vegetation included grasses and small shrubs (Attachment X.VIII, Figure X.VIII-13). Substrate near the shoreline consisted predominantly of silt and sand with several patches of cobble and boulder. Sand was the dominant substrate throughout much of the open water area, while boulder, cobble and gravel were subdominant. Cover habitat consisted largely of inundated vegetation and emergent vegetation. Interstitial spaces in the coarse substrate were also present.

There was an area on the west end of the pond that appeared to be an inflow area. There were two areas on the east side of the lake, which may be discharge channels (Attachment X.VIII,

Figure X.VIII-13). None of these channels were defined and there was not a contiguous channel connecting Pond 7 to other waterbodies in the Lower Lake sub-basin. The shallow nature of the lake, combined with ice thickness, suggests that this pond would not provide overwintering habitat.

Pond 8

Surface area was 0.44 ha and the shoreline perimeter was 259 m (Attachment X.VIII, Table X.VIII-1). Shoreline development index was 1.1, due to the round shape of the pond. The maximum water depth in Pond 8 was 0.7 m at the time of the habitat assessment (Attachment X.IV, Figure X.IV-20).

Shoreline slope was flat. Shoreline vegetation included of grasses and low shrubs (Attachment X.VIII, Figure X.VIII-14). Substrate near the shoreline consisted primarily of organic material and silt, with patches of sand, gravel and clay occurring in isolated areas. Open water substrate consisted primarily of sand and silt with some patches of clay. Cover habitat consisted primarily of emergent vegetation and large areas of inundated vegetation.

There was no defined channel connecting this pond to the mainstem stream in the Lower Lake sub-basin. The shallow nature of the lake, combined with ice thickness, suggests that the pond would not provide overwintering habitat.

End Grid Lake

Bathymetry data were collected in End Grid Lake during the summer 2008 field program (Attachment X.IV, Figure X.IV-21). The surface area of the lake was 13.2 ha and the shoreline perimeter was 1,551 m. The maximum water depth was 1.4 m (Attachment X.VIII, Table X.VIII-1). End Grid Lake has a shoreline development index of 1.2, which indicates that it is almost round.

The shoreline substrate consisted primarily of sand and organics, with cobble and boulder also present (Attachment X.VIII, Figure X.VIII-15). The shoreline slope was predominantly flat. Shoreline vegetation was primarily grasses. Cover habitat consisted primarily of interstitial spaces in substrate with some inundated vegetation.

Cigar Lake

Cigar Lake is the largest lake in the Lower Lake sub-basin. The surface area of Cigar Lake was 113 ha and the shoreline perimeter was 7,590 m. Cigar Lake has a shoreline development index of 2.0, which is due to the elongated shape of the lake. At the time of the assessment in 2008, the maximum depth recorded at the sampling stations was 3.6 m (Attachment X.IV, Figure X.IV-23; Attachment X.VIII, Table X.VIII-1).

Cigar Lake shoreline substrate consisted primarily of cobble and boulder, with areas of gravel (Attachment X.VIII, Figure X.VIII-16). The shoreline slope was predominantly flat, with areas on the west shoreline exhibiting a moderate to moderately high slope. The shoreline vegetation was dominated by grass with some patches of low shrubs. Cover habitat consisted primarily of interstitial spaces in substrate, with limited amount of submergent vegetation.

Knee Lake

The surface area of Knee Lake was 34.9 ha and the shoreline perimeter was 3,331 m. Knee Lake has a shoreline development index of 1.6, which is due to the elongated shape of the lake and the presence of some small bays. At the time of the assessment in 2008, the maximum depth at the sampling stations was 0.8 m (Attachment X.IV, Figure X.IV-24; Attachment X.VIII, Table X.VIII-1).

Knee Lake shoreline substrate consisted primarily of sand and gravel, with cobble, boulder, silt, and organic material present (Attachment X.VIII, Figure X.VIII-17). The shoreline slope was predominantly flat, with an area on the west shoreline with moderate slope. The shoreline vegetation was dominated by grass with some patches of low shrubs. Shoreline cover habitat consisted primarily of interstitial spaces in substrate, with inundated vegetation on the southwest shoreline.

Lunch Lake

The surface area of Lunch Lake was 77.8 ha and the shoreline perimeter was 4,492 m. Lunch Lake has a shoreline development index of 1.4. At the time of the assessment in 2008, the maximum depth recorded was 1.6 m (Attachment X.IV, Figure X.IV-24; Attachment X.VIII, Table X.VIII-1).

Lunch Lake shoreline substrate consisted primarily of boulder and silt with cobble, gravel, sand and organic material (Attachment X.VIII, Figure X.VIII-18). The shoreline slope was predominantly flat. The shoreline vegetation was dominated by grass with some patches of low shrubs. Shoreline cover habitat consisted primarily of interstitial spaces in substrate.

Andrew Lake

Bathymetric data were collected in Andrew Lake in the summer 2009 field program (Attachment X.IV, Figure X.IV-25). The surface area of Andrew Lake was 54 ha and the shoreline perimeter was 5,029 m. Andrew Lake has a shoreline development index of 1.9, which is identical to Lower Lake. At the time of the assessment in 2009, the maximum water depth recorded at the sampling stations was 1.0 m. An assessment of overwintering conditions was undertaken in May 2009; ice thickness was about 1.0 m and the lake was frozen to the bottom (Attachment X.VIII, Table X.VIII-1).

Andrew Lake shoreline substrate consisted primarily of sand and cobble, with boulders (Attachment X.VIII, Figure X.VIII-19). The shoreline slope was predominantly flat. Shoreline vegetation was primarily grasses and low shrubs. Shoreline cover consisted primarily of interstitial spaces in substrate with some areas of inundated vegetation.

Shack Lake

The surface area of the lake was 60 ha with a shoreline perimeter of 4,983 m. Shack Lake has a shoreline development index of 1.8, which is mainly due to the elongated shape of the lake. At the time of the assessment in 2007, the maximum water depth was 1.6 m (Attachment X.IV, Figure X.IV-28; Attachment X.VIII, Table X.VIII-1).

Shack Lake shoreline substrate consisted primarily of sand and boulders, with cobble also present (Attachment X.VIII, Figure VIII-20). The shoreline slope was predominantly flat. The shoreline vegetation was primarily grasses and low shrubs with sand beach areas. Shoreline cover consisted primarily of interstitial spaces in substrate with inundated vegetation.

Lower Lake

The surface area was 49 ha and the shoreline perimeter was 4,828 m. Lower Lake has a shoreline development index of 1.9, which is mainly due to the elongated shape of the lake. At the time of the assessment in 2007, the maximum water depth recorded was 1.4 m (Attachment X.IV, Figure X.IV-28; Attachment X.VIII, Table X.VIII-1).

The lake is divided into north and south basins by a channel about 500 m long and 75 m wide. The channel consisted of run and riffle stream habitat. Substrate within the channel was cobble and boulder, with some inundated vegetation present.

Lower Lake shoreline substrate consisted primarily of cobble and boulder, with some sand and organic material also present (Attachment X.VIII, Figure X.VIII-21). The shoreline slope was predominantly flat. Shoreline vegetation was primarily grasses. Shoreline cover consisted primarily of interstitial spaces in substrate and areas with inundated vegetation.

10.2.1.3 Caribou Lake Sub-Basin

Ridge Lake

The surface area of Ridge Lake was 16.7 ha and the shoreline perimeter was 2,643 m. The lake has a shoreline development index of 1.8, which is due to its elongated shape. At the time of the habitat assessment in 2007, the maximum water depth recorded at the sampling stations was 7.1 m (Attachment X.IV, Figure X.IV-29; Attachment X.VIII, Table X.VIII-1).

Ridge Lake shoreline substrate consisted primarily of cobble and boulder (Attachment X.VIII, Figure X.VIII-22). The shoreline slope was predominantly flat. The shoreline vegetation was minimal and shoreline cover consisted primarily of interstitial spaces in substrate.

Cirque Lake

The surface area of Cirque Lake was 5.6 ha and the shoreline perimeter was 946 m. Cirque Lake has a shoreline development index of 1.1, as the waterbody is almost round. At the time of the habitat assessment in 2007, the maximum water depth recorded at the sampling stations was 5.0 m (Attachment X.IV, Figure X.IV-30; Attachment X.VIII, Table X.VIII-1).

Cirque Lake shoreline substrate consisted primarily of cobble and boulder, with small amounts of gravel also present (Attachment X.VIII, Figure X.VIII-23). The shoreline exhibited predominantly low slopes, with higher slopes present on the north shore. The shoreline vegetation was primarily grasses. Shoreline cover consisted primarily of interstitial spaces in substrate with some inundated vegetation.

Crash Lake

The surface area of the lake was 8.1 ha and the shoreline perimeter was 1,078 m. Crash Lake has a shoreline development index of 1.1, which is identical to Cirque Lake. The maximum depth reported on the bathymetric map for Crash Lake was 2.0 m. At the time of the habitat assessment in 2007, the maximum water depth recorded at the sampling stations was 1.0 m (Attachment X.IV, Figure X.IV-31; Attachment X.VIII, Table X.VIII-1).

Crash Lake shoreline substrate consisted primarily of silt and sand, with occasional boulders present (Attachment X.VIII, Figure X.VIII-24). The shoreline slope was predominantly flat. The shoreline vegetation was primarily grasses and low shrubs. Shoreline cover consisted primarily of interstitial space in the coarse substrates.

Fox Lake

The surface area of the lake was 128 ha and the shoreline perimeter was 5,194 m. Fox Lake is round in shape and has a shoreline development index of 1.3, which is similar to Calf Lake. The maximum water depth recorded at the sampling stations was 2.6 m (Attachment X.IV, Figure X.IV-32; Attachment X.VIII, Table X.VIII-1).

The Fox Lake shoreline substrate consisted primarily of cobble and boulder, with sand and gravel also present (Attachment X.VIII, Figure X.VIII-25). The shoreline slope was low. The shoreline vegetation consisted primarily of grasses with a sand beach area. Shoreline cover consisted of interstitial spaces in the coarse substrate.

Caribou Lake

The surface area of Caribou Lake was 341 ha and the shoreline perimeter was 14,485 m. Caribou Lake has a shoreline development index of 2.2, which is mainly due to the elongated shape of the lake rather than an abundance of bays. The maximum water depth recorded at the sampling stations was 2.7 m (Attachment X.IV, Figure X.IV-33; Attachment X.VIII, Table X.VIII-1).

Caribou Lake shoreline substrate consisted primarily of cobble and boulder, with occasional deposits of sand also present (Attachment X.VIII, Figure X.VIII-26). The shoreline slope was predominantly flat, with moderate slope on the east shoreline. The shoreline vegetation was dominated by grass with some patches of low shrubs. Shoreline cover consisted primarily of interstitial space in substrates. There was a high concentration of coarse substrates on the western shoreline and near the inflow of the Fox/Caribou Stream.

Calf Lake

The surface area of the lake was 35.8 ha and the shoreline perimeter was 2,662 m. Calf Lake is almost round and had a low (1.3) development index. The maximum water depth was 1.1 m (Attachment X.IV, Figure X.IV-34; Attachment X.VIII, Table X.VIII-1).

The Calf Lake shoreline substrate consisted primarily of cobble and boulder, with small areas of gravel and sand (Attachment X.VIII, Figure X.VIII-27). The shoreline slope was predominantly flat, with areas on the northeast shoreline exhibiting moderately high slopes. The shoreline vegetation was dominated by grass with some patches of low shrubs and inundated vegetation. Upland habitat surrounding Calf Lake was tundra. Shoreline cover consisted primarily of interstitial space in the substrate, with an area of submergent vegetation and some inundated vegetation.

10.2.1.4 Judge Sissons Lake Sub-Basin

Judge Sissons Lake

Judge Sissons Lake was the largest lake in the mine site LSA. Bathymetric data for the northern portion of the lake was collected in the summer 2009 field program (Attachment X.IV, Figures X.IV-35 and X.IV-36). The surface area of Judge Sissons Lake was 9,550 ha with a shoreline perimeter of 119,370 m. Judge Sissons Lake had the highest shoreline development index (3.4) of all the lakes evaluated in the study. The high shoreline development index is a result of the complex shape of the lake and the large bays. At the time of the assessment, the maximum depth recorded at the sampling station was about 21 m (Attachment X.VIII, Table X.VIII-1).

Habitat was assessed in the northern portion of the lake in 2008. The shoreline substrate consisted primarily of sand mixed with coarse substrate on the west shoreline. Gravel mixed with coarse substrates was the dominate substrate along the northwest and east shorelines, with several areas of cobble and boulder substrate (Attachment X.VIII, Figure X.VI-28). The shoreline slope was predominantly flat in the northwest section of Judge Sissons Lake, and ranged from low to high slopes in the northeast section of the lake. The shoreline vegetation was grass with some patches of low shrubs, and several areas of exposed cobble, boulder, gravel, or sand. Shoreline cover habitat consisted primarily of interstitial spaces in substrate, with small areas of emergent and submergent vegetation, and inundated terrestrial vegetation.

10.2.1.5 Siamese Lake Sub-Basin

A bathymetric survey was conducted in the summer 2008 field program (Attachment X.IV, Figure X.IV-37). The surface area of the lake was 2,792 ha and the shoreline perimeter was 45,877 m. Siamese Lake has a shoreline development index of 2.4, which is due to the elongated shape of the lake, composed of two distinct basins as well as the presence of several bays. The maximum water depth was 12 m (Attachment X.VIII, Table X.VIII-1).

Siamese Lake shoreline substrate consisted primarily of boulder and cobble, but also contained some large areas of exposed sand or gravel mixed with the larger substrate (Attachment X.VIII, Figure X.VI-29a and Figure X.VI-29b). The shoreline slope was predominantly flat, ranging from low to moderately high slopes in the southwest and northeast sections of the lake. Shoreline vegetation was dominated by grass with some patches of low shrubs. Shoreline cover consisted primarily of interstitial space in the substrates and small areas of inundated terrestrial vegetation.

10.2.2 Lakes in the Site Access Local Study Area

10.2.2.1 Baker Lake

Bathymetric surveys were conducted at five sites on Baker Lake. The results of the surveys indicate that Station 2 had the deepest water conditions (up to 14.4 m) and the most uniform lake bottom (Figure 10.2-1). The slope at Station 2 was steep close to shore, indicating that this site would be well suited for docking facilities and vessel traffic. While water at Station 1 was up to 13 m deep, the slope was shallow, which could prevent vessels from getting close to shore. The remaining three sites (stations 3, 4 and 5) had shallow shelves and sloped away gradually from the shoreline.

Station 1

Substrate composition and vegetation abundance was assessed along a 100 m transect that traversed two habitat zones of the foreshore: a shoreline zone and one backshore zone. The shoreline zone from the water's edge to about 5 m upslope consisted of a relatively homogeneous mix of sand, gravel, cobble and boulder, with no vegetation present. Rooted vegetation (grasses and willow) was present in high density (80% coverage) within the backshore zone (5 to 100 m upslope). Grass was the predominant species from about 12.5 to 100 m upslope (Photo 10.2-1). From 5 to 12.5 m from the water's edge, substrates were primarily cobble and gravel (70%) with smaller components of sand and boulder. From 12.5 to 100 m, the substrate became a homogenous mix of sand and gravel.

Station 2

The slope of the beach was considerably steeper than at the other survey stations (up to 66%) (Photo 10.2-2). Substrate composition and vegetation abundance was assessed along a 65 m transect that traversed three distinct zones: one shoreline zone and two backshore zones. The shoreline zone, from the lake shore to 5 m upslope, had well-mixed substrates of gravel, cobble and boulders, with no vegetation. The first backshore zone extended from 5 to 34 m from the lakeshore, with predominantly cobble (70%) substrates and smaller components of gravels and boulders. Vegetation was moderately abundant and consisted primarily of grasses (5%), moss (30%), lichen (50%) and willow (1%). The second backshore zone extended from 34 to 65 m and had a more homogenous mix of gravel, cobble, sand, and boulder substrates, with lower vegetation density (50% coverage).

Station 3

A transect 20 m long was surveyed at Station 3, in which three zones (foreshore, berm crest, and backshore) were identified. The berm crest is a transitional zone between the foreshore and the backshore. The foreshore zone, from the lake shore to 3.2 m landward and a section of the berm crest, from 10.5 to 14.2 m landward, were dominated by sand with large and small cobbles, and sparse boulders. Within the berm crest, a band of sand and fine gravel was present between 3.2 m and 10.5 m. No vegetation was present in the foreshore or berm crest zones. The backshore extended from 14.2 to 20 m from the lake shoreline, and was characterized by gravel, cobble, and boulder substrates and moderate vegetative cover. Vegetation consisted primarily of grasses (20%), moss (20%), and lichen (40%). The shoreline and backshore area had a consistent slope of about 17% (Photo 10.2-3).

Station 4

The 55 m transect at Station 4 intersected two zones. The foreshore, from the lake shoreline to about 18 m, was similar to Station 2, with primarily cobble substrates (80%), and with no vegetation. The backshore extended from 18 to 55 m and consisted almost entirely of sand (70%) with some cobble and boulders. Vegetation was not present within the backshore zone, but was noted upslope from the 55 m mark (Photo 10.2-4).

Photo 10.2-1 Foreshore substrate and vegetation composition, Site 1, September 2008, Kiggavik Project

Photo 10.2-2 Foreshore substrate and vegetation composition, Site 2, September 2008, Kiggavik Project

Photo 10.2-3 Foreshore substrate and vegetation composition, Site 3, September 2008, Kiggavik Project

Photo 10.2-4 Foreshore substrate and vegetation composition, Site 4, September 2008, Kiggavik Project

Station 5

A 98 m long transect, crossing three zones, was assessed at Station 5. Substrate in the foreshore, which extended from the lake shore to 15 m landward, consisted of relatively even proportions of sand, gravel, cobble and boulder, with no vegetation present. The first backshore zone, from 15 to 50 m landward from the shoreline, consisted of a substrate mix similar to foreshore, with 30% vegetation coverage. Willow, the predominant vegetation species, was present about 30 m from the lake shoreline. The second backshore zone extended from 50 to 98 m, and consisted of organics (60%), cobble (10%), and boulder (30%). Vegetation cover was about 60% within this zone and included lichen, mosses, willow, crowberry (*Empetrum nigrum*) and grasses (Photo 10.2-5).

Photo 10.2-5 Foreshore substrate and vegetation composition, Site 5, September 2008, Kiggavik Project

10.2.3 Streams of the Mine Site Local Study Area

10.2.3.1 Willow Lake Sub-Basin

A summary of the habitat characteristics for streams in the Willow Lake sub-basin is provided in Table 10A-1.

Northeast Inflow of Pointer Lake

A total of 5,575 m of the Northeast Inflow stream to Pointer Lake was assessed (Table 10A-1; Attachment X.VIII, Figure X.VIII-31 and Table X.VIII-2). Maximum depth recorded in the stream was about 1 m. Wetted width ranged from 0.2 to 1,000 m (an area of unconfined flow at highwater). Bankfull width ranged from 0.2 to 44 m.

The Northeast Inflow of Pointer Lake consisted primarily of run habitat with portions of riffle, flat, cascade, and pool habitats also present. Within the length of stream surveyed, habitat consisted of 4,789 m of shallow run (R3), 410 m of riffle, 211 m of shallow flat, 108 m of cascade, and 57 m of deep pool (P1). Several boulder gardens and a falls were present within the habitat units. The stream exhibited large areas of braided channel throughout its length. Shoreline slope was predominantly low. Shoreline and instream substrate consisted primarily of cobble and organic material, with patches of boulder, sand, and small amount of gravel also present. Instream cover consisted of interstitial spaces in the substrate and submerged terrestrial vegetation. Overhead cover consisted of flooded grasses and overhanging low shrubs. During the time of assessment, large areas of flooded tundra were present.

Upper Tributary to the Northeast Inflow of Pointer Lake

In summer 2009, habitat mapping of the lower reach of the tributary to the Northeast Inflow of Pointer Lake was attempted; however, no visible channel was observed near its mapped confluence with the Northeast Inflow of Pointer Lake stream. In spring 2010, the habitat mapping of the upper reach of the tributary to the Northeast Inflow of Pointer Lake was completed from about 1,600 m upstream of the mapped confluence to the top of the stream.

In spring 2010, a total of 1,660 m of the upper reach of the tributary to the Northeast Inflow of Pointer Lake was assessed (Table 10A-1; Attachment X.VIII, Table X.VIII-2). Maximum depth recorded was 0.9 m. Wetted width ranged from 0.4 m to 15 m in the channel, from 20 m to 100 m in the ponds, and from 20 m to 120 m in the areas with no defined channel. Bankfull width ranged from 0.4 to 15 m in the channel and from 20 m to 100 m in the ponds.

Stream habitat in the upper reach of the tributary to the Northeast Inflow of Pointer Lake consisted primarily of runs with sections of no defined channel, flat, ponds, riffle, and pools habitats also present (Attachment X.VIII, Figure X.VIII-32a and X.VIII-32b; Table X.VIII-2). Within the length of stream surveyed, habitat consisted of 419 m of shallow run (R3), 395 m of no defined channel, 336 m of flat, 174 m of pond, 173 m of riffle, and 164 m of shallow pool (P3). Shoreline slope ranged from flat to intermediate slope. Shoreline vegetation was predominantly grasses backed by tundra. Instream substrate consisted primarily of organic material and boulder, with sand, silt, cobble, and gravel also present. Instream cover consisted of interstitial spaces in the coarse substrate, depth/turbulence, submergent and emergent vegetation, and large woody debris in the form of a piece of plywood installed across the stream. Overhead cover consisted of undercut banks and inundated vegetation.

The upper reach of this tributary stream is located about 1,600 m from where the confluence with the Northeast Inflow of Pointer Lake has been mapped. There is no visible channel connecting the mapped section of the tributary stream to the Northeast Inflow of Pointer Lake. The tributary is isolated and has sections of no visible channel. Therefore, it is unlikely that fish can enter this tributary stream.

Upper Northwest Inflow of Pointer Lake

A total of 1,815 m of the upper reach of the Northwest Inflow of Pointer Lake was assessed upstream of Pointer Pond (Table 10A-1; Attachment X.VIII, Table X.VIII-2). Maximum depth recorded was 0.8 m. Wetted width ranged from 0.1 to 10 m in the channel and from 30 to 100 m in the ponds. Bankfull width ranged from 0.1 m to 6 m in the channel and from 30 m to 100 m in the ponds.

The upper reach of the Northwest Inflow of Pointer Lake stream habitat consisted primarily of flat with riffle, pond, run, and pool habitats also present (Attachment X.VIII, Figure X.VIII-33a and X.VIII-33b; Table X.VIII-2). Within the length of stream surveyed, habitat consisted of 962 m of flat, 283 m of riffle, 222 m of pond, 192 m of shallow run (R3), 122 m of shallow pool (P3), and 34 m with no visible channel. Boulder garden was also present, along with riffle habitats. Shoreline slope ranged from flat to steep slope. Shoreline vegetation included grasses and low shrubs, backed by tundra. There was also a section of shoreline without vegetation present. Instream substrate consisted primarily of organic matter and boulder, with cobble, gravel, and sand also present in smaller quantities. Instream cover consisted of interstitial spaces in the coarse substrate, depth/turbulence, and emergent and submergent vegetation. Overhead cover consisted of undercut banks, inundated vegetation, and overhanging vegetation.

Northwest Inflow of Pointer Lake

A total of 2,426 m of the Northwest Inflow stream to Pointer Lake was assessed downstream of Pointer Pond. Maximum depth recorded was greater than 1 m; however, the maximum depth could not be confirmed as it was unsafe to wade in the deeper portions of the stream channel. Wetted width ranged from 1.0 to 75 m and bankfull width ranged from 0.6 m to greater than 100 m (Table 10A-1).

The Northwest Inflow of Pointer Lake habitat consisted primarily of runs with riffle, flat, and pool habitats also present (Attachment X.VIII, Figure X.VIII-34; Table X.VIII-2). Within the length of stream surveyed, habitat consisted of 1,542 m of shallow run (R3), 530 m of riffle, 284 m of flat, and 70 m of shallow pool (P3). Shoreline slope was predominantly low. Shoreline and instream substrate consisted primarily of gravel and cobble, with occasional organic material, sand, and boulder also present. Instream cover consisted of interstitial spaces in the substrate, submerged terrestrial vegetation, and depth/turbulence. Overhead cover consisted of flooded grasses and overhanging low shrubs. During the time of assessment, large areas of flooded tundra were present.

Pointer/Rock Stream

A total of 1,071 m of Pointer/Rock stream was assessed (Table 10A-1; Attachment X.VIII, Figure X.VIII-35; Table X.VIII-2). Stream velocity was too high for the field crew to wade the width of the stream, therefore maximum depth, wetted widths, channel widths were not measured. Maximum depth recorded near the shoreline was greater than 1.5 m in many places.

Pointer/Rock Stream consisted primarily of riffle and rapid habitats with run habitat also present. Within the length of the stream surveyed, habitat consisted of 375 m of riffle, 350 m of rapid, 296 m of moderate run (R2), and 50 m of shallow run (R3; Attachment X.VIII Table X.VIII-2). Several boulder gardens were present within the habitat units. Shoreline slope was predominantly low. Shoreline and instream substrate consisted primarily of boulder and cobble, with small amounts of gravel, sand, and low amount of organic material also present. Instream cover consisted of interstitial spaces in the substrate, depth, turbulence, and submergent terrestrial vegetation. Overhead cover consisted of inundated vegetation. During the time of assessment, areas of flooded tundra were present.

Sik Sik/Rock Stream

The total length of the Sik Sik/Rock stream reach was 925 m. Maximum depth recorded was 0.9 m. Wetted width ranged from 2.5 to 100 m (Table 10A-1; Attachment X.VIII, Figure X.VIII-36; Table X.VIII-2).

The Sik Sik/Rock Stream habitat consisted of flat and run habitats. Within the portion of the stream surveyed, habitat consisted of 375 m of moderate run (R2), 172 m of shallow run (R3), and 378 m of flat (Attachment X.VIII Table X.VIII-2). Shoreline slope was predominantly low. Shoreline and instream substrate consisted primarily of organic material, with some boulder, cobble, and gravel also present. Instream cover consisted of interstitial spaces in the substrate, turbulence, and submerged terrestrial vegetation. Overhead cover consisted of flooded terrestrial grasses and low shrubs. During the time of assessment, areas of flooded tundra were present.

Rock/Willow Stream

The length of the Rock/Willow stream reach was 420 m. Maximum depth recorded was 2.0 m; however, the maximum depth could not be confirmed as it was unsafe to wade in the deeper portions of the stream channel. Wetted width ranged from 25 to 48 m. Bankfull width ranged from 18 to 51 m (Table 10A-1).

Rock/Willow Stream habitat consisted of riffle and runs. Within the length of the stream surveyed, habitat consisted of 329 m of riffle and 91 m of moderate run (R2; Attachment X.VIII, Figure X.VIII-37; Table X.VIII-2). Several boulder gardens were present within the habitat units. Shoreline slope was predominantly low. Shoreline and instream substrate consisted of gravel, cobble and boulder. Instream cover consisted of interstitial spaces in the substrate (i.e., interstitial spaces of the boulders), submerged vegetation and small woody debris. Overhead cover consisted of flooded grasses and overhanging low shrubs. During the time of assessment, areas of flooded tundra were present.

Willow/Judge Sissons Stream

This reach of stream channel, located between Willow and Judge Sissons lakes was 595 m in length. Due to high water velocity, bankfull widths could not be measured. Maximum depth recorded was greater than 2 m; however, the maximum depth could not be confirmed as it was unsafe to wade in the deeper portions of the stream channel. Wetted width ranged from 60 to 110 m (Table 10A-1).

The Willow/Judge Sissons Stream habitat consisted primarily of run and riffle, with flat habitat also present. Within the stream surveyed, habitat consisted of 33 m of deep run (R1), 44 m of moderate run (R2), 210 m of shallow run (R3), 219 m of riffle, and 90 m of flat (Attachment X.VIII, Figure X.VIII-38; Table X.VIII-2). Shoreline slope was predominantly low. Shoreline and instream substrate consisted primarily of cobble and organic material, with gravel and boulder also present. Instream cover consisted of interstitial spaces in the substrate, submerged vegetation, depth, and turbulence. Overhead cover consisted of flooded grasses and low shrubs. During the time of assessment, areas of flooded tundra were present.

10.2.3.2 Lower Lake Sub-Basin

A summary of the habitat characteristics for streams in the Lower Lake sub-basin is provided in Table 10A-1.

Mushroom/End Grid Stream

The length of the Mushroom/End Grid stream reach surveyed was 1,313 m. Maximum depth recorded was 0.3 m in the main channel and up to 1.2 m in pools. Wetted width ranged from 5.2 to 19 m. Bankfull width ranged from 1.0 to 6.2 m (Table 10A-1).

The Mushroom/End Grid stream habitat consisted primarily of shallow run (R3) habitat (Attachment X.VIII, Figure X.VIII-39; Table X.VIII-2). Two deep pools (P1), a backwater area, a snye area, and a pond were also present within the habitat unit. The lower 360 m of the stream consisted of braided channels. Shoreline slope was variable and ranged from moderate to high slopes. Shoreline and instream substrate consisted primarily of cobble and gravel, with silt, boulder, and sand also present. Instream cover consisted of interstitial spaces in the substrate, depth, turbulence, and inundated terrestrial vegetation. Overhead cover consisted of flooded grasses. During the time of assessment, areas of flooded tundra were present.

End Grid/Shack Stream

This stream reach extended for 1,431 m between End Grid and Shack lakes. The depth within the surveyed length ranged from 0.3 m to greater than 1.0 m in some of the pools. Wetted width ranged from 30 to 500 m and bankfull width ranged from 1.9 to 25 m (Table 10A-1).

The End Grid/Shack stream reach contained primarily flat and pool habitats, with short sections of run also present. Within the length of the stream surveyed, habitat consisted of 736 m of flat habitat, 585 m of moderate pool (P2), and 110 m of shallow run (R3) habitat (Attachment X.VIII, Figure X.VIII-40; Table X.VIII-2). Shoreline slope was predominantly low. Shoreline and instream substrate consisted primarily of organic material and silt, with smaller amounts of boulder, cobble, gravel and sand also present. Instream cover consisted of interstitial spaces in the substrate, submerged and emergent vegetation, and inundated terrestrial vegetation. Overhead cover consisted of flooded grasses; during the time of assessment, large areas of flooded tundra were present.

Cigar/Lunch Stream

This stream reach was 1,190 m in length. Maximum depth recorded was 0.8 m. Wetted width ranged from 12 to 200 m and bankfull width ranged from 2.5 to 6.5 m (Table 10A-1).

The Cigar/Lunch stream habitat consisted primarily of run habitat, with flat and riffle habitats also present (Attachment X.VIII, Figure X.VIII-41; Table X.VIII-2). Within the length of the stream surveyed, habitat consisted of 840 m of shallow run (R3), 230 m of flat, and 120 m of riffle. Shoreline slope was predominantly low. Shoreline and instream substrate consisted primarily of cobble and boulder, with silt and gravel deposits also present. Instream cover consisted of interstitial space in substrate, depth, turbulence, and inundated terrestrial vegetation. Overhead cover consisted of flooded grasses, low shrubs, and undercut banks. During the time of assessment, large areas of flooded tundra were present.

Knee/Lunch Stream

The Knee/Lunch Stream was a short, 258 m long, section of stream channel located between Knee and Lunch lakes. Maximum depth was 0.8 m. Wetted width ranged from 4.5 to 19 m and bankfull width ranged from 0.8 to 3.8 m (Table 10A-1).

The Knee/Lunch stream habitat consisted of run and riffle habitats (Attachment X.VIII, Figure X.VIII-42, Table X.VIII-2). Within the stream surveyed, habitat consisted of 152 m of moderate run (R2) and 106 m of riffle. Shoreline slope was predominantly low. Shoreline and instream substrate was primarily sand and cobble, with occasional boulders. Instream cover consisted of interstitial spaces in the substrate, depth, turbulence, and inundated terrestrial vegetation. Overhead cover consisted of flooded grasses and undercut banks. At the time of assessment, large areas of flooded tundra were present.

Lunch/Andrew Stream

A total of 763 m of Lunch/Andrew stream was assessed. Maximum depth was 1.2 m. Wetted width ranged from 10 to 35 m and bankfull width ranged from 8.6 to 28 m (Table 10A-1).

Lunch/Andrew stream consisted of flat and run habitats. Within the length of the stream surveyed, habitat consisted of 475 m of flat and 288 m of moderate run (R2) (Attachment X.VIII, Figure X.VIII-43, Table X.VIII-2). Shoreline slope was moderately high near the shoreline and low to moderately low further away from the shoreline. Shoreline and instream substrate consisted primarily of silt and cobble, with boulder and small amounts of gravel and sand also present. Instream cover consisted of interstitial spaces in the substrate, depth, turbulence, and inundated terrestrial vegetation. Overhead cover consisted of flooded grasses and low shrubs. During the time of assessment, large areas of flooded tundra were present.

Andrew/Shack Stream

The surveyed reach of this stream was 1,014 m in length. Maximum depth recorded was 1.1 m. Wetted width ranged from 12 to 60 m and bankfull width ranged from 7.5 to 15 m (Table 10A-1).

The Andrew/Shack stream habitat consisted of run and riffle habitats. Within the length of the stream surveyed, habitat consisted of 314 m of moderate run (R2), 380 m of shallow run (R3), and 320 m of riffle (Attachment X.VIII, Figure X.VIII-44, Table X.VIII-2). Shoreline slope was predominantly low. Shoreline and instream substrate consisted of cobble and boulder, with occasional boulder gardens and gravel also present. Instream cover consisted of interstitial space between the boulders, depth, turbulence, and inundated terrestrial vegetation. Overhead cover consisted of flooded grasses and low shrubs. Upland habitat surrounding the stream was open tundra. During the time of assessment, large areas of flooded tundra were present.

Shack/Lower Stream

The Shack/Lower stream was one of the longest reaches surveyed in the LSA, extending for about 6,000 m. Maximum depth recorded was greater than 1.3 m. Wetted width ranged from 7.0 to 100 m and bankfull width ranged from 2.0 to 25 m (Table 10A-1). Depths and widths were not measured in some areas due to high discharge and velocities at the time of the survey.

The Shack/Lower stream habitat consisted primarily of run habitat, with flat, rapid, pool, and riffle habitats also present. Within the length of the stream surveyed, habitat consisted of 885 m of deep run (R1), 1,080 m of moderate run (R2), 356 m of shallow run (R3), 1,244 m of flat, 1,230 m of rapid, 974 m of moderate pool (P2), and 232 m of riffle (Attachment X.VIII, Figure X.VIII-45a,b,c, Table X.VIII-2). Shoreline slope was variable and ranged from low to moderately high slopes. Shoreline and instream substrate consisted primarily of boulder and cobble, with sand, gravel, silt and organic material also present. Instream cover was fairly complex in this reach, consisting of interstitial spaces in the substrate, turbidity, depth, turbulence, and inundated terrestrial vegetation. Overhead cover consisted of flooded grasses and low shrubs, as well as undercut banks and ledges. During the time of assessment, large areas of flooded tundra were present.

Lower/Judge Sissons Stream

The surveyed reach of Lower/Judge Sissons stream was 976 m in length. Maximum depth recorded was 0.9 m. Wetted width ranged from 24 to 75 m and bankfull width ranged from 4 and 5 m (Table 10A-1).

The Lower/Judge Sissons stream habitat consisted of run, flat, and riffles. Within the length of the stream surveyed, habitat consisted of 743 m of moderate run (R2), 140 m of flat, and 92.5 m of riffle (Attachment X.VIII, Figure X.VIII-46, Table X.VIII-2). Shoreline slope was predominantly low. Shoreline and instream substrate consisted primarily of cobble and organic material, with smaller amounts of boulder, silt, and gravel also present. Instream cover consisted of interstitial spaces in the substrate, depth, turbulence, and inundated terrestrial vegetation. Overhead cover consisted of flooded grasses and low shrubs. During the time of assessment, large areas of flooded tundra were present.

10.2.3.3 Caribou Lake Sub-Basin

Due to time constraints during the 2008 field program, detailed habitat assessments of the upper stream reaches in the Caribou Lake sub-basin were not completed. This included Ridge/Crash Stream, Cirque/Crash Stream, and Crash/Fox Stream. An overview helicopter reconnaissance was completed and the habitat in these reaches was documented for future reference in video imagery taken during the aerial survey. Habitat maps were completed for the stream reaches between Fox Lake and Judge Sissons Lake.

A summary of the habitat characteristics for streams in the Caribou Lake sub-basin is provided in Table 10A-1.

Fox/Caribou Stream

The Fox/Caribou stream reach was 650 m in length. Maximum depth recorded was 0.5 m. Wetted width ranged from 15 to 40 m and the bankfull width ranged from 7.5 to 20 m (Table 10A-1).

The Fox/Caribou stream habitat consisted of riffle and run habitats. Within the length of the stream surveyed, habitat consisted of 540 m of riffle and 110 m of shallow run (R3; Attachment X.VIII, Figure X.VIII-47, Table X.VIII-2). Shoreline slope was predominantly low. Shoreline and instream substrate consisted primarily of cobble and boulder, with organic material also present. Instream cover consisted of interstitial spaces in the substrate and inundated terrestrial vegetation. Overhead cover consisted of flooded grasses and low shrubs. During the time of assessment, areas of flooded tundra were present.

Caribou/Calf Stream

The surveyed reach of Caribou/Calf Stream was 251 m in length. Maximum depth recorded was 0.5 m. Wetted width ranged from 18 to 19 m and the bankfull width ranged from 20 to 22 m (Table 10A-1).

The Caribou/Calf Stream habitat consisted of riffle and runs. Within the length of the stream surveyed, habitat consisted of 180 m of riffle and 71 m of shallow run (R3; Attachment X.VIII, Figure X.VIII-48, Table X.VIII-2). Several boulder gardens were present within the habitat units. Shoreline slope was predominantly shallow. Shoreline and instream substrate consisted of boulder and cobble. Instream cover consisted of interstitial spaces in the boulder substrate, water depth, turbulence, and inundated terrestrial vegetation. Overhead cover consisted of flooded grasses and low shrubs. During the time of assessment, areas of flooded tundra were present.

Calf/Judge Sissons Stream

This stream reach extended for 1,765 m, between Calf and Judge Sissons lakes. Maximum depth recorded was 0.8 m. Wetted width ranged from 60 to 150 m and bankfull width ranged from 7.0 to 49 m (Table 10A-1).

The Calf/Judge Sissons stream habitat consisted of run and flat habitats. Within the length of the stream surveyed, habitat consisted of 1,325 m of shallow run (R3) and 440 m of flat (Attachment X.VIII, Figure X.VIII-49, Table X.VIII-2). Shoreline slope was predominantly low. Shoreline and instream substrate consisted of gravel and cobble, intermixed with sand and boulder. Instream cover consisted primarily of inundated terrestrial vegetation. Overhead cover consisted of flooded grasses and low shrubs. At the time of assessment, areas of flooded tundra were present.

10.2.3.4 Aniguq River

An aerial video of the Aniguq River, from Judge Sissons Lake downstream to Baker Lake was recorded during spring 2008. Two potential barriers to upstream fish movements from Baker Lake were observed. Both barriers are located in the section of the Aniguq River between Audra Lake and Baker Lake (Photo 10.2-6). The single cascade (Photo 10.2-7) may be passable under some flow conditions. The double cascade (Photo 10.2-8) is likely a complete barrier to upstream fish migrations. This may explain why Arctic char have been recorded in Baker Lake, but are not present in Judge Sissons Lake (refer to Section 11).

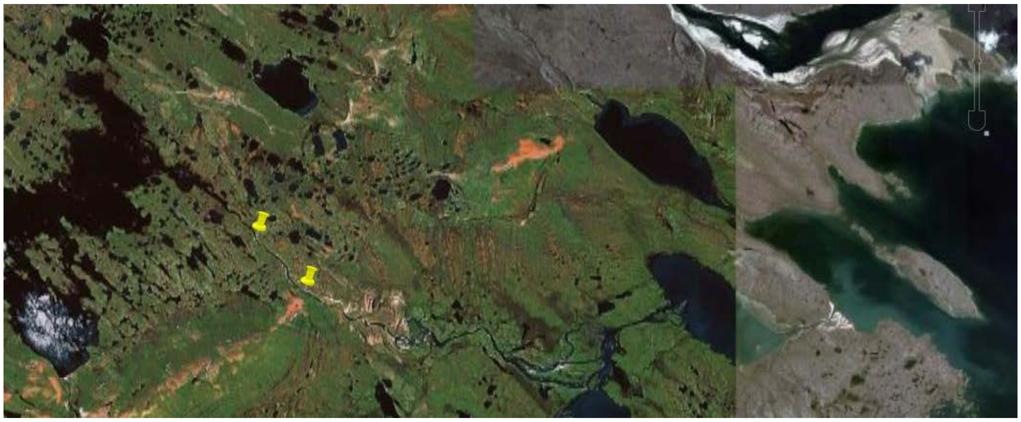


Photo 10.2-6 Two potential fish barriers to Arctic char migration located between Audra Lake (left) and Baker Lake (right)

Photo 10.2-7 Cascade located on the Aniguq River, looking upstream

Photo 10.2-8 Double cascades located on the Aniguq River, looking upstream

10.2.4 Streams Crossed by Proposed Access Road Options

Stream crossing assessments were completed along the proposed northern, southern, eastern and winter road alignments during the fall 2008 and 2009 surveys (see Attachment X.VIII, Table X.VIII-3). Stream crossing assessment were carried out at 37 streams along the proposed North All-Weather Access Road (west of the Thelon River) and 6 stream crossings along the proposed Winter Access Road corridor. The eastern portion of the road alignment includes road options between the Thelon River and the town of Baker Lake. An additional southern alignment, which would link an optional barge facility on the southwest shore of Baker Lake to the northern route, thereby avoiding the Thelon River, was examined in 2009. A total of 16 and 18 stream crossings were examined along the eastern and southern road alignments, respectively (refer to summary figures in Attachment X.IX, Figures X.IX-3a and X.IX-3b). In 2010, the habitat assessment of the Thelon River was extended to include several new potential crossing locations and a bathymetry map was produced (Attachment X.IV, Figure X.IV-41).

A summary of the habitat characteristics for stream crossings along the proposed Kiggavik road alignments is provided in Table 10A-2. Streams crossed by the proposed road alignments generally fell into three categories:

- First: small drainages that had no defined or no visible channel. The distinction between the two is the watercourse with no defined channel exhibited wet areas or evidence of overland flow; whereas, the no visible channel did not exhibit signs of overland flow. These types of streams are seasonal flow paths that appear to convey snow melt.
- Second: small to intermediate sized streams with channel widths of 1 to 5 m; and
- Third: large streams or rivers (i.e., greater than 5 m in width).

Habitat assessments were performed for crossings along the proposed road alignments. Many watercourses were undefined, seasonal or dry channels. Small streams were generally characterized by organic substrate and low habitat diversity (i.e., few habitat types present). Large streams or rivers contained more instream and overhead cover and had a greater diversity of substrates and habitat types present.

10.2.4.1 North All-Weather Access Road (West of the Thelon River)

The naming convention for the stream crossings was to use the kilometre where the stream crossing will be located on the 2011 proposed north all-weather access road (EBA 2010). However, several stream crossings do not have a kilometre because they were not on the newest road alignment; for these streams “alternate” was added in front of the Golder identifier.

The majority of the water courses crossed along the northern road alignment were first category streams (i.e., no defined or no visible channel). Seven were classified as large streams or rivers (i.e., crossings Km 11.3, Km 127.5, Km 129.2, Km 147.6, Km 157.3, Km 157.7, and Km 174.8 [Thelon River]). The remainder of the streams were small to intermediate in size with channel widths less than 5 m (Table 10A-2; Attachment X.VIII, Table X.VIII-3). Detailed habitat maps for crossings where there was a defined stream channel are provided in Attachment X.VIII, Figures X.VIII-50 to X.VIII-72. A summary of channel widths and fish species present at the various crossing locations is provided in Attachment X.IX, Figures X.IX-3a and X.IX-3b.

Thelon River (Km 174.8)

Detailed habitat maps of the Thelon River are provided in Attachment X.VIII, Figures X.VIII-72a and X.VIII-72b. A summary of the channel widths and other characteristics is provided in Table 10A-2. Detailed habitat characteristics are provided in Attachment X.VIII, Table X.VIII-3.

Fish habitat was assessed on about 3.8 km of the Thelon River and bathymetry was conducted on a 4.5 km section of the river. The maximum depth encountered was 7.5 m. Wetted and bankfull channel widths ranged from 300 to 520 m and 330 to 550 m, respectively. The river section is generally fast flowing with run sections most common and a rapid section further upstream.

The Thelon River is a fish bearing stream with good overwintering habitat, and year round cover and spawning habitats in the assessed river section. Interstitial spaces in the coarse substrate, depth, and turbulence of the water provide good cover habitat for all sizes of fish.

The Thelon River crossing included the crossing Km 174.8 on the all-weather road crossing and the Nuna ice bridge as discussed further in the following sections.

Upstream Thelon River – Proposed Bridge and Cable Ferry Crossings (Km 174.8)

About 3.2 km of the Thelon River was assessed near the proposed bridge and cable ferry locations between 2008 and 2010 (Table 10A-2; Attachment X.VIII, Figure X.VIII-72a and Table X.VIII-3). In 2010, a bathymetric survey was conducted on a 4.5 km section of the Thelon River, and included the proposed bridge, cable ferry, and Nuna ice bridge locations (Attachment X.IV, Figure X.IV-41). Maximum depth observed during the bathymetric survey was 7.5 m. Wetted and bankfull channel widths ranged from 300 to 520 m and 330 to 550 m, respectively.

The Thelon River near the proposed bridge and cable ferry crossings consisted of run and rapid habitats. Within the length of the surveyed stream section, habitat consisted of 3,205 m of deep run (R1) and 85 m of rapid sections (Table 10A-2). The narrow rapid is located on the west side of a gravel bar, while the majority of the river, which is a deep run, flows on the east side of the gravel bar. Shoreline slope ranged from moderate to very steep. The slope was predominantly moderate near the water and very steep further away from the water on the west shore (right downstream bank) and predominantly moderate on the east shore (left downstream bank) with several steep sections. Shoreline vegetation was open tundra. Shoreline substrate ranged from sand to bedrock; instream substrate consisted primarily of cobble, boulder and gravel, with sand, bedrock and silt also present. Instream cover consisted of interstitial spaces in the substrate, depth, and turbulence. Overhead cover was not present.

Downstream Thelon River – Proposed Nuna Ice Bridge

A 560 m long section of the Thelon River was assessed near the proposed Nuna ice bridge location (Table 10A-2; Attachment X.VIII, Figure X.VIII-72b and Table X.VIII-3). This area is about 700 m downstream of the habitat assessed in the previous section: Upstream Thelon River. Maximum depth observed during the bathymetric survey was 4.7 m. Wetted and bankfull channel widths were 460 m and 520 m, respectively.

The Thelon River near the proposed Nuna ice bridge consisted of a deep run (R1; Table 10A-2). Shoreline slope ranged from moderate to steep. The slope was predominantly steep on the west shore (right downstream bank) and predominantly moderate on the east shore (left downstream bank). Shoreline vegetation was open tundra. Shoreline substrate ranged from sand to bedrock; instream substrate consisted primarily of cobble and gravel, with boulder also present. Instream cover consisted of interstitial spaces in the substrate, depth, and turbulence. Overhead cover was not present.

10.2.4.2 North All-Weather Access Road (East of the Thelon River)

The majority of the water courses crossed along this portion of the northern all-weather access road alignment were also first category streams. Three streams were second category intermediate streams (e.g., crossings Km 195.1, Km 209.4, and Km 212.2). The remaining large watercourses had average channel widths ranging from 6.0 m (crossing Km 213.1) to 7.7 m (crossing alternate EC22; Table 10A-2; Attachment X.VIII, Table X.VIII-3). Detailed habitat assessments were only completed on these larger streams. Detailed habitat maps are provided in Attachment X.VIII, Figures X.VIII-73 to X.VIII-77. A summary of channel widths and fish species present at the various crossing locations is provided in Attachment X.IX, Figures X.IX-3a and X.IX-3b.

10.2.4.3 Winter Access Road

The majority of the water courses along the winter road alignment were in the second category of stream; that is the bankfull widths were between 1 and 5 m (Table 10A-2). Several of the streams (e.g., alternate W3 and alternate W6) had localized pond areas where the bankfull width was substantially wider than the bankfull width of the remainder of the stream. For example, the bankfull width of Stream alternate W3 was1 to 3 m for most of its length; however, there were several ponds that were 40 to 75 m wide (Attachment X.VIII, Table X.VIII-3). Three crossings had either no defined (i.e., a wetland area) or no visible channel. Detailed habitat maps for crossings where there was a defined stream channel are provided in Attachment X.VIII, Figures X.VIII-78 to X.VIII-83. A summary of channel widths and fish species present at the various crossing locations is provided in Attachment X.IX, Figures X.IX-3a and X.IX-3b.

Several lakes were also present along the winter road alignment (Attachment X.VIII, Table X.VIII-1). From west to east, the Winter Access Road alignment crosses the following large waterbodies: Siamese Lake, an unnamed lake (Lake 2), Long Lake, Audra Lake, and Quinguq Bay (Baker Lake). For details regarding Siamese Lake, refer to Sections 4.2.2.1.5 and 10.2.1.5; the remainder of the lakes are discussed below.

Unnamed Lake (Lake 2)

Lake 2 is located between Siamese Lake and Audra Lake. The drainage area of Lake 2 is 66.9 km^2, with a surface area of 792.4 ha and a shoreline perimeter of 13,257 m (Attachment X.VIII, Table X.VIII-1). In May 2009, the maximum ice thickness on Lake 2 was 1.8 m and the maximum water depth recorded at the sampling stations was 8.0 m.

Long Lake

Long Lake is located upstream from Audra Lake. The drainage area of Long Lake is 355.7 km^2, the surface area is 614.4 ha and the shoreline perimeter is 23,804 m (Attachment X.VIII, Table X.VIII-1). In May 2009, the maximum ice thickness was 1.8 m. The maximum water depth recorded was 2.5 m.

Audra Lake

Audra Lake is located downstream of Judge Sissons Lake. The drainage area of Audra Lake is 2,740 km^2 and the surface area is 9,520 ha (Attachment X.VIII, Table X.VIII-1). In May 2009, the maximum ice thickness was 2.0 m. The maximum water depth recorded was 6.8 m.

Qinguq Bay

Qinguq Bay is located at the west end of Baker Lake. The drainage area of Qinguq Bay is 465.9 km^2, the surface area of the bay is 998 ha and the shoreline perimeter is 17,147 m (Attachment X.VIII, Table X.VIII-1). In May 2009, the maximum ice thickness was 1.8 m. The maximum water depth recorded was 4.5 m.

10.2.4.4 South All-Weather Access Road

The majority of the water courses crossed along the southern all-weather road alignment were first category streams. Three streams were in the large stream or river category (i.e., crossings crossing S5 [Aniguq River], S11, and S13). The remaining streams had average channel widths ranging from 2.8 m (crossing S3) to 3.7 m (crossing S14; Table 10A-2). Due to time constraints in the September 2009 sampling session, detailed habitat assessments were only completed on the selected larger streams, which were most likely to have supported fish populations (Attachment X.VIII, Table X.VIII-3). Detailed habitat maps for selected crossing are provided in Attachment X.VIII, Figures X.VIII-84 to X.VIII-88. A summary of channel widths and fish species present at the various crossing locations is provided in Attachment X.IX, Figures X.IX-3a and X.IX-3b.

10.3 Summary

Between 2007 and 2010, fish habitat mapping was completed for 29 waterbodies of the mine site LSA (i.e., Pointer Pond, Pointer, Sik Sik, Rock, Willow, Mushroom, Pond 1 to Pond 8, End Grid, Cigar, Knee, Lunch, Andrew, Shack, Lower, Ridge, Cirque, Crash, Fox, Caribou, Calf, Judge Sissons, and Siamese lakes). Fish habitat assessments of five sites in Baker Lake were also completed between 2008 and 2009. Between 2007 and 2010, bathymetric surveys were completed for 18 waterbodies of the mine site LSA (i.e., Pointer Pond, Pointer, Sik Sik, Rock, Mushroom, Pond 1 to Pond 8, End Grid, Andrew, Calf, Judge Sissons, and Siamese lakes).

Late winter surveys in 2009 found that four shallow lakes (i.e., Sik Sik, Rock, Willow and Andrew lakes) were frozen to the bottom. Deeper lakes had up to 2.1 m of ice. The lakes offering overwintering habitats in the LSA were limited to Pointer Lake (3 m deep) in the Willow Lake sub-basin; Mushroom Lake (8.9 m deep) and Cigar Lake (3.6 m deep) in the Lower Lake sub-basin; Ridge Lake (7.1 m deep) and Cirque Lake (5 m deep) in the Caribou Lake sub-basin; Judge Sissons

Lake (20.6 m deep) and Siamese Lake (11.6 m deep). Fox and Caribou lakes may also provide overwintering habitat; however, they were shallower (i.e., about 3 m), which would provide only 1 m of water by late winter. In Baker Lake, Site 2 had the deepest water conditions (up to 14.4 m) and had the most uniform lake bottom. Since the slope was steep close to the shore, Site 2 would be well suited for docking facilities and vessel traffic.

In 2008 and 2010, fish habitat assessments were completed on the entire length of 19 streams in the LSA. Run and riffle habitat were the dominant habitat types in most streams, with flats also being common. Pool, rapid, cascade, backwater, snye, and pond types of habitat were observed less frequently. Cobble was observed as dominant substrate in seven streams. Organic matter, boulder and gravel were observed as dominant substrate in several streams.

In 2008, habitat assessments were also conducted during aerial reconnaissance of three other streams in the Caribou Lake sub-basin (i.e., Ridge/Crash Stream, Cirque/Crash Stream, and Crash/Fox Stream). The habitat types and channel morphology in the small streams in the Caribou Lake sub-basin were similar to those examined in the other sub-basins of the mine site LSA.

Habitat in the Aniguq River, from Judge Sissons Lake downstream to Baker Lake, was assessed during a helicopter reconnaissance. Two potential barriers to upstream fish movements from Baker Lake were observed in the section of the Aniguq River between Audra Lake and Baker Lake. The first barrier is a single cascade that may be passable under some flow conditions. The second barrier is a double cascade that likely completely obstructs upstream fish migrations. This may explain why Arctic char have been recorded in Baker Lake, but are not present in Judge Sissons Lake.

Habitat assessments were also conducted between 2008 and 2010 for streams crossed by the proposed road access, including 37 stream crossings along the proposed North All-Weather Access Road (west of the Thelon River), six stream crossings along the proposed Winter Access Road corridor, 16 stream crossings along the North All-Weather Access Road (east of the Thelon River), and 18 stream crossings along the South All-Weather Access Road. Streams crossed by the proposed road alignments generally fell into three categories:

- small drainages that had no defined or no visible channel.
- small to intermediate sized streams with channel widths of 1 to 5 m; and
- large streams or rivers (i.e., greater than 5 m in width).

Many watercourses were undefined, seasonal or dry channels. Small streams were generally characterized by organic substrate and low habitat diversity (i.e., few habitat types present). Large streams or rivers contained more instream and overhead cover and had a greater diversity of substrates and habitat types present.

The majority of the water courses crossed along the North All-Weather Access Road (west of the Thelon River) were first category streams (i.e., no defined or no visible channel). Seven were classified as large streams or rivers (e.g., crossings Km 11.3, Km 127.5, Km 129.2, Km 147.6, Km 157.3, Km 157.7, and Km 174.8 [Thelon River]). The remainder of the streams were small to intermediate in size with channel widths less than 5 m.

The portion of the Thelon Rivers in the site access LSA is generally fast flowing with run sections most common and a rapid section further upstream. The Thelon River is a fish bearing stream with good overwintering habitat, and year round cover and spawning habitats in the assessed river section. Interstitial spaces in the coarse substrate, depth, and turbulence of the water provide good cover habitat for all sizes of fish.

The majority of the water courses crossed along the portion of the North All-Weather Access Road located east of the Thelon River were first category streams. Three streams were in the second category (e.g., crossings Km 195.1, Km 209.4, and Km 212.2). The remaining large watercourses had average channel widths ranging from 6.0 m (crossing Km 213.1) to 7.7 m (crossing alternate EC22). Detailed habitat assessments were only completed on these larger streams.

The majority of the water courses crossed along the Winter Access Road were in the second category of stream (i.e., the channel widths were between 1 and 5 m). Several of the streams (e.g., alternate W3 and alternate W6) had localized pond areas where the channel width was substantially wider than the channel width of the remainder of the stream. Three crossings had either no defined (i.e., a wetland area) or no visible channel. Several lakes were also present along the Winter Access Road. From west to east, the Winter Access Road crosses the following large waterbodies: Siamese Lake, an unnamed lake (Lake 2), Long Lake, Audra Lake, and Quinguq Bay (Baker Lake). The ice thickness of these lakes ranged from 1.8 to 2.1 m.

The majority of the water courses crossed along the South All-Weather Road were first category streams. Three streams were in the large stream or river category (i.e., crossings S5 [Aniguq River], S11, and S13). The remaining streams had average channel widths ranging from 2.8 m (crossing S3) to 3.7 m (crossing S14). Due to time constraints in the September 2009 sampling session, detailed habitat assessments were only completed on the selected larger streams that were most likely to support fish populations.

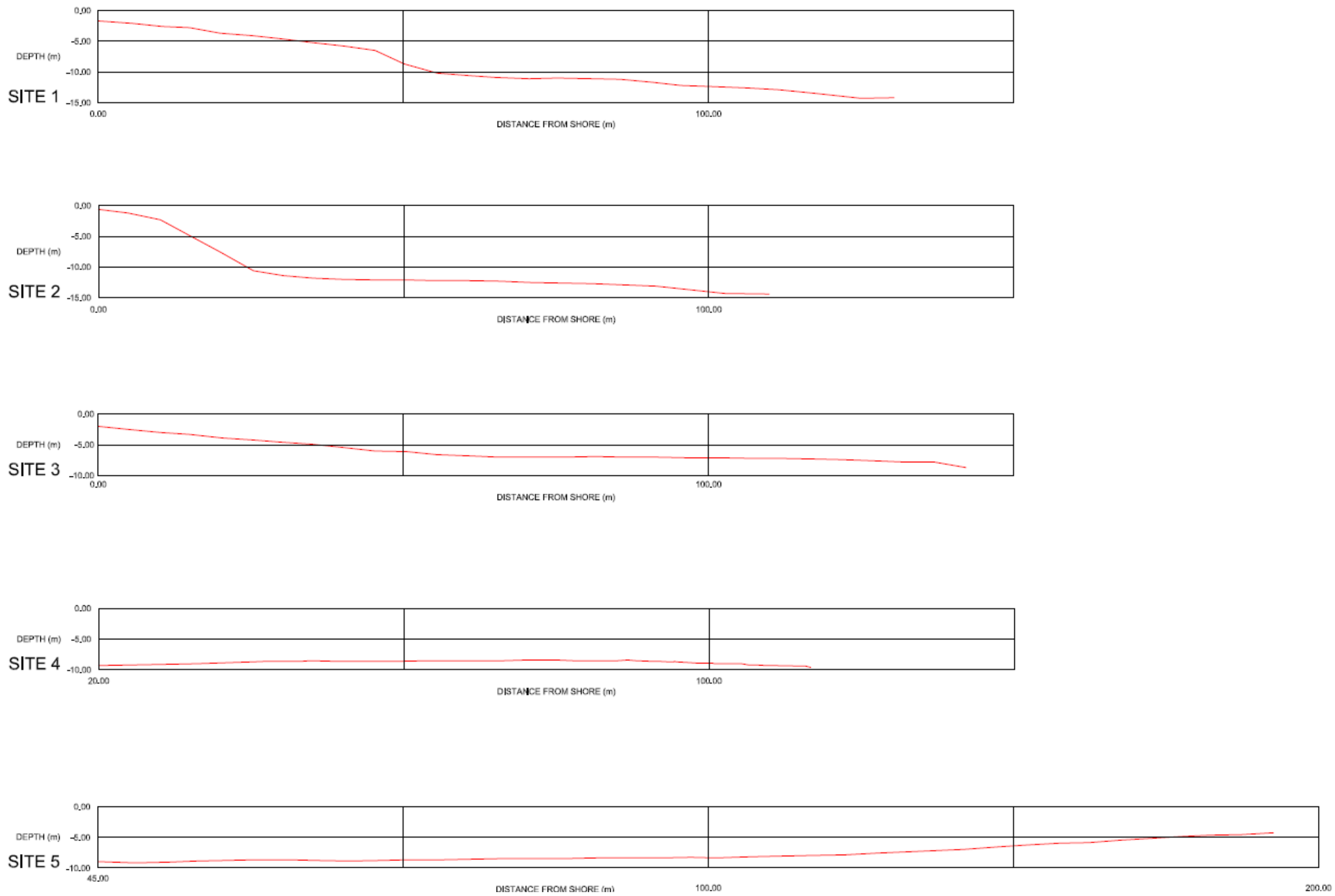


Figure 10.2-1 Lake Bathymetry for Baker Lake, September 2008 and August 2009.

11 Fish Distribution, Health, and Tissue Chemistry

A series of fisheries investigations were undertaken to describe the fish communities within Kiggavik Project area. Several historic fish investigations were documented from lakes and streams in the mine site Local Study Area (LSA) between 1975 and 1992. From 2007 to 2010, fisheries investigations were focused on five sub-basins of the Aniguq River Watershed (Figure 1.3-1).The objectives of the 2007 to 2010 study were to:

- assess fish communities in waterbodies not previously sampled;
- assess the fish communities (presence/absence; juvenile/adult) in the mine site and the site access LSA;
- conduct fish spawning surveys to locate areas were spring and fall spawning may be occurring;
- collect large-bodied fish (i.e., Arctic grayling [*Thymallus arcticus*], lake trout [*Salvelinus namaycush*], round whitefish [*Prosopium cylindraceum*], and cisco [*Coregonus artedi*]) in selected lakes for chemical analyses of flesh and bone; and
- assess if overwintering is possible for fish in selected lakes in the LSA.

The study area included lakes and streams presented in Tables 11.0-1 to 11.0-2.

11.1 Overview of Studies

11.1.1 Historical Summary 1975 to 1991

A literature review was completed in 2008, to provide a comprehensive and current understanding of the biophysical environment at and surrounding the Project Site. The literature review included a wide range of pre-development baseline data for the Project from numerous sources. Much of this information is part of the initial site characterization and included inventories of local and regional fauna and flora as well as data regarding various components of the physical environment (e.g., lake sediment and water chemistry). It also included a large amount of baseline data that was used in the early 1990s to assess environmental effects of the Project proposed at that time. The literature review integrates information collected during previous fish and fish habitat investigations conducted between 1975 and 1991 (BEAK 1987, 1990, 1992; McLeod et al. 1976).

Table 11.0-1 Summary of Lakes and Ponds in the Kiggavik Project Area in Which Fish and Fish Habitat Assessments Have Been Conducted, 1975 to 2010

Watershed	Sub-Basin	Waterbody	Historical	Recent[a]
Aniguq River	Willow Lake	Meadow Lake	BEAK 1990	-
		Felsenmeer Lake	BEAK 1990, 1992a	-
		Escarpment Lake	BEAK 1990, 1992a	-
		Drum Lake	BEAK 1990	-
		Lin Lake	BEAK 1990, 1992a	-
		Scotch Lake	BEAK 1990, 1992a	-
		Jaeger Lake	BEAK 1987	-
		Pointer Pond	-	2010
		Pointer Lake	BEAK 1990, 1992a	2007, 2008, 2009
		Sik Sik Lake	-	2007
		Rock Lake	BEAK 1990	2008
		Willow Lake	BEAK 1990, 1992a	2007, 2008
	Lower Lake	Mushroom Lake	BEAK 1992a	2008
		Pond 1 to Pond 8	-	2010
		End Grid Lake	-	2007, 2008
		Smoke Lake	BEAK 1992a	-
		Cigar Lake	BEAK 1992a	2008
		Knee Lake	BEAK 1992a	2008
		Lunch Lake	BEAK 1992a	2008
		Andrew Lake	BEAK 1992a	2007, 2008, 2009
		Shack Lake	BEAK 1992a	2007, 2008
		Bear Island Lake	BEAK 1992a	-
		Lower Lake	BEAK 1992a	2007, 2008
	Caribou Lake	Ridge Lake	BEAK 1990, 1992a	2007, 2008
		Cirque Lake	BEAK 1990, 1992a	2007,2008
		Crash Lake	BEAK 1990	2007

Table 11.0-1 Summary of Lakes and Ponds in the Kiggavik Project Area in Which Fish and Fish Habitat Assessments Have Been Conducted, 1975 to 2010

Watershed	Sub-Basin	Waterbody	Historical	Recent[a]
		Rhyolite Lake	-	-
		Fox Lake	BEAK 1990	2007, 2008
		Sleek Lake	-	-
		Caribou Lake	BEAK 1990, 1992a	2008
		Calf Lake	-	2008
	Boulder Lake	Boulder Lake	-	-
Aniguq River	Judge Sissons Lake	Judge Sissons Lake	BEAK 1990, 1992a	2008, 2009
	Siamese Lake	Siamese Lake	-	2008
	Skinny Lake	Skinny Lake	BEAK 1990, 1992a	-
	Kavisilik Lake	Kavisilik Lake	BEAK 1990, 1992a	-
Thelon River	Squiggly Lake	Squiggly Lake	BEAK 1990, 1992a	-
Baker Lake	Baker Lake	Baker Lake	BEAK 1990; McLeod et al. 1976	2008, 2009[b]

(a) Sampling in the period of 2007 to 2010 conducted by Golder.
(b) Baker Lake was sampled in 2008 and 2009 by Nanumi Stantec.
- = not applicable.

Table 11.0-2 Summary of Stream Reaches in the Kiggavik Project Area in Which Fish and Fish Habitat Assessments Have Been Conducted, 2008 to 2010

Watershed	Sub-Basin	Watercourse	Recent[a]
Aniguq River	Willow Lake	Northeast Inflow of Pointer Lake	2008, 2009, 2010
		Upper Tributary to the Northeast Inflow of Pointer Lake	2010
		Upper Northwest Inflow of Pointer Lake	2010
		Northwest Inflow of Pointer Lake	2008, 2009
		Pointer/Rock Stream	2008, 2009
		Sik Sik/Rock Stream	2008, 2009
		Rock/Willow Stream	2008, 2009
		Willow/Judge Sissons Stream	2008, 2009
	Lower Lake	Mushroom/End Grid Lake	2008

Table 11.0-2 Summary of Stream Reaches in the Kiggavik Project Area in Which Fish and Fish Habitat Assessments Have Been Conducted, 2008 to 2010

Watershed	Sub-Basin	Watercourse	Recent[(a)]
		End Grid/Shack Stream	2008
		Cigar/Lunch Stream	2008
		Knee/Lunch Stream	2008
		Lunch/Andrew Stream	2008, 2009
		Andrew/Shack Stream	2008, 2009
		Shack/Lower Stream	2008
		Lower/Judge Sissons Stream	2008
	Caribou Lake	Ridge/Crash Stream	-
		Cirque/Crash Stream	-
		Crash/Fox Stream	-
		Fox/Caribou Stream	2008
		Caribou/Calf Stream	2008
		Calf/Judge Sissons Stream	2008
	Aniguq River	Aniguq River[(b)]	2009

(a) Sampling in the period of 2008 to 2010 conducted by Golder.
(b) Historical information available in McLeod et al. 1976.

11.1.2 Field Surveys

11.1.2.1 Fish Capture and Handling

Fish capture and handling methods during the 2007 to 2010 surveys varied depending on the fishing location (i.e., lakes or streams) and the objectives of the fish sampling (i.e., spawning survey, fish community investigations, or fish chemistry). Fish sampling was completed in accordance with Golder's *Aquatic Technical Procedure TP 8.1-3 Fish Inventory Methods* (unpublished file information) and the requirements of relevant fishing permits (e.g., Fisheries and Oceans Canada [DFO] Animal Use Protocol and Nunavut Research Institute). Information regarding the location of each fishing effort can be found in Attachment X.I, Figures X.I-1 and X.I-2; Tables X.I-10 to X.I-14).

Methods of fish capture included short-duration and overnight gill nets, minnow traps, angling, backpack electrofishing, and Fyke nets. For each fishing effort, the following information was recorded:

- specifications of fishing equipment (e.g., gill net mesh size and net length);
- sampling date and time (start and end times);
- Universal Transverse Mercator (UTM) coordinates of each sampling station;
- number of fish species captured and observed;
- general habitat description for the site sampled;
- ambient weather conditions;
- water depth; and
- limnology measurements (i.e., water temperature, dissolved oxygen, specific conductivity, and pH).

Captured fish were placed in a holding pen until they could be processed. Each fish captured was assigned a unique identification code, with the exception of some fish captured during the summer 2008 session, which were released without measurements to reduce stress. Fish species, fork or total length (depending on fish species), and total body weight were recorded for all processed fish. Fork or total length was measured using a special cradle marked by metric graduations with a precision of +/-1 millimetre (mm). Small-bodied fish were weighed using an Acculab® Model VI-600 electronic scale with a precision of 0.1 gram (g). A Model AM2501 dial scale, with a precision of 10 g, was used to weigh large-bodied fish.

An external examination was conducted on all fish captured following Golder's *Aquatic Technical Procedure 8.15-0: Fish Health Assessment* (unpublished file information). Detailed observations were made on any external feature that did not appear normal (i.e., body deformities, wounds, lesions, or tumours on skin, etc.). Reproductive status (e.g., life-stage and maturity) and gender were determined when possible, by applying light pressure to the abdomen and seeing if eggs or milt could be expressed. The fish fate (i.e., released or sacrificed) was recorded. Released fish were observed until the fish swam away.

Pectoral fin rays were collected from lake trout; and scales were collected from Arctic grayling, round whitefish, and cisco for ageing. Additionally, otoliths were collected from euthanized fish. In 2009, pectoral fin rays of lake trout were no longer collected due to the discrepancy between ages determined from otoliths and fin rays collected from the same fish.

Passive Integrated Transponder (PIT) tags were implanted in all large-bodied fish as part of the assessment of fish movements between lakes. The PIT tag and tag injector were disinfected and rinsed between each use. The PIT tag was injected near the back of the head between the skin and the skull of the fish. The PIT tag number was verified with an AVID Power TracKer™ VI PIT tag reader and recorded on the data form. The tagged fish were kept in a shaded holding area until they were swimming normally and then released back into the water.

A number of fish were euthanized and retained for metals analysis. Fish were euthanized with a stunning blow to the head followed by severing the spinal cord behind the head with a knife, in accordance with the Canadian Council on Animal Care guidelines (CCAC 2005).

An internal examination was conducted on retained fish and on accidental mortalities that occurred during capture. Liver and gonad weights were measured using an Acculab® Model VI-600 electronic scale (with a precision of +/-0.1 g). Internal health assessments were conducted and observations on internal features of the fish (i.e., liver, spleen, gall bladder, gonad, kidney, parasites, and stomach fullness and mesenteric fat present) that did not appear normal were noted on the field data forms. Photographs were taken of abnormalities. Information on reproductive status (e.g., life-stage and maturity), gender (e.g., male or female) was recorded.

Fish retained for chemical analyses, were dissected on a cutting board covered with a clean sheet of wax paper. The paper was changed and all dissecting equipment was cleaned after each dissection to reduce the potential for cross-contamination. Fish carcasses (i.e., gonad, heart, and gut removed) were placed into individual plastic bags marked with the fish identification number and frozen for future submission to Saskatchewan Research Council (SRC) Laboratories.

11.1.2.2 Fish Community Investigations

Four fish community surveys were conducted between 2007 and 2010. In 2007 (August 25 to September 3, 2007), the effort included lakes from the Willow Lake, Lower Lake and Caribou Lake sub-basins. In 2008 (July 21 to August 7, 2008), the effort was expanded to complete at least one fish community survey per lake in the LSA as well as the Caribou Lake sub-basin and to re-sample lakes where large-bodied fish had not been captured in 2007. In 2009 (August 21 to September 2, 2009), sampling effort was focussed on specific lakes in the LSA that may be affected by project infrastructure. The Aniguq River was also sampled to determine if Arctic char (*Salvelinus alpinus*) were present upstream and downstream of two potential obstacles identified during a 2008 overview flight of the river. In 2010 (June 29 to July 7, 2010), sampling effort was focussed on small ponds in the mine site LSA that may be affected by project infrastructure. Information regarding the location of each fishing effort can be found in Attachment X.I, Figures X.I-1 and X.I-2; Tables X.I-10, X.I-11, and X.I-14).

Fish capture methods in lakes included gill netting, angling, and minnow trapping, while methods used in the Aniguq River and streams included angling, minnow trapping, backpack electrofishing, and Fyke netting. Sampling was performed according to Golder's *Aquatic Technical Procedure 8.1-3 Fish Inventory Methods* (unpublished file information). Information recorded during the fish community survey included capture methods, fish species, length and weight, and external fish health assessments, as well as non-lethal ageing structures were taken. Additionally, large-bodied fish from all watercourses were PIT tagged, excluding the Aniguq River, (refer to Section 11.1.2.1 for more details on tagging methods). Supporting environmental information was also recorded at each sampling station.

11.1.2.3 Spring Spawning Surveys

Two Arctic grayling spring spawning surveys were conducted in 2008 and 2009. In 2008 (June 16 to 27, 2008), the sampling effort included streams from the Willow Lake, Lower Lake, and Caribou Lake sub-basins. In 2009 (June 24 to July 3, 2009), the sampling effort was concentrated to the Willow Lake sub-basin. Information regarding the location of each fish effort can be found in Attachment X.I, Figure X.I-2; Tables X.I-11 and X.I-14).

In 2008, fish capture methods included backpack electrofishing, angling, and visual observations, while Fyke netting was added in 2009. Kick netting for eggs was also included in both years. Sampling methods were performed according to Golder's *Aquatic Technical Procedure 8.1-3 Fish Inventory Methods* (unpublished file information). The spawning survey included recording fish measurements, an external fish health assessment, assessment of gender and maturity from external characteristics, collecting non-lethal ageing structures from Arctic grayling, and fish tagging (refer to Section X11.1.2.1 for more details).

Kick net efforts were performed in areas with substrate suitable for Arctic grayling spawning (i.e., gravel). The surface area sampled by kick net was about 900 square centimetres (cm^2). A minimum of three kicks were conducted per sampled area. If eggs were collected, a maximum of five eggs per egg type were kept and fixed in 5% formalin. These eggs were later examined to confirm identification.

The UTM coordinates and current velocity were measured at each kick netting location. Water velocity was measured using a Swoffer 2100-C140 open stream current velocity meter, following the methods outlined in Golder's *Aquatic Technical Procedure 8.24-0 Stream Discharge Measurement Methods* (unpublished file information). Substrate composition, maximum depth and number of eggs captured were recorded for each effort. Additional supporting information recorded for each station included weather (i.e., air temperature, wind direction and speed, precipitation type and rate, and cloud cover), and water quality point measurements (i.e., pH, temperature, dissolved oxygen, conductivity).

11.1.2.4 Fish Movements

Tagging of large-bodied fish with PIT tags was included in all fishing efforts conducted in lakes and streams of the Willow Lake, Lower Lake, Caribou Lake, and Judge Sissons Lake sub-basins in 2008 and 2009. Information regarding the location of each fish effort can be found in Attachment X.I, Figures X-I-1 and X.I-2; Tables X.I-10, X.I-11, and X.I-14). The objective was to tag fish and monitor subsequent catches for tagged fish. Recapture of tagged fish would provide on movement within and between lakes. During the examination and health assessments conducted on captured fish, all large-bodied fish were scanned with a PIT tag reader (refer to Section 11.1.2.1) to identify recaptures. A PIT tag was injected into each untagged fish and all fish captured were released.

11.1.2.5 Fall Spawning Surveys

A lake trout spawning survey was conducted in lakes from the Willow Lake, Lower Lake, Caribou Lake, Judge Sissons Lake, and Siamese Lake sub-basins between August 25 and September 11, 2008. An Arctic char survey was conducted in the Aniguq River from August 17 to September 1, 2009. Information regarding the location of each fish effort can be found in Attachment X.I, Figure X-I-1; Tables X.I-10 and X.I-14).

Fish capture methods in lakes included short duration gill netting and angling in 2008. Backpack electrofishing and angling were used in the Aniguq River in 2009. Sampling methods were performed according to Golder's *Aquatic Technical Procedure 8.1-3 Fish Inventory Methods* (unpublished file information). The fall spawning surveys included collecting fish measurements, an external fish health assessment, assessment of gender and maturity from external characteristics, collecting non-lethal ageing structures from lake trout (pelvic fin rays) and Arctic char (scales). A fish tagging component was limited to the lakes in the mine site LSA (refer to Section 11.1.2.1 for more details). Internal assessment of gender and maturity were done on fish retained for metals and radionuclide analysis (refer to Section 11.1.2.7).

11.1.2.6 Baker Lake Fish Surveys

Nunami Stantec conducted fish surveys in Baker Lake in 2008 and 2009, at the same stations used for water quality, sediment and biota surveys. Information regarding the location of each fishing effort can be found in Attachment X.I, Figure X.I-3; Tables X.I-10 and X.I-14). Sampling procedures generally followed those outlined in the *British Columbia Field Sampling Manual* (MWLAP 2003). Captured fish were measured for length (mm) and weight (g), euthanized and placed in a cooler with ice pack for later dissection for aging and metals analysis. For each fish, the following information was recorded:

- location;
- collection date and time;
- species;
- sample number;
- sex;
- maturity;
- length;
- weight; and
- age class.

2008

Fish sampling was conducted at Station 1 on Baker Lake in an attempt to characterize fish populations in this area (Attachment X.I, Figure X.I-3). A 60 m long-line with 15 to 30 size 6/0 to 7/0 circle hooks baited with Power Bait™ was set perpendicular from the lake shoreline to sample fish. A 100 metres (m) long gill net of variable mesh size (2.5 to 8.9 centimetres [cm]) and comprising five 20 m panels was also deployed perpendicular to the shoreline. The net and long-line were each set for four hours on September 20, 2008.

2009

Fish sampling was conducted at Station 2 (proposed dock site) on Baker Lake in an attempt to characterize fish populations in this area (Attachment X.I, Figure X.I-3). One 90 m long, floating gill net of variable mesh size and comprising six 15 m panels was set overnight for 19 hours. The set was made perpendicular to shore to capture any fish migrating through the littoral zone.

11.1.2.7 Fish Tissue Chemistry

Local Study Area

Collections of fish for tissue chemistry analysis were undertaken in 2008 and 2009.

Sampling in 2008 occurred during the period of July 21 to August 7 and included:

- Pointer Lake (Willow Lake sub-basin);
- Mushroom and Lower lakes (Lower Lake sub-basin);
- Caribou Lake (Caribou Lake sub-basin); and
- Judge Sissons Lake (Judge Sissons Lake sub-basin).

The 2009 fish collections were undertaken during the period of August 21 to 26, 2009, and focused:

- Pointer Lake (Willow Lake sub-basin); and
- Judge Sissons Lake (Judge Sissons Lake sub-basin).

Fish tissue was collected from up to five Arctic grayling, lake trout, and round whitefish per selected lakes in the mine site LSA in 2008 and 2009. Cisco were added to the analysis as they were the only species captured in August 2009 in Pointer Lake. Arctic char were also to be included in the fish tissue chemistry program; however, none were captured. Fish were captured using a variety of fishing methods including short-duration gill nets, beach seines, and backpack electrofishing. Once a fish was captured and identified for the fish tissue chemistry survey, the fish was euthanized and health assessments were carried out (refer to Section 11.1.2.1). After the health assessment was completed, the fish carcass was bagged, individually labelled and frozen. Frozen fish were shipped to the Golder office in Saskatoon, prior to delivery to SRC Analytical Laboratories.

Baker Lake

Nunami Stantec collected fish from Baker Lake for chemical analysis. Tissue samples were obtained from lake trout and lake whitefish (*Coregonus clupeaformis*) captured in Baker Lake and sent to SRC for metals analysis. For lake trout, 12 individual tissue samples were obtained. Captured lake whitefish were generally small in size, therefore six composite samples, comprised of tissue from two to four individual fish per sample, were obtained. For lake trout, 5 g of tissue were removed from the area above the lateral line and behind the dorsal fin, sealed in a Ziploc plastic bag, and weighed. Livers samples were taken from lake trout and lake whitefish, sealed in a Ziploc bag and weighed. All tissue and liver samples were labelled and shipped to SRC laboratories for metals analysis.

11.1.3 Laboratory Analysis

11.1.3.1 Ageing Structures

Ageing structures were collected from the majority of the processed fish. The primary and secondary type of ageing structure varies by species (Mackay et al. 1990). The majority of the ageing structures collected were non-lethal (i.e., fin rays, scales). Otoliths were removed from fish retained for metals analysis and some of the incidental mortalities. Comparison of fin rays and otoliths from lake trout captured in 2008 showed a high variation between the ages determined from each structure for the same fish; therefore, fin rays were not collected in 2009 as otoliths are the more accurate ageing structure.

Ageing structures were sent to a Ms. Louise Stanley (Welland, ON) for analysis. Age structures were prepared and read as follows:

- Peripheral material were removed from the fin rays using either a grinder or bone saw leaving a section perpendicular to the ray containing the material at the base distal to the condyl. This section was mounted with or embedded into (depending on the size) thermoplastic cement and placed onto a piece of glass slide. Then, this section was grounded to the proper thickness for readability and the number of continuous translucent zones enumerated (L. Stanley pers. comm. 2008).
- Scales were aged directly by enumerating the number of checks (breaks in the configuration of annuli) using either reflected or transmitted light (L. Stanley pers. comm. 2008).

- Small, relatively translucent otoliths with distinct annuli were assessed whole, without processing, using transmitted light. Larger and/or more opaque otoliths were either ground on a transverse plane with a grinder, or cut with a bone saw, to remove peripheral structures and produce a section containing the core. This section was then mounted onto a piece of glass slide using thermoplastic cement and grounded (reheating, flipping, and grinding the other side if necessary) to produce a thin section containing the core. Annuli were then counted using transmitted light (L. Stanley pers. comm. 2008).

11.1.3.2 Chemical Analysis

Whole fish samples were submitted to SRC Analytical Laboratories for analysis. Fish were separated into flesh and bone by SRC Laboratories and analyzed separately. Samples were analysed for:

- ash and percent (%) moisture;
- Inductively Coupled Plasma Mass Spectrometry Scan (ICP-MS Scan) for total metals: aluminum (Al), antimony (Sb), arsenic (As), barium (Ba), beryllium (Be), boron (B), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), molybdenum (Mo), nickel (Ni), selenium (Se), silver (Ag), strontium (Sr), thallium (Tl), tin (Sn), titanium (Ti), uranium (U), vanadium (V), and zinc(Zn); and
- Radionuclides: lead-210 (Pb-210), polonium-210 (Po-210), radium-226 (Ra-226), thorium-228 (Th-228), thorium-230 (Th-230), and thorium-232 (Th-232).

Whole fish or composite samples from Baker Lake were also submitted to and analyzed for metals using the ICP-MS method. Mercury (Hg) was analyzed by Cold Vapour Atomic Fluorescence Spectrometry (CVAFS).

11.1.4 Data Entry and Data Analysis

11.1.4.1 Data Entry

All fish captured, fish health, and fish tissue chemistry data were entered into emLine™. Fish data were exported into Excel for data analysis and presentation.

11.1.4.2 Data Analysis

Fishing effort was calculated for each fishing method by waterbody or watercourse. Catch-per-unit-effort (CPUE) was calculated for successful fishing efforts and summarized by sampling area and method to document the effort expended in collecting the fish. The CPUE data also provided a measure of relative abundance among lakes and streams by standardizing the catch data.

Summary statistics (i.e., sample size, minimum, maximum, arithmetic mean, median, standard deviation, and standard error) for each fish health variable (i.e., length, condition factor, etc.) were calculated for all fish and summarized by area waterbody or watercourse and species. Fish health data including age, length, total body weight, liver weight, and gonad weight were summarized. Condition factor (K) was calculated for all processed fish. Liversomatic index [LSI] and gonadosomatic index (GSI) were calculated for fish that were given internal health assessments.

Condition factor (K) is a comparison of body weight to length and is a measure of the energy stores in a fish. The K value will be 1.0 for fish whose weight is equal to the cube of its length. Fish which have a K value greater than 1.0 are more plump and are thought to have a higher degree of well-being or better nutritional state-of-health, whereas fish with a K value less than 1.0 are considered to be in poorer condition. Condition factor is calculated as follows:

$K = [\text{weight (g)} \times 10^5] / [\text{fork length}^3 \text{ (mm)}]$

Liversomatic index allows the comparison of liver weights between fish of different sizes. The liver stores the energy (i.e., glycogen) and the LSI is used to provide an indication of the nutritional state or well-being of an individual fish. The LSI is the ratio of wet liver weight to wet body weight and is calculated as follows:

LSI = [liver weight (g) * 100] / [total body weight (g)]

GSI is the proportion of reproductive tissue in the body of the fish to total body weight. The GSI represents an estimate of the energy diverted to the development of the gonads and is calculated as follows:

GSI = [total gonad weight (g) *100] / [total body weight (g)]

11.1.5 Quality Assurance/Quality Control

Detailed specific work instructions outlining each field task were provided to field personnel prior to the field program. Samples were collected, labelled, preserved, and shipped according to Golder's *Aquatic Technical Procedure 8.15-0: Fish Health Assessment and Technical Procedure 8.1-3: Fish Inventory Methods* (unpublished file information) and laboratory protocols. Detailed field notes were recorded in waterproof field notebooks and on pre-printed waterproof field data sheets. All double-bagged fish carcasses were labelled with waterproof ink and a waterproof label was inserted between the two bags.

Data collected during the field session underwent a variety of individual Quality Assurance/Quality Control (QA/QC) checks. Field data sheets were checked at the end of each day for completeness and accuracy. Chain of Custody (COC) forms were used to track sample shipment from the field to Golder's Saskatoon office. SRC Analytical Request Forms were submitted with the fish samples.

Data entered into emLine™ underwent a 100% transcription check by a second person not involved in the initial data entry process. All summary tables generated from the database underwent an additional QA/QC screening.

The QA/QC procedures for age assessments included measures repeated by the same reader on different occasions. Each sample was assessed three times. If the assessments were consistent among readings, the age was recorded. If the assessments were not consistent among readings, the sample was reassessed later. If subsequent assessments were still inconsistent among readings, the sample was not assigned an age. Questionable results were noted as such and the reasons recorded. Assessed ages were recorded on the sample envelopes and on raw data sheets and transcribed into a spreadsheet. The electronic data were proofed against the raw data sheets and all materials and samples returned to Golder (L. Stanley 2008, pers. comm.).

11.2 Results

Fisheries results have been separated into the following six components:

- life history summary for each species known to occur in the Project area;
- fish community summary based on recent (2007 to 2010) data including fish presence, fish abundance, and fish health information;
- summary of Arctic grayling spawning data;
- summary of fish movement patterns and timing;
- spawning assessment for lake trout and Arctic char; and
- fish tissue chemistry.

11.2.1 Species and Life History

Seven species of fish that have been captured in previous studies in the mine site LSA, including: Arctic grayling, burbot (*Lota lota*), cisco, lake trout, ninespine stickleback (*Pungitius pungitius*), round whitefish, and slimy sculpin (*Cottus cognatus*) (BEAK 1990, 1992a). Four additional species of fish have been captured in Baker Lake and/or the Thelon River. These include Arctic char, fourhorn sculpin (*Myoxocephalus quadricornis*), lake whitefish, and longnose sucker (*Catostomus catostomus*) (McLeod et al. 1976).

Eleven fish species document in the mine site and site access LSAs are from the following five taxonomic families:

- Catostomidae (longnose sucker);
- Cottidae (fourhorn sculpin and slimy sculpin);
- Gadidae (burbot);
- Gasterosteidae (ninespine stickleback); and
- Salmonidae (Arctic char, Arctic grayling, cisco, lake trout, lake whitefish, and round whitefish).

The following sections provide a brief summary of the life-history and habitat requirements for fish species known to occur in the mine site and site access LSAs. These summaries are not intended to be exhaustive literature reviews, but to provide information that will assist in placing the data collected in the fish and fish habitat studies into context. Species summaries are present in alphabetical order of common name.

11.2.1.1 Arctic Char

Arctic char occur in the coastal regions of both the Northwest Territories (NT) and Nunavut (NU). It is the most northerly distributed freshwater fish, occurring on northern Ellesmere Island, as well as on many of the Arctic islands (e.g., Banks, Victoria, Devon, Somerset and Baffin) (Babaluk et al. 1997; McPhail and Lindsey 1970; Scott and Crossman 1998; Walters 1955). In coastal regions of the Arctic, Arctic char populations are found east of the Mackenzie River, around the Boothia and Melville peninsulas then south along the west Hudson Bay coast (Babaluk et al. 1997; Lee et al. 1980; McPhail and Lindsey 1970; Scott and Crossman 1998). In some northern fresh waters, Arctic char are the only fish present (Johnson 1980).

Arctic char display both anadromous and freshwater resident lacustrine life histories and they are found in rivers, lakes, estuaries and marine environments at different stages of their lifecycle (Johnson 1989; Lee et al. 1980; Scott and Crossman 1998). Anadromous char generally remain in freshwater systems for four or five years before undertaking their first seaward migration; however, there is variability in freshwater residence time as some char will only stay two years while others reside as long as nine years (Johnson 1989; McPhail and Lindsey 1970; Stewart et al. 1993).

When residing in lakes, adult Arctic char usually occupy the pelagic zone during the summer months feeding on zooplankton, making seasonal shifts to benthic and littoral areas in the latter months when food is less plentiful (Bjoru and Sandlund 1995; Jamet 1995). Within the lake, Arctic char may occur at various depths, but they are most common in less than 5 m of water over boulder, rubble and cobble substrates (Jamet 1995). Arctic char feed on a wide variety of organisms including algae, insects, fish and plankton while residing in freshwater habitats (Hunter 1970; McPhail and Lindsey 1970).

Anadromous adult char overwinter in lakes and migrate downstream during the spring ice break-up (Morrow 1980; Scott and Crossman 1998). They will then reside and feed in estuarine and marine environments before making the return migration to overwinter in lakes (Johnson 1980, 1989; Moore 1975; Scott and Crossman 1998). While in the marine environment they feed on several marine fish species during summer migrations including capelin (*Mallotus villosus)*, sand lance (*Ammodytes americanus*), Arctic cod (*Boreogadus saida*) and young Greenland cod (*Gadus ogac*) (Johnson 1989). Migrating char do not always return to the same river and may emigrate to other river systems (Gyselman 1984; Johnson 1980). Younger anadromous Arctic char display a high fidelity rate to their natal systems to spawn; however, fidelity decreases as they get older. In addition, there is an exchange of resting fish (non-spawning adults or juvenile fish) between different freshwater systems (Gyselman 1994; Johnson 1980).

The anadromous and resident forms of Arctic char spawn in both rivers and/or lakes; however, in the more northern regions, they principally spawn in deep lakes that withstand freezing over the winter months (Johnson 1980). Arctic char will mainly use rivers as migration routes, but some populations are believed to spawn in larger rivers (Kristofferson 1988; MacDonell 1997).

Timing for lacustrine spawning populations of Arctic char has been noted from September through October (Johnson 1980; Scott and Crossman 1998). This is at approximately the same time as the anadromous populations of char spawn (Gyselman 1984). Spawning occurs mainly over cobble and gravel substrates (Johnson 1980; McPhail and Lindsey 1970; Scott and Crossman 1998) in water ranging from 0.5 to 6 m deep (Gyselman 1984; Johnson 1989). Additionally, they have also been reported as spawning in shallow water (0.5 to 2 m) over silt, mud and clay substrates at times in association with vegetation (Gyselman 1984 ; Hunter 1970).

Individual Arctic char spawn on an intermittent basis every two to five years and three years is believed to be the likely average (Johnson 1980; 1989). A female char will build a redd in which her eggs are deposited and then later covered with gravel (Johnson 1989; Scott and Crossman 1998). After spawning, the adults over winter in the lake then migrate downstream to the ocean to feed the following spring (Johnson 1989).

The fry will hatch from the eggs in late March to April, but will remain in the gravel for a few more weeks before emerging close to the time of ice breakup (Johnson 1980; Scott and Crossman 1998). The young-of-the-year initially remain on the spawning grounds and move to the littoral zone later in the summer (Johnson 1980). When residing in the littoral zone, young-of-the-year are found amongst cobble, rubble, rocks seeking shelter and protection from predators (McPhail and Lindsey 1970; Richardson et al. 2001). Juvenile char may reside in small tributary streams and lacustrine habitats, moving in the fall to over winter in deeper lacustrine habitats that do not freeze to the bottom (Hunter 1976; Johnson 1980). Young-of-the-year have also been observed occasionally in rivers (Moore 1975).

Within the Arctic char complex, both normal and dwarf forms have been well documented as occurring in the same lake (Johnson 1980; Reist et al. 1995). Dwarf forms of adult char generally inhabit shallow littoral habitats and then move to pelagic zones during late summer and fall. Normal forms of Arctic char occupy shallower littoral and benthic habitats than the dwarf forms (Richardson et al. 2001). Spawning differences also occur between forms, the dwarf char spawn at greater depths than normal char and are believed to mature much earlier (Parker and Johnson 1991). Sympatric populations of freshwater resident morphs of Arctic char are also known to occur in lakes (Richardson et al. 2001).

11.2.1.2 Arctic Grayling

Arctic grayling is found throughout most of the NT and NU and has a holarctic distribution (Northcote 1995, Scott and Crossman 1998). In the Project study areas, the Arctic grayling is the most commonly occurring fish species and has been captured in each of the associated sub-basins (BEAK 1990, 1992a). Arctic grayling are primarily distributed in clear and cold waters of rivers, streams and lakes. They are known to exhibit lacustrine, adfluvial as well as riverine life-history types (Richardson et al. 2001). Their preferred habitats consists of clear and cold waters, avoiding turbid areas such as the Mackenzie River, but are known to enter milky glacier streams (Scott and Crossman 1998). They are assumed to overwinter in deep pools of rivers and in deeper portions of lakes (Ford et al. 1995).

Spawning occurs as the ice is first starting to break up in the smaller streams. This timing can vary from April to June depending on the particular subarctic to arctic habitat (Scott and Crossman 1998). As the ice actually begins to break up the adults will begin their migration from the lakes and larger rivers to smaller streams and tributaries with areas of small gravel or rock bottomed substrates (Scott and Crossman 1998). Arctic grayling do not prepare a redd; however, males are territorial on the spawning grounds and will chase away other intruding males, displaying their large raised fins (Scott and Crossman 1998). The spawning pair creates vibrations that help the discharged eggs and milt settle into the substrate with a covering of material stirred up during mating vibrations. This may occur once or several times during the spawning period. Post-spawning adults return to the lakes or rivers from which they migrated from (Scott and Crossman 1998).

The eggs hatch after approximately 13 to 18 days, with the alevin still absorbing their egg sac for a further eight or more days. Additionally, the young display rapid growth (Scott and Crossman 1998). Lakes provide important rearing habitat for young-of-the-year Arctic grayling. Lakes tend to contribute to higher summer water temperatures, which is attributed to increased growth rates compared to sub-basins with few or no lakes (Luecke and MacKinnon 2008).

Both males and females have been noted to reach maturity at four years of age, but most spawners are between six and nine years of age (Bishop 1971; Scott and Crossman 1998). Arctic grayling spawn numerous times throughout their lives; however, spawning does not always occur each and every year. Most spawners over the age of nine years tend to be females within the population and maximum ages for both sexes are between 11 to 12 years of age (Scott and Crossman 1998).

Young Arctic grayling feed primarily on zooplankton, shifting to immature insects as they grown in size. Adult grayling are primarily planktivores (Schmidt and O'Brien 1982), although they will feed on a large assortment of invertebrates, including both aquatic and terrestrial insects (Scott and Crossman 1998). The insects consumed include: caddisflies, midges, bees, wasps, grasshoppers, ants and a variety of beetles. They will also feed on small fishes, eggs, and crustaceans (Scott and Crossman 1998).

11.2.1.3 Burbot

Burbot is found throughout most of the continental portions of the NT and NU (McPhail and Lindsey 1970; Scott and Crossman 1998). Burbot generally live in deep-water lakes; however, they are also found in rivers, streams and ponds (McPhail and Lindsey 1970; Scott and Crossman 1998). Burbot are known to exhibit lacustrine and riverine life history types within the Canadian Arctic, including both NT and NU (Scott and Crossman 1998). There are resident populations that complete their life cycle within a single lake. There are also migratory populations that feed and rear mainly in lakes but then spawn in rivers or streams (Ford et al. 1995; McPhail 1997). Burbot have been documented as spawning in lakes, rivers and streams (McPhail and Lindsey 1970; Scott and Crossman 1998).

Burbot reach sexual maturity between three and four years of age, or later in the NT, with males maturing faster than females (Scott and Crossman 1998). They are a highly fecund species of fish, and a single female may lay up to a million eggs in its lifetime.

Burbot spawn under the ice between January and April, with spawning associated with water temperatures that are usually between 0.6 degree Celsius (°C) and 1.7°C (Scott and Crossman 1998). Burbot are broadcast spawners, dispersing their eggs over sand, gravel or rubble substrates at a depth of 0.5 m to 3.0 m (Ford et al. 1995; Morrow 1980; Scott and Crossman 1998). Typically burbot spawn in shallow water, although activity has been documented at much greater depths (Goodyear et al. 1982; Morrow 1980). After fertilization, the eggs settle into interstices of the substrate (Ford et al. 1995; Scott and Crossman 1998). The eggs incubate from three weeks to three months depending on water temperature (Goodyear et al. 1982; Scott and Crossman 1998).

Upon hatching sac-fry are found primarily in the pelagic zone congregating over sand and rubble substrates (McPhail 199). At the fingerling stage, young-of-the-year burbot become benthic littoral feeders (Ryder and Pisendorfer 1992). This change in habitat is matched by a change in activity patterns, from crepuscular (active at twilight) to nocturnal.

Nocturnal juvenile burbot seek daytime shelter in shallow water under physical structure such as boulders, cobble, logs, or within submergent vegetation, remaining inactive unless disturbed (Ford et al. 1995; Ryder and Pisendorfer 1992). Juvenile habitat includes rock and gravel bottoms along rocky shorelines (Ford et al. 1995). In early summer, both juvenile and adults will move to deeper offshore waters in the hypolimnion (Ford et al. 1995; Scott and Crossman 1998).

Adult burbot prefer cooler deeper waters in the summer, and like juveniles, may make diel movements at night into shallower waters to feed. Both juveniles and adults are found over boulder, rubble, cobble and sand substrates (Scott and Crossman 1998).

In the north, burbot using river habitats are associated with the turbid waters in the main channels, and then enter tributaries in autumn (Breeser et al. 1988). Studies show that they prefer areas of moderate to high turbidity's, low velocities (under 46 centimetres per second [cm/s]) and shallow depths (under 76 cm) (Suchanek et al. 1984). The turbidity of the water is used as cover (Ford et al. 1995).

Burbot are known to be sensitive to sub-surface illumination; they will seek shelter under stones, roots and in aquatic vegetation during the day (McPhail and Lindsey 1970). Despite being considered to be a sedentary fish, they are known to make extensive migrations of over 400 kilometres (km) in the NT. Northern populations also are thought to live longer, reaching greater size than southern populations (Scott and Crossman 1998).

Burbot are known to be voracious night feeding predators. Young burbot will feed on aquatic insects, crayfish, molluscs and invertebrates. Adults feed on eggs, invertebrates and numerous species of fish (Scott and Crossman 1998).

11.2.1.4 Cisco

Cisco are also known as lake herring, and commonly referred to simply as cisco in many reports. It has the most extensive North American distribution of any cisco species and is found throughout much of Canada (Scott and Crossman 1998). It is found in lakes from eastern Quebec, through the Great Lakes system and in Ontario, Manitoba, Saskatchewan, Alberta, Nunavut and the Northwest Territories. In the Arctic, cisco are present from the western Hudson Bay coast of NU to the Mackenzie River system in the NT, as far north as Great Bear Lake and south to the border with Alberta, Saskatchewan and Manitoba (Scott and Crossman 1998).

Cisco is primarily a lacustrine species but may be found in larger rivers in the NT and NU. They primarily exhibit a lacustrine life-history but anadromous[7] populations are known to occur in areas outside of the NT and NU (e.g., James Bay - Quebec).

In Hudson Bay, the cisco can enter salt water and occurs in ponds on many of the islands (Richardson et al. 2001). A dwarf form of the cisco exists but literature does not report it selecting a different habitat than the normal form and will therefore not be separated when discussing habitat requirements. The dwarf-form can occur sympatrically with normal forms of cisco. Spawning is reported to primarily occur in lakes during the fall but McLeod et al. (1976) reported large concentrations of ciscoes at the mouth of the Thelon River during mid-November, where there is a considerable amount of coarser sand, gravel, and cobble that could provide suitable spawning habitat. Also cisco were caught in a pool area of the Thelon River 11 km upstream from the mouth. This area is separated from Baker Lake by sections of rapids. River spawning runs have also been reported in the Hudson Bay Region; however, rivers are not normally considered as cisco habitat (Scott and Crossman 1998).

A wide variety of food items comprise the diet of the cisco. The young are reported to feed on algae, copepods and Cladocera (Pritchard 1930). As adults they feed on copepods, small minnows, crustaceans, aquatic insects (mayflies and caddisflies), water mites, zooplankton, their own eggs and those of other fish species (Scott and Crossman 1998). Cisco are a significant part of the diet of many other fishes, including being a preferred food source for lake trout (Scott and Crossman 1998).

11.2.1.5 Fourhorn Sculpin

The fourhorn sculpin (freshwater form) is a land locked relic, found in cold, deep freshwater lakes of northern Canada, Finland, Norway, Sweden, and Russia (COSEWIC 2003). Canadian museum records indicate that the fourhorn sculpin inhabits lakes in both the NT and NU (COSEWIC 2003). Very little is known about the freshwater life-history of the fourhorn sculpin. The distribution of the species is believed to be restricted to about 23 lakes in the Canadian Arctic, only one of which has been studied in any detail (COSEWIC 2003).

The freshwater fourhorn sculpin is small, usually less than 100 mm long (Bengtsson and Bengtsson 1983; Muus and Dahlstrøm 1999). The marine form[8] of the fourhorn sculpin is easily distinguished

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[7] Note that the term anadromous is often applied to many Arctic fish species that move into marine environments as part of their life-history; however, most of the species in the Arctic are not truly anadromous (Myers 1949). Anadromous species undergo smoltification and adapt their physiology to the marine environment (e.g., Pacific salmon Oncorhynchus species).

from other cottids by the presence of four long, club-like protuberances, which are actually frontal and parietal spines, on the top of the head (COSEWIC 2003). These spines are usually either reduced or entirely absent in the freshwater form (COSEWIC 2003). Although fourhorn sculpin that are found in lakes are considered to be of the freshwater form, some of these forms are known to be capable of inhabiting saline to hypersaline conditions (COSEWIC 2003).

A large part of the biological information regarding this species comes from research conducted in Garrow Lake, a meromictic lake on Little Cornwallis Island, NU (Dickman 1991; Fallis et al. 1987). Sculpin from this lake have been found at a depth range of 3.8 m to 15 m (Dickman 1991, 1995; Fallis et al. 1987) within the salinity range of 3-35 parts per thousand (ppt) (Dickman 1995). The majority of specimens were caught at 7 m to 12 m (Dickman 1995). The Garrow Lake sculpin were shown to have a restricted depth range due to temperature, oxygen, and dissolved oxygen preference ranges. It is currently unknown if other lacustrine Canadian Arctic fourhorn populations exhibit similar depth distributions or if migrations occur (COSEWIC 2003). In the European range, freshwater fourhorn sculpin have a much deeper depth distribution, with specimens having been collected from depths up to 90 m (COSEWIC 2003).

Temperature preferences are also believed to be a factor contributing to their depth distribution. Fourhorn sculpin population studies appear to show the fish are restricted to depths greater than 40 m in late summer (August to September) to avoid warm water temperatures (Hammar et al. 1996). Seasonal migrations have been demonstrated within the Lake Vättern population as they migrate to depths greater than 40 m from August through September to avoid warmer summer waters (Hammar et al. 1996). Juveniles that were collected in studies were from within or below the thermocline in temperatures below 10°C. Fourhorn sculpin are usually found near the lake bottom at temperatures of 5°C or less; although, the freshwater form may have a higher tolerance for warmer temperatures, with some specimens being caught near the surface at 17°C (Hammar et al. 1996).

The reproduction of the freshwater fourhorn sculpin is not well understood (COSEWIC 2003). The age at first maturity for the species is unknown. A study of Lake Vättern fourhorn sculpin, ranging in length from 82 to 110 mm, suggested that sexual maturity may be reached at age four to six, or older (Hammar et al. 1996). In comparison, the reproductive cycle of the marine form has been described by Morrow (1980) and it is believed that some general features could also apply to the freshwater form (COSEWIC 2003). Fertilization is internal for the species. They are known to be territorial nest-builders with the males defending the eggs until they hatch into pelagic larvae (COSEWIC 2003).

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[8] The marine form of four-horned sculpin was captured in Baker Lake in 1976. These fish likely entered the lake via Chesterfield Inlet (C. McLeod, Senior Fisheries Biologist, Golder Associated Ltd. Edmont, pers. comm.)

As with reproduction, little is known concerning the growth of this sculpin. Garrow Lake sculpin are noted as having a very slow growth rate when compared to marine specimens from the Beaufort Sea based on length-weight regressions (COSEWIC 2003). In the Yukon, marine fourhorn sculpin grew slowly to a maximum otolith age of 14 years (Bond and Erickson 1989). Young-of-the-Year (YOY) sculpin were 10 to 14 mm in total length in late June and by September total lengths of 15 to 39 mm were observed by Bond and Erickson (1989). Other age-classes of sculpin ranged in size from 40 to 99 mm (Bond and Erickson 1989). Both the maximum age and timing of generations in the freshwater form are unknown (COSEWIC 2003).

The fourhorn sculpin is preyed on by piscivorous fishes and birds, including burbot, lake trout and Arctic char (Dickman 1995; Hammar et al. 1996). The feeding patterns of the fourhorn sculpin are largely nocturnal, but such activities become diurnal from November to April (COSEWIC 2003). Priapulids, mysids, isopods, amphipods, copepods, annelids, chironomids, and molluscs, small fishes and fish eggs comprise most of the food items consumed by the fourhorn sculpin (COSEWIC 2003). Stomach contents also have been found to contain insects, plant material, sand, gravel, and unidentified animal material (Morrow 1980; Muus et al. 1999).

11.2.1.6 Lake Trout

Lake trout are found throughout the NT and NU, including on many of the Arctic islands, primarily in deep-water lakes (Lee et al. 1980; McPhail and Lindsey 1970). Lake trout may also be found in large, clear rivers (Lawrence and Davies 1978; McPhail and Lindsey 1970; Morrow 1980; Scott and Crossman 1998).

Both lacustrine and adfluvial life-history types are exhibited by lake trout (Goodyear et al. 1982; Scott and Crossman 1998). Lake trout are also known to exhibit several ecological forms or morphs within larger lakes (Alfonso 2004; Richardson et al. 2001).

Lake trout are late summer and early autumn lacustrine spawners. They are known to spawn through September and October in northern regions (Ford et al. 1995; McPhail and Lindsey 1970; Martin and Oliver 1980; Scott and Crossman 1998; Scott and Wheaton 1954). The shallow, inshore areas of the lake are where most spawning tends to occur (Ford et al. 1995; McPhail and Lindsey 1970). Spawning substrate includes: cobble, rubble and large gravel substrates, interspersed with boulders. Areas free of sand, silt, clay and mud are preferable (Ford et al. 1995; McPhail and Lindsey 1970; Scott and Crossman 1998), although spawning has been known to occur, to a lesser extent, over these areas as well (Beauchamp et al. 1992; Goodyear et al. 1982). Additionally, lake spawning grounds are often associated with areas affected by water currents and wave actions. This is believed to keep the coarse spawning substrates free of silt, sand and detritus (McPhail and Lindsey 1970; Martin and Oliver 1980; Sly and Evans 1996). Lake trout spawn at a variety of depths, from 0.12 to 55 m deep (Goodyear et al. 1982; Marcus et al. 1984; Morrow 1980); although, depths in excess of 100 m have also been noted (Thibodeau and Kelso 1990). In large northern lakes, such as

Great Slave and Great Bear lakes, individual lake trout appear to spawn every second or third year respectively (McPhail and Lindsey 1970).

Once laid, lake trout eggs settle into the cracks and crevices amongst the rocks, incubating for four to five months (Goodyear et al. 1982; Marsden et al. 1995; Thibodeau and Kelso 1990). The eggs usually hatch from March to April and even June in northern lakes such as Great Bear Lake (Scott and Crossman 1998). The young-of-the-year may remain in spawning areas for several weeks or several months, before moving to deeper cooler waters (Goodyear et al. 1982; Martin and Oliver 1980; Morrow 1980; Peck 1982; Scott and Crossman 1998). Juvenile lake trout are often closely associated with cobble, boulder and rubble substrates usually within 0.3 m of the bottom. They seek shelter amongst boulders and woody debris (Davis et al. 1997; Ford et al. 1995). Juvenile lake trout are primarily solitary and display diel depth distribution. They are usually found in deeper waters during the day and move into shallow water habitat at night (Davis et al. 1997).

Adult lake trout may disperse to deeper water habitats after spawning has occurred (Goodyear et al. 1982; Scott and Crossman 1998). Often found in the pelagic zone within a lake, adults are most commonly found at depths in excess of 10 meters (Ford et al. 1995; Martin and Oliver 1980; Scott and Crossman 1998). Warmer summer water temperatures will drive the lake trout deeper to cooler (about 10°C) waters below the thermocline (Martin and Oliver 1980; Scott and Crossman 1998; Sellers et al. 1998). Although lake trout exhibit a low salinity tolerance, they have been reported to occur in coastal regions of the NT (Communications Directorate 1991).

Stream and river spawning does occur in the Arctic, although it is less frequent than lake spawning (Evans et al. 2002). In the NT, lake trout are known to spawn in some river mouths from September to early October (MacDonald and Stewart 1980; Scott and Wheaton 1954). In NU, spawning is also thought to occur in rivers, although perhaps not every year (MacDonald and Stewart 1980). Riverine spawning habitat and substrate consists of large boulders mixed with rubble and gravel in eddies in wide slow sections of the rivers (MacDonald and Stewart 1980).

Although lake trout are dispersed throughout Arctic and northern river systems, knowledge of riverine habitat use is limited compared to known lacustrine use.

Lake trout are able to take advantage of a variety of food sources. They are predacious and will feed on everything from freshwater sponges, plankton, aquatic insects, terrestrial insects, crustaceans, small mammals and numerous species of fishes (Scott and Crossman 1998).

11.2.1.7 Lake Whitefish

The lake whitefish complex includes three species of whitefish: lake whitefish, Alaskan whitefish (*Coregonus nelsoni*) and humpback whitefish (*C. pidschian*) (Richardson et al. 2001). Three species complex is simply referred to as lake whitefish as they are not recognized as distinct species by many authors and are only distinguishable from each other by modal gill raker counts (Mecklenburg et al. 2002).

Lake whitefish is found throughout the NT to their northern limit on Banks Island, as well as in NU from Victoria Island to the Keewatin District (McPhail and Lindsey 1970; Scott and Crossman 1998). They are most commonly found in lakes, although they may be found in larger rivers and brackish waters. As such, they are known to exhibit lacustrine, adfluvial and “anadromous” life history types (Richardson et al. 2001). In the Ungava, Hudson Bay Region, lake whitefish will enter brackish waters (Scott and Crossman 1998). Lacustrine populations have been shown to occur in two differing forms, normal and dwarf, as noted by Richardson et al. (2001); however, the literature does not show differential habitat use between the two forms, and it has been assumed they exhibit similar habitat preferences (Richardson et al. 2001).

Anadromous Forms

Anadromous lake whitefish populations in the Mackenzie River begin upstream spawning migrations from September to October (Richardson et al. 2001). Spawning then occurs in upper reaches of tributary rivers starting from late September to October, followed by post-spawning out-migration to near shore areas and deep delta channels to overwinter (Richardson et al. 2001). Spawning is presumed to take place over gravel substrates for both anadromous and lacustrine populations. Lake whitefish eggs incubate over the winter and the fry will emerge the following spring and then are entrained in downstream flows to the delta or estuary (Richardson et al. 2001). In the Mackenzie River Delta, juvenile whitefish appear to use lakes in the Tuktoyaktuk Peninsula and other coastal reaches in the Mackenzie Delta (Richardson et al. 2001).

Anadromous lake whitefish tend to prefer waters with relatively low salinity, but in the NT will feed during the summer in the outer delta, channels and near shore areas (Reist et al. 2001). The diet of the anadromous lake whitefish includes a variety of organisms: gastropods, pelecypods, amphipods, chironomids, notostracans, cladocerns, ostracods and various insects (Reist et al. 2001).

Freshwater Resident Forms

In northern waters, individual fish may only spawn every two or three years (Scott and Crossman 1998). In Great Slave and Great Bear lakes, approximately half of all males and females mature within their eighth year (McPhail and Lindsey 1970). Freshwater resident forms of lake whitefish may spawn anywhere from the late summer to December; however, spawning usually occurs from mid-September to mid-October in northern regions (Richardson et al. 2001). They are known to spawn in both lake and river systems over a variety of substrates from large boulders to gravel and occasionally sand (Richardson et al. 2001). Although lake whitefish appear to avoid using soft bottomed substrates for spawning locations, several authors have noted spawning in areas with silt substrates or emergent vegetation (Richardson et al. 2001).

Spawning usually takes place in shallow water areas at depths less than 8 m, but deeper spawning has been reported (Scott and Crossman 1998). Eggs are released randomly over the hard or stony substrate (Scott and Crossman 1998). The eggs settle into crevices where they incubate for several months before hatching in approximately March to May (Richardson et al. 2001).

Juveniles are commonly found near the surface in shallow water areas close to spawning areas. Within these shallow water zones, young lake whitefish are frequently associated with boulder, cobble or sand substrates in association with emergent vegetation and woody debris (Ford et al. 1995).

Adult lake whitefish tend to leave the spawning grounds shortly after spawning, and to immediately return to deepwater habitat to over winter (Ford et al. 1995). They are frequently found at depths greater than 10 m for most of the year and can occur at depths in excess of 100 m (McPhail and Lindsey 1970). Despite being primarily bottom dwelling, they may be found in the pelagic zone of lakes as well (Ford et al. 1995).

Lake whitefish are known to have nocturnal onshore movements into shallow water habitats at night to feed (McPhail and Lindsey 1970). The diet of lake whitefish includes: snails, clams, terrestrial insects, aquatic insects, plankton, and small fishes (Scott and Crossman 1998). The types of food consumed by lake whitefish are associated with the number and length of gill rakers. Food type has been correlated with gill raker length to such a strong degree that fish with shorter and more plentiful rakers have been shown to eat a higher proportion of benthic food sources (Scott and Crossman 1998).

Lake whitefish are preyed upon by lake trout, burbot and whitefish themselves in both the egg and adult life-stages (Scott and Crossman 1998). They are also deemed to be one of the most valuable commercial freshwater fish species in Canada (Scott and Crossman 1998).

11.2.1.8 Longnose Sucker

The longnose sucker is common throughout the NT and NU (Richardson et al. 2001). Longnose suckers occur in a variety of freshwater habitats including lakes, rivers and streams throughout their geographic range. The species is known to exhibit lacustrine, adfluvial, and riverine life history types (Richardson et al. 2001).

Sexual maturity occurs at approximately five years for males and six years for females (Richardson et al. 2001). Longnose suckers spawn in the spring, from April to June, shortly after melting of ice cover on lakes (Richardson et al. 2001). Longnose sucker are broadcast spawners that primarily spawn in streams and rivers. Lake spawning may also occur in the shallows of lakes, along rocky and wave swept shorelines. Lake spawning usually occurs in water depths of 15 to 30 cm, over gravel or sand substrates (Richardson et al. 2001). The adhesive eggs incubate from 11 to 15 days before hatching (Richardson et al. 2001). The young remain in the gravel substrate for seven to fourteen days before emerging (depending upon water temperature). They will then occupy shallow areas of lakes, in association with vegetation and sandy substrates. Juveniles are also known to inhabit shallow weedy areas (Richardson et al. 2001).

Adult longnose suckers often inhabit deeper waters than other species of sucker, and have been known to occur at water depths of up to 183 m (Richardson et al. 2001). Longnose sucker grow considerably larger and live much longer in northern lakes, such as Great Slave Lake in the NT, than in southern water bodies.

The diet of longnose sucker consists mostly of amphipods, chironomids, midge larvae, caddisfly larvae and sphaeriid clams (Richardson et al. 2001). Their ventral mouth and large papillose lips aid in suction as they primarily feed on invertebrates from stream and lake beds (Mecklenburg et al. 2002).

11.2.1.9 Ninespine Stickleback

The ninespine stickleback occurs throughout the NT and NU, from the Mackenzie Delta and River, in most rivers and lakes of north-central Canada, as well as in portions of the Arctic Archipelago (Lee et al. 1980; McPhail and Lindsey 1970; Scott and Crossman 1998). Ninespine stickleback is known to frequent slow streams, tundra ponds and the shallow bays of lakes (Lee et al. 1980; McPhail and Lindsey 1970; Scott and Crossman 1998). It displays lacustrine, riverine and anadromous life history types (McPhail and Lindsey 1970; Scott and Crossman 1998).

Ninespine sticklebacks primarily mature in their first year, with a life expectancy of approximately only three and a half years (Scott and Crossman 1998; Wootton 1984). They tend to spawn in shallow waters during the spring and summer, ranging from May to July (McPhail and Lindsey 1970; Scott and Crossman 1998; Wootton 1976). Nests are built by the males, amongst weeds in densely vegetated areas. The nests are usually 10 to 15 cm off the bottom or sometimes directly on the bottom (McPhail and Lindsey 1970; Morrow 1980; Scott and Crossman 1998; Scott and Scott 1988; Wootton 1976). The male produces a secretion to bind the aquatic vegetation and debris together into a nest like structure. Males may also create nests using burrows made in muddy organic bottoms or may use areas between rocks along wave swept lake shores (McPhail and Lindsey 1970; Morrow 1980; Scott and Crossman 1998; Wootton 1976). Females will enter the nest, laying 20 to 30 eggs, which the male then fertilizes (Scott and Crossman 1998). The male chases the female away and guards the nests from predators (Scott and Crossman 1998). Eggs hatch after four to seven days and the young-of-the-year are then moved into a nursery area constructed by the male from nest building material immediately above the nest (McPhail and Lindsey 1970; Morrow 1980; Wootton 1976). The young remain in the nest until they are free swimming. They then disperse into vegetation filled shallow waters and into deeper waters in the fall to overwinter (Goodyear et al. 1982; McPhail and Lindsey 1970; Morrow 1980).

Adult stickleback typically inhabit densely vegetated areas; however, they can also use open water areas over sand and gravel beaches with sparse vegetation (McPhail and Lindsey 1970; Scott and Crossman 1998). The stickleback is a species that is able to tolerate low oxygen levels (Morrow 1980).

The diet of the ninespine stickleback consists of aquatic insects, chronomid larvae, small crustaceans, molluscs, cladocerans and other zooplankton (McPhail and Lindsey 1970; Scott and Crossman 1998). When their numbers are in abundance, the ninespine stickleback is of considerable importance to the diets of other piscivorous fish species (Scott and Crossman 1998).

11.2.1.10 Round Whitefish

Round whitefish occur in the NT and NU. It is found from Great Slave Lake and the Mackenzie River Valley in the NT, east to the Keewatin district of NU (Scott and Crossman 1998).

Spawning occurs from autumn to early winter, although in the more northern regions it usually occurs in October, primarily in lakes and occasionally in streams and rivers. Gravel and rubble (cobble sized material) substrates are preferred by round whitefish for spawning purposes (Normandeau 1969; Richardson et al. 2001). Males will usually arrive on the spawning grounds first, once the females arrive the fish will pair up instead of large spawning schools occurring (Scott and Crossman 1998). Round whitefish broadcast spawn their eggs over the chosen substrate, in 15 to 200 cm of water (Normandeau 1969). Hatching time will vary depending upon water temperatures, but generally occurs between March and May (Goodyear et al. 1982). After emerging from the eggs the young are generally found near the bottom and are associated with rock, sand and gravel substrates (Goodyear et al. 1982).

Adult round whitefish tend to be found over rocky substrates often in association with boulders (McPhail and Lindsey 1970). They are commonly found in shallows of lakes or slow flowing rivers and streams, and even in brackish waters (McPhail and Lindsey 1970; Scott and Crossman 1998).

The diet of round whitefish consists of a variety of benthic invertebrates, primarily mayfly, caddisfly and chironomids larvae, as well as small crustaceans, fishes and molluscs (Scott and Crossman 1998). Round whitefish are also suspected to feed on the eggs of other species of fish (Scott and Crossman 1998). In the north, they are known to be a component of the diet of lake trout; however, they do not make up a large portion of the diet (Scott and Crossman 1998).

11.2.1.11 Slimy Sculpin

The slimy sculpin is distributed throughout the NT and NU, with the exception of the mainstem Mackenzie River and Arctic islands (McPhail and Lindsey 1970; Scott and Crossman 1998). It has both lacustrine and riverine life-history types and can be found in cool, clear or muddy waters of rivers; in streams with rocky or gravelly bottoms; as well as in lacustrine habitats (Craig and Wells 1976; Lee et al. 1980; McPhail and Lindsey 1970; Scott and Crossman 1998).

Slimy sculpin spawn in May, usually over sand, gravel and rock substrates in shallow waters (Lee et al. 1980; McPhail and Lindsey 1970; Morrow 1980; Scott and Crossman 1998). Males will select the spawning site, preferably under a rock, a log or a submerged tree root. A female is courted by the male, entering the nest to deposit her adhesive eggs on the ceiling, which the male then fertilizes. The female is driven out by the male, which will then guard the nest until they hatch approximately four weeks later (Lee et al. 1980; Mousseau and Collins 1987; Scott and Crossman 1998). A male sculpin may entice several females to lay eggs in his nest (Goodyear et al. 1982). Most male and female slimy sculpin reach maturity at age-2 (Mohr 1984).

After emerging, young are commonly found over shallow gravel and sand substrates (Mohr 1984). As they mature the young slimy sculpin will gradually shift from shallow water habitat to utilizing deepwater habitat (Mohr 1985). Adult slimy sculpin can be found at a wide range of depths (0.5 m to 210 m) and commonly occupy gravel and rocky substrates in lakes (Mohr 1984, 1985; Scott and Crossman 1998). Some slimy sculpin are known to inhabit soft sediment substrates and show increased growth, suggesting that these environments may be more productive. When living in small and shallow lakes their distribution has been known to show seasonal and diurnal changes due to changes in water temperature and/or oxygen concentrations (Mohr 1984, 1985). In the NT, slimy sculpin were found in areas with both current and wind action in waters less than 10 m deep (McPhail and Lindsey 1970).

Slimy sculpin prey on a variety of aquatic insects, crustaceans, small fishes and aquatic vegetation (McPhail and Lindsey 1970; Mohr 1984).

11.2.2 Fish Communities and Distribution

This section provides a summary of fish presence and distribution within the mine site and site access LSAs, based on fish capture information from the period between 1975 and 2010. Fish abundance and fish health information is limited to recent data collected between 2007 and 2010.

11.2.2.1 Fishing Effort

A number of focused surveys were conducted between 2007 and 2010 to assess spawning, species composition, and to capture fish for metals analysis. The results of the surveys were compiled to develop an understanding of fish distribution. Location (UTM coordinates) of all fishing stations are presented in Attachment X.I.

Arctic grayling spring spawning surveys were conducted on 17 streams; six streams in the Willow Lake sub-basin, eight streams in the Lower Lake sub-basin, and three streams in the Caribou Lake sub-basin. In spring 2008, all 17 streams were sampled (Table 11.2-1). In spring 2009, the spring spawning surveys were focussed on six streams from the Willow Lake sub-basin and only two streams from the Lower Lake sub-basin (Table 11.2-1).

Fish community surveys and fish tissue chemistry collections were conducted on 20 lakes, nine ponds, one river, and three streams (Table 11.2-2). In fall 2007, 11 lakes were sampled, including three from the Willow Lake sub-basin, four from the Lower Lake, and four from the Caribou Lake sub-basins (Table 11.2-2). In summer 2008, the study included 16 lakes, including two lakes from the Willow Lake sub-basin, all eight lakes from the Lower Lake sub-basin, four lakes from the Caribou Lake sub-basin, Judge Sissons Lake and Siamese Lake (Table 11.2-2). In fall 2008, the study included only Cirque Lake from the Caribou Lake sub-basin (Table 11.2-2). In fall 2009, sampling was focussed on select lakes in the Willow Lake sub-basin and Judge Sissons Lake (Table 11.2-2). In spring 2010, sampling was focussed on select pond and streams in the Willow Lake sub-basin and ponds in the Lower Lake sub-basin (Table 11.2-2).

A lake trout fall spawning survey was conducted during fall 2008. The 2008 survey was limited to 14 lakes, including two lakes in the Willow Lake sub-basin, seven lakes in the Lower Lake sub-basin, three lakes in the Caribou Lake sub-basin, Judge Sissons Lake and Siamese Lake (Table 11.2-3).

Fish community surveys were conducted at three stream crossings along the proposed All-Weather Access Road in fall 2008. In summer and fall 2009 fish sampling was done on streams crossed by all proposed road corridors (Table 11.2-4).

Table 11.2-1 Fishing Effort for the Arctic Grayling Spring Spawning Survey, 2008 to 2009

Watercourse	Year	Angling (hour)	Backpack Electrofishing (seconds)	Fyke Netting (hour)	Fish Species	
					Captured	Observed
Willow Lake Sub-Basin						
Northeast inflow of Pointer Lake	2008	1.97	3,100	-	ninespine stickleback	unidentified species
	2009	-	1,158	133.95	ninespine stickleback	ninespine stickleback
Northwest inflow of Pointer Lake	2008	0.92	2,035	-	lake trout	lake trout
	2009	-	1,151	-	-	Arctic grayling
Pointer/Rock Stream	2008	2.00	-	-	no fish captured	-
	2009	4.22	3,095	87.90	Arctic grayling, round whitefish	Arctic grayling, burbot, ninespine stickleback, unknown species

Table 11.2-1 Fishing Effort for the Arctic Grayling Spring Spawning Survey, 2008 to 2009

Watercourse	Year	Angling (hour)	Backpack Electrofishing (seconds)	Fyke Netting (hour)	Fish Species	
					Captured	Observed
Sik Sik/Rock Stream	2008	0.67	1,046	-	no fish captured	-
	2009	-	2,217	137.90	ninespine stickleback	ninespine stickleback
Rock/Willow Stream	2008	-	1,168	-	no fish captured	Arctic grayling[(a)]
	2009	4.75	3,642	90.62	Arctic grayling, cisco, ninespine stickleback, round whitefish	Arctic grayling, lake trout
Willow /Judge Sissons Stream	2008	-	1,896	-	no fish captured	-
	2009	8.55	2,421	94.00	Arctic grayling, lake trout, ninespine stickleback, slimy sculpin	Arctic grayling
subtotal		*22.41*	*22,929*	*544.37*		
Lower Lake Sub-Basin						
Mushroom/End Grid Stream	2008	-	612	-	lake trout	Arctic grayling
End Grid/Shack Stream	2008	-	-	-	-	Arctic grayling[(b)]
Cigar/Lunch Stream	2008	1.00	1,024	-	no fish captured	unidentified species
Knee/Lunch Stream	2008	-	397	-	no fish captured	lake trout[(c)]
Lunch/Andrew Stream	2008	1.20	635	-	no fish captured	-
	2009	1.97	1,139	26.22	Arctic grayling	-
Andrew/Shack Stream	2008	2.13	1,696	-	no fish captured	-
	2009	2.63	717	21.32	Arctic grayling	Arctic grayling
Shack/Lower Stream	2008	6.58	1,192	-	lake trout	lake trout
Lower/Judge Sissons Stream	2008	3.35	975	-	lake trout, ninespine stickleback	unidentified species
subtotal		*18.86*	*8,387*	*47.54*		
Caribou Lake Sub-Basin						
Fox/Caribou Stream	2008	-	904	-	no fish captured	-
Caribou /Calf Stream	2008	1.88	-	-	no fish captured	-
Calf/Judge Sissons Stream	2008	2.07	865	-	Arctic grayling, lake trout	lake trout

Table 11.2-1 Fishing Effort for the Arctic Grayling Spring Spawning Survey, 2008 to 2009

Watercourse	Year	Angling (hour)	Backpack Electrofishing (seconds)	Fyke Netting (hour)	Fish Species	
					Captured	Observed
subtotal		*3.95*	*1,769*	*0*		
Total		**45.22**	**30,085**	**591.91**	**-**	**-**

[(a)] An Arctic grayling was observed while doing the habitat mapping of this stream.
[(b)] An Arctic grayling was observed and photographed while doing the habitat mapping of this stream.
[(c)] A lake trout was observed while collecting water in this stream.

Table 11.2-3 Fishing Effort for the Lake Trout Fall Spawning Survey, 2008

Waterbody	Angling (hour)	Gill Netting		Fish Species	
		Time (hour)	Total Net Length (metre)	Captured	Observed
Willow Lake Sub-Basin					
Pointer Lake	4.62	-	-	no fish captured	-
Willow Lake	2.50	-	-	no fish captured	-
subtotal	*7.12*	*0*	*0*		
Lower Lake Sub-Basin					
Mushroom Lake	2.50	-	-	lake trout	-
Cigar Lake	1.47	-	-	lake trout	-
Knee Lake	1.00	-	-	no fish captured	-
Lunch Lake	1.00	-	-	no fish captured	-
Andrew Lake	3.00	-	-	no fish captured	-
Shack Lake	3.30	-	-	no fish captured	-
Lower Lake	2.07	-	-	no fish captured	-
subtotal	*14.34*	*0*	*0*		
Caribou Lake Sub-Basin					
Ridge Lake	2.20	-	-	lake trout	-
Fox Lake	3.75	-	-	no fish captured	-
Caribou Lake	4.45	-	-	no fish captured	-
subtotal	*10.40*	*0*	*0*		
Judge Sissons Lake Sub-Basin					
Judge Sissons Lake	6.00	1.68	60	lake trout	lake trout
subtotal	*6.00*	*1.68*	*60*		
Siamese Lake Sub-Basin					
Siamese Lake	1.78	-	-	lake trout	-
subtotal	*1.78*	*0*	*0*		

Total	39.64	1.68	60		
Notes: Individual gill net used was 30 m long, with only one panel of 7.6 cm as mesh size.					
- = not applicable.					

11.2.2.2 Fish Distribution

Seven fish species (Arctic grayling, burbot, cisco, lake trout, ninespine stickleback, round whitefish, and slimy sculpin) were captured or observed in lakes in the mine site and site access LSAs (Appendix 11A, Table 11A-1). Squiggly Lake, which is located in the Thelon River Watershed, is reported to have five fish species including Arctic char, Arctic grayling, burbot, lake trout, and round whitefish (Table 11A-1). Baker Lake is reported to have 11 fish species including Arctic char, Arctic grayling, burbot, cisco, fourhorn sculpin, lake trout, lake whitefish, longnose sucker, ninespine stickleback, round whitefish, and slimy sculpin (Table 11A-1).

The most widely distributed fish species is the Arctic grayling, captured or reported in 25 of 34 lakes and nine ponds in the Aniguq River Watershed. Conversely, slimy sculpin has been reported in only two lakes (Scotch and Judge Sissons lakes) in the Aniguq River Watershed as well as in Baker Lake. Fourhorned sculpin have only been captured in Baker Lake.

Seven fish species (Arctic grayling, burbot, cisco, lake trout, ninespine stickleback, round whitefish, and slimy sculpin) were captured or observed in streams within the Aniguq River watershed (Table 11A-2). Eight species (Arctic char, Arctic grayling, cisco, lake trout, longnose sucker, ninespine stickleback, round whitefish, and slimy sculpin) were captured or observed in the Thelon River. Similar to its presence in the lakes of the watershed, Arctic grayling is the most widely distributed fish species in the streams of the Aniguq River watershed. Conversely, the cisco was captured only in Rock/Willow Stream.

Figures summarizing the distribution of fish in the Kiggavik Project Area have been included in Attachment X.IX. Figure X.IX-1a provides a summary of fish captured in lakes in the mine site LSA and Baker Lake. Figure X.IX-1b provides a summary of fish captured in small ponds in the mine site LSA. Figure X.IX-2 provides a summary of fish captured in streams in the sub-basins that flow into Judge Sissons Lake (i.e., Lower Lake, Willow Lake, and Caribou Lake sub-basins). The results of the fish sampling on the various road alignment options examined in 2008 and 2009 are shown in Figures X.IX-3a and X.IX-3b (Attachment X.IX).

Mine Site Local Study Area

Willow Lake Sub-Basin

The Willow Lake sub-basin 2008 spring spawning survey included 5.56 hours of angling and 9,245 seconds of backpack electrofishing (Table 11.2-1). Fish were captured or observed in 50% of the streams, including the northeast (ninespine stickleback) and northwest (lake trout) inflow of Pointer Lake and in the Rock/Willow Stream (Arctic grayling).

During the fish community and fish chemistry surveys completed from fall 2007 to spring 2010, the fishing effort included 9.8 hours of angling, 12,491 seconds of backpack electrofishing, 102 hours of gill netting, and 798 hours of minnow trapping (Table 11.2-2). Fish were captured or observed in all lakes, with Arctic grayling present in all lakes other than Sik Sik Lake, ninespine stickleback in two lakes (Sik Sik and Willow lakes), and cisco and lake trout captured or observed only in Pointer Lake.

During the 2008 fall spawning survey 2008, fishing effort included 7.1 hours of angling (Table 11.2-3). No fish were captured in Pointer or Willow lakes.

Fish sampling was carried out in 11 lakes and Pointer Pond in the Willow Lake sub-basin between 1975 and 2010 (Table 11A-1). Fish were captured in all lakes except Meadow Lake, the furthest upstream lake of the sub-basin. No fish were captured in Pointer Pond, but fishing was limited. Slimy sculpin were captured in spring 2010 within the first 10 m upstream of Pointer Pond in the Upper Northwest Inflow of Pointer Lake (Table 11A-2). This stream was dry by late August 2010. Arctic grayling were present in all lakes, except Meadow, Scotch, and Sik Sik lakes. Lake trout were present in six lakes located throughout the sub-basin. Ninespine stickleback were reported in four lakes, from Scotch Lake down to Willow Lake. Round whitefish were present in three lakes located from Felsenmeer Lake to Pointer Lake. Cisco were captured only in Pointer Lake and slimy sculpin were only present in Scotch Lake.

Lower Lake Sub-Basin

In the Lower Lake sub-basin, spring 2008 sampling included 14.26 hours of angling and 6,531 seconds of backpack electrofishing in (Table 11.2-1). Fish were captured or observed in 62% of the streams throughout the sub-basin. Lake trout were found in four streams (Mushroom/End Grid Stream, Knee/Lunch Stream, Shack/Lower Stream, and Lower/Judge Sissons Stream). Arctic grayling were in two connected stream sections (Mushroom/End Grid Stream and End Grid/Shack Stream). Ninespine stickleback was only found at the bottom of the sub-basin in Lower/Judge Sissons Stream.

During the fish community and fish chemistry surveys completed from fall 2007 to spring 2010, the fishing effort included 8.9 hours of angling, 10,571 seconds of backpack electrofishing, 280 hours of gill netting, and 1,993 hours of minnow trapping (Table 11.2-2). No fish were captured in the eight ponds, but fish were captured or observed in all lakes, with Arctic grayling in all lakes other than Cigar Lake. Round whitefish were present in five lakes located throughout the sub-basin, including Mushroom, Cigar, Lunch, Andrew, and Lower lakes. Burbot were present in Cigar, Andrew, and Lower lakes. Lake trout were present in Mushroom and Cigar lakes. Cisco were captured only in Cigar Lake and ninespine stickleback was present only in Lower Lake.

During the lake trout fall spawning survey of 2008, the fishing effort was composed of 14.3 hours of angling (Table 11.2-3). Lake trout in spawning conditions were captured in Mushroom and Cigar lakes, while no fish were captured in the other five lakes sampled (Knee, Lunch, Andrew, Shack, and Lower lakes).

A total of 10 lakes and eight ponds were sampled in the Lower Lake sub-basin between 1975 and 2010 (Table 11A-1). No fish were captured in the eight ponds. Arctic grayling were present in all ten lakes. Round whitefish were present in five lakes (Mushroom, Cigar, Lunch, Andrew, and Lower lakes). Lake trout were present in three lakes located throughout the sub-basin, including Mushroom, Cigar and Lunch lakes. Cisco were present in five lakes located throughout the sub-basin, including Mushroom, Smoke, Cigar, Lunch, and Lower lakes. Burbot were present in Cigar, Andrew, and Lower lakes. Finally, ninespine stickleback were present only in Lower Lake, at the downstream end of the sub-basin.

Caribou Lake Sub-Basin

The spring 2008 spawning survey in the Caribou Lake sub-basin included 3.9 hours of angling and 1,769 seconds of backpack electrofishing (Table 11.2-1). Arctic grayling and lake trout were the only species captured or observed. These fish were captured only in the Calf/Judge Sissons Stream section.

The fish community and fish chemistry surveys from fall 2007 to summer 2008 included 1.2 hours of angling, 173 hours of gill netting, and 462 hours of minnow trapping (Table 11.2-2). Fish were captured or observed in all lakes sampled in the sub-basin. Ninespine stickleback were captured in Cirque, Fox, Caribou, and Calf lakes. Arctic grayling were present in three lakes located in the lower half of the sub-basin (Crash, Fox, and Caribou lakes). Cisco were found in the three lakes located at the downstream end of the sub-basin, including Fox, Caribou, and Calf lakes. Burbot were found in two lakes, Caribou and Calf lakes, at the downstream end of the sub-basin. Lake trout were also found in only two lakes, one of which was a headwater lake (Ridge Lake) and the other near the downstream end of the sub-basin (Caribou Lake). Round whitefish was only found in Caribou Lake.

During the lake trout fall spawning survey of 2008, fishing effort consisted of 10.4 hours of angling (Table 11.2-3). Lake trout in spawning conditions were captured in Ridge Lake, while no fish were captured in the two other lakes sampled (Fox and Caribou lakes).

Six lakes had been sampled in the Caribou Lake sub-basin between 1979 and 2009 (Table 11A-1). Fish were captured in all sampled lakes in this sub-basin. Arctic grayling were present in four lakes (Cirque, Crash, Fox, and Caribou lakes). Ninespine stickleback were also present in four lakes (Cirque, Fox, Caribou, and Calf lakes). Lake trout were present in Ridge, Fox, and Caribou lakes. Spatially, lake trout were found in lakes throughout the sub-basin, from Ridge Lake near the headwaters to Caribou Lake near Judge Sissons Lake. Cisco were also present in three lakes in the lower portion of the sub-basin (i.e., Fox, Caribou, and Calf lakes). Burbot were present in two lakes located at the downstream end of the sub-basin (Caribou and Calf lakes). Finally, round whitefish were only present in Caribou Lake, at the downstream end of the sub-basin.

Judge Sissons Lake Sub-Basin

During the fish community and fish chemistry surveys completed from summer 2008 to fall 2009, the fishing effort included 26 hours of angling, 8.3 hours of gill netting, and 379 hours of minnow trapping (Table 11.2-2). Six fish species were captured or observed in Judge Sissons Lake, including Arctic grayling, burbot, cisco, lake trout, ninespine stickleback, and round whitefish.

The lake trout fall spawning survey of 2008 in Judge Sissons Lake, included 6.0 hours of angling and 1.7 hours of gill netting (Table 11.2-3). Lake trout in spawning condition were captured.

Seven fish species have been captured in Judge Sissons Lake in surveys conducted between 1975 and 2009, including Arctic grayling, burbot, cisco, lake trout, ninespine stickleback, round whitefish, and slimy sculpin. Of the seven fish species reported from the lake during historic surveys, only slimy sculpin were not captured again in recent years (Table 11A-1). This likely reflects bias in the sampling methods used between 2007 and 2009 and the focus on large-bodied fish species. Arctic char have not been captured or observed in Judge Sissons Lake.

Siamese Lake Sub-Basin

Only Siamese Lake was sampled in this sub-basin. The fish community survey completed during summer 2008 employed 4.6 hours of angling and 5.1 hours of gill netting (Table 11.2-2). Lake trout was the only species encountered.

During the lake trout fall spawning survey of 2008, the fishing effort included 1.8 hours of angling (Table 11.2-3). Lake trout in spawning conditions were captured.

Lake trout is the only fish species which has been captured or observed in Siamese Lake (Table 11A-1). As this lake is not in the LSA it was not subject to intensive fish surveys, therefore, the lack of other fish species in the catch may be an artifact of the lack of sampling.

Skinny Lake Sub-Basin

Skinny lake was sampled several time between 1987 and 1992. Four fish species have been reported in Skinny Lake (Table 11A-1). These included Arctic grayling, cisco, lake trout, and round whitefish.

Kavisilik Lake Sub-Basin

Kavisilik Lake was sampled several time between 1987 and 1992. Four fish species have been reported in Kavisilik Lake (Table 11A-1). These included Arctic grayling, cisco, lake trout, and round whitefish.

Site Access Local Study Area

Squiggly Lake Sub-Basin

Kavisilik Lake was sampled several time between 1987 and 1992. Squiggly Lake is the only lake in the Project Area that is located in the Thelon River watershed. The species assemblage is similar to other lakes in the project area, with the notable addition of Arctic char. Species reported in the lake include Arctic char, Arctic grayling, burbot, lake trout, and round whitefish (Table 11A-1).

Baker Lake Sub-Basin

Baler Lake was sampled in 1976 and again in 2008 and 2009. Eleven fish species have been reported from Baker Lake (Table 11A-1), including Arctic char, Arctic grayling, burbot, fourhorn sculpin, cisco, lake trout, lake whitefish, longnose sucker, ninespine stickleback, round whitefish, and slimy sculpin.

Aniguq River

Five species have been captured in the Aniguq River between 1975 and 2009 (Table 11A-2). These included Arctic grayling, burbot, lake trout, ninespine stickleback, and slimy sculpin. During the sampling carried out in September 2009, Arctic char were not captured or observed at the sampling stations located upstream and downstream of a set of chutes and cascades believed to be barriers to fish movement.

Thelon River

Eight fish species have been captured in the Thelon River (Table 11A-2), including Arctic char, Arctic grayling, cisco, lake trout, longnose sucker, ninespine stickleback, round whitefish, and slimy sculpin. Lake trout, Arctic grayling and slimy sculpin were the only fish species captured near the current proposed bridge crossing of the Thelon River.

Site Access Local Study Area

Stream crossing assessments were carried out at 37 stream crossings along the proposed North All-Weather Access Road (west of the Thelon River) and six stream crossings along the proposed Winter Access Road corridor. The eastern portion of the road alignment includes road options between the Thelon River and the town of Baker Lake. An additional southern alignment, which would link an optional barge facility on the southwest shore of Baker Lake to the northern route, thereby avoiding the Thelon River, was examined in 2009. A total of 16 and 18 stream crossings were examined along the eastern and southern road alignments, respectively (refer to summary figures in Attachment X.IX Figures X.IX-3a and X.IX-3b)

As noted in Section 10.2.4, streams crossed by the proposed road alignments generally fell into three categories:

- Small drainages that had no defined or no visible channel:
- Small to intermediate sized streams (channel widths of 1 to 5 m); and
- Large streams or rivers (i.e., channel widths greater than 5 m).

North All-Weather Access Road – West of the Thelon River

Fish are widely distributed in the streams crossed by the northern road corridor (Attachment X.IX, Figures X.IX-3a and X.IX-3b). Fish species present during the 2009 surveys included Arctic grayling, longnose sucker, lake trout, round whitefish, slimy sculpin, and ninespine stickleback. No fish were captured or observed in water courses that were less than 1 m in width. Ninespine stickleback and slimy sculpin were present if the stream was greater than 1 m wide, (e.g., crossing Km 147.1). Large-bodied fish species, such as lake trout and Arctic grayling, were found in streams with bankfull widths of approximately 3 m or more (e.g., crossing Km 2.0). Although Arctic char were historically reported in the Thelon River (crossing Km 174.8), none were observed or captured during the time of the 2009 surveys. Fish were generally not present in stream channels where substrates were dominated by organics.

North All-Weather Access Road – East of the Thelon River

Arctic grayling, lake trout, and ninespine stickleback were observed at five crossings along the eastern road alignment (Attachment X.IX, Figures X.IX-3a and X.IX-3b). Lake trout were present in lakes upstream and downstream of crossing Km 197.5. Arctic grayling were only observed at crossing Km 213.1. Small-bodied fish (including ninespine stickleback and an unidentified fish species) were observed at crossing Km 203.0 and alternate crossing EC22, which had average channel widths of 6.3 and 7.7 m, respectively. Unlike the streams surveyed along other road corridors, the presence of fish did not appear to be related to substrate type, channel width, habitat type or availability of instream cover.

Winter Access Road

Ninespine stickleback and slimy sculpin were the only fish species captured during the 2009 assessment of the winter road alignment (Attachment X.IX, Figures X.IX-3a and X.IX-3b). Ninespine stickleback were only captured in a pond upstream of alternate crossing W1 (there was no visible channel at the crossing location) as well as at alternate crossing W2 and W3. Slimy sculpin were captured near alternate crossing W2. Habitat assessments performed on the six potential winter road crossing sites (refer to Section 10.2.4.3) suggest that fish were present if instream cover was available and the bankfull channel width was at least 0.5 m. Dominant substrate did not appear to influence fish presence. Water depth in all of the streams surveyed along the winter road alignment were less than 0.7 m, therefore, these streams would freeze to the bottom during the winter months. Based on the observed habitat conditions, it is unlikely that fish could overwinter at the proposed crossing locations.

South All-Weather Access Road

Fish species present along the southern road alignment were similar to those found in the other road corridors assessed in 2009 (Attachment X.IX, Figures X.IX-3a and X.IX-3b). Arctic grayling, slimy sculpin, burbot, and ninespine stickleback were encountered; ninespine stickleback were present in all streams sampled. The next most common species captured was slimy sculpin. Fish were captured or observed in streams with average channel widths from 2.8 (crossing S3) to 57.5 m (crossing S5).

11.2.3 Relative Abundance

During the Arctic grayling spawning surveys only 22 Arctic grayling was encountered. Other species captured included 31 lake trout, 12 ninespine stickleback, 6 slimy sculpin, 3 round whitefish, and 1 cisco (Table 11.2-5). Arctic grayling abundance was variable between streams and by method. Backpack electrofishing effort ranged from 0.12 fish per 100 seconds (fish/100s) of backpack electrofishing. Angling effort was 1.1 fish per angling hour. Fyke nets captured between 0.01 and 0.19 fish per net hour (Table 11A-3). Arctic grayling CPUE was highest for all methods in Andrew/Shack Stream. Lake trout CPUE was 0.3 to 2.9 fish per hour (fish//h) for angling; 0.04 to 0.33 fish/100 s for backpack electrofishing; and 0.01 to 0.19 fish/h for the Fyke net (Table 11A-3).

During the fish community and fish chemistry surveys in 2008, 2009, and 2010, a total of 534 fish were captured, including 140 lake trout, 164 Arctic grayling, 107 cisco, 56 ninespine stickleback, 50 round whitefish, 9 burbot, and 8 slimy sculpin (Table 11.2-5). Lake trout CPUE ranged from 0.52 to 3.27 fish/h for angling, and from 0.008 to 2.72 fish/h/100 m of gill net (Table 11A-4). Arctic grayling CPUE ranged from 0.08 to 3.27 fish/h for angling; 0.008 to 0.55 fish/h/100 m of gill net, and 0.05 to 0.10 fish/h for minnow trapping. Cisco CPUE ranged from 0.006 to 0.74 fish/h/100 m of gill net. Round whitefish CPUE ranged from 0.006 to 1.11 fish/h/100 m of gill net. Burbot CPUE ranged from

0.002 to 0.02 fish/h/100 m of gill net and from 0.003 to 0.02 fish/h for minnow trapping. Ninespine stickleback CPUE was 0.02 fish/h/100m of gill net and 0.005 to 0.17 fish/h for minnow traps. Slimy sculpin CPUE was 0.22 fish/100 s for backpack electrofishing (Table 11A-4).

Table 11.2-5 Summary of Fish Species and Number Captured During the 2007 to 2010 Surveys, by Type of Survey

Fish Species	Arctic Grayling Spawning Survey	Fish Community and Chemistry Surveys	Lake Trout Spawning Survey	All-Weather Access Road Survey	Total
Arctic grayling	22	164	0	74	**260**
Burbot	0	9	0	2	**11**
Cisco	1	107	0	0	**108**
Lake trout	31	140	21	12	**204**
Longnose sucker	0	0	0	4	**4**
Ninespine stickleback	12	56	0	488	**556**
Round whitefish	3	50	0	4	**57**
Slimy sculpin	6	8	0	87	**101**
Total	**75**	**534**	**21**	**671**	**1,301**

During the fall lake trout spawning survey, 21 lake trout were captured. The CPUE ranged from 0.80 to 3.40 fish/h for angling (Table 11.2.-6).

During the fish survey along the access road corridors in 2008 and 2009, 671 fish were captured (Table 11.2-5). The CPUE is summarized in Table 11.2-7. Arctic grayling CPUE ranged from 0.04 to 5.15 fish/100 s of backpack electrofishing and 1 fish/h of angling. Burbot CPUE ranged from 0.11 to 0.12 fish/100 s of backpack electrofishing. Lake trout CPUE ranged from 0.25 to 2.70 fish/h of angling. Longnose sucker CPUE was 62 fish/100 s of backpack electrofishing. Ninespine stickleback CPUE was 0.11 to 95 fish/100 s of backpack electrofishing. Round whitefish CPUE was 0.86 fish/100 s of backpack electrofishing. Slimy sculpin CPUE ranged from 0.11 to 4.1 fish/100 s of backpack electrofishing.

Table 11.2-6 Catch-Per-Unit-Effort for the Lake Trout Fall Spawning Survey, 2008

Waterbody	Season and Year	Fish Species	Angling (hour)	Angling		Gill Netting			
				Fish Captured	CPUE (fish/h)	Time (hour)	Net Length (metres)	Fish Captured	CPUE (fish/h/100 m net)
Willow Lake Sub-Basin									
Pointer Lake	fall 2008	no fish captured	4.62	0	0	-	-	-	-
Willow Lake	fall 2008	no fish captured	2.50	0	0	-	-	-	-
Lower Lake Sub-Basin									
Mushroom Lake	fall 2008	lake trout	2.50	2	0.80	-	-	-	-
Cigar Lake	fall 2008	lake trout	1.47	5	3.40	-	-	-	-
Knee Lake	fall 2008	no fish captured	1.00	0	0	-	-	-	-
Lunch Lake	fall 2008	no fish captured	1.00	0	0	-	-	-	-
Andrew Lake	fall 2008	no fish captured	3.00	0	0	-	-	-	-
Shack Lake	fall 2008	no fish captured	3.30	0	0	-	-	-	-
Lower Lake	fall 2008	no fish captured	2.07	0	0	-	-	-	-
Caribou Lake Sub-Basin									
Ridge Lake	fall 2008	lake trout	2.20	6	2.73	-	-	-	-
Fox Lake	fall 2008	no fish captured	3.75	0	0	-	-	-	-
Caribou Lake	fall 2008	no fish captured	4.45	0	0	-	-	-	-
Judge Sissons Lake Sub-Basin									
Judge Sissons Lake	fall 2008	lake trout	6.00	6	1.00	1.68	60	0	0
Siamese Lake Sub-Basin									
Siamese Lake	fall 2008	lake trout	1.78	2	1.12	-	-	-	-

Notes: Individual gill net used was 30 m long, with only one panel of 7.6 cm as mesh size.
\- = not applicable; CPUE = catch-per-unit-effort; fish/h = fish per hour; fish/h/100 m net = fish per hour per 100 metres of net.

11.2.3.1 Mine Site Local Study Area

Willow Lake Sub-Basin

Cisco (66) was the most abundant fish species represented in the Willow Lake sub-basin, but its presence was limited to Pointer Lake (Table 11.2-8). Arctic grayling (38) was found in three lakes: Pointer, Rock, and Willow. Ninespine stickleback (18) was present in all streams but Pointer/Rock Stream and also present in two lakes (Pointer and Sik Sik lakes). Round whitefish (3) was the least abundant fish species captured in the sub-basin. The CPUE during the spring spawning survey is summarized in Table 11A-3. The CPUE during the fish community and fish chemistry surveys is summarized in Table 11A-4.

Table 11.2-8 Summary of Fish Species and Numbers Captured During the 2007 to 2010 Surveys in the Willow Lake Sub-Basin, by Type of Survey

Watercourse and Waterbody	Type of Survey	Fish Species					
		Arctic Grayling	Cisco	Lake Trout	Ninespine Stickleback	Round Whitefish	Slimy Sculpin
Northeast Inflow of Pointer Lake	spring spawning	0	0	0	3	0	0
Upper Tributary to the Northeast Inflow of Pointer Lake	fish community survey	0	0	0	0	0	0
Upper Northwest Inflow of Pointer Lake	fish community survey	0	0	0	0	0	8
Pointer Pond	fish community survey	0	0	0	0	0	0
Northwest Inflow of Pointer Lake	spring spawning	0	0	2	0	0	0
Pointer Lake	fish community, chemistry	16	65	5	5	0	0
	fall spawning	0	0	0	0	0	0
Pointer/Rock Stream	spring spawning	1	0	0	0	1	0
Sik Sik Lake	fish community	0	0	0	3	0	0
Sik Sik/Rock Stream	spring spawning	0	0	0	4	0	0
Rock Lake	fish community	10	0	0	0	0	0
Rock/Willow Stream	spring spawning	6	1	0	2	2	0
Willow Lake	fish community	1	0	0	0	0	0
Willow/Judge Sissons Stream	spring spawning	4	0	10	1	0	6
Total		**38**	**66**	**17**	**18**	**3**	**14**

Lower Lake Sub-Basin

Arctic grayling (87) and lake trout (64) were the most abundant species in the Lower Lake sub-basin catch. Cigar and Mushroom lakes exhibited the highest abundance of lake trout (Table 11.2-9). Arctic grayling were present in all lakes except for Cigar Lake and were observed in two streams. Round whitefish (38) was most abundant in Mushroom Lake and was also present in low numbers in several shallow lakes. Ninespine stickleback (25) was only present in Lower Lake and Lower/Judge Sissons Stream reach. Burbot (4) was present in Lower, Andrew, and Cigar lakes; and cisco (2) was present in Cigar and Andrew lakes. No fish were captured in the eight ponds located north of Andrew Lake despite abundant effort (i.e., 5.6 hours of angling, more than 10,000 seconds of backpack electrofishing, and 787 hours of minnow trapping; Table 11A-4).

Table 11.2-9 Summary of Fish Species and Number Captured During the 2007 to 2009 Surveys in the Lower Lake Sub-Basin, by Type of Survey

Watercourse and Waterbody	Type of Survey	Fish Species					
		Arctic Grayling	Burbot	Cisco	Lake Trout	Ninespine Stickleback	Round Whitefish
Mushroom Lake	fish community, chemistry	5	0	0	17	0	31
	fall spawning	0	0	0	2	0	0
Pond 1 to Pond 8	fish community	0	0	0	0	0	0
Mushroom/End Grid Stream	spring spawning	observed	0	0	2	0	0
End Grid Lake	fish community	3	0	0	0	0	0
End Grid/ Shack Stream	spring spawning	observed	0	0	0	0	0
Cigar Lake	fish community	0	1	1	27	0	1
	fall spawning	0	0	0	5	0	0
Cigar/Lunch Stream	spring spawning	0	0	0	0	0	0
Knee Lake	fish community	3	0	0	0	0	0
	fall spawning	0	0	0	0	0	0
Knee/Lunch Stream	spring spawning	0	0	0	0	0	0
Lunch Lake	fish community	3	0	0	0	0	1
	fall spawning	0	0	0	0	0	0
Lunch/Andrew Stream	spring spawning	1	0	0	0	0	0

Table 11.2-9 Summary of Fish Species and Number Captured During the 2007 to 2009 Surveys in the Lower Lake Sub-Basin, by Type of Survey

Watercourse and Waterbody	Type of Survey	Fish Species					
		Arctic Grayling	Burbot	Cisco	Lake Trout	Ninespine Stickleback	Round Whitefish
Andrew Lake	fish community	24	2	1	0	0	2
	fall spawning	0	0	0	0	0	0
Andrew/Shack Stream	spring spawning	9	0	0	0	0	0
Shack Lake	fish community	6	0	0	0	0	0
	fall spawning	0	0	0	0	0	0
Shack/Lower Stream	spring spawning	0	0	0	2	0	0
Lower Lake	fish community, chemistry	33	1	0	0	24	3
	fall spawning	0	0	0	0	0	0
Lower/Judge Sissons Stream	spring spawning	0	0	0	9	1	0
Total		**87**	**4**	**2**	**64**	**25**	**38**

The CPUE during the spring spawning survey is summarized in Table 11A-3. The CPUE during the fish community and fish chemistry surveys is summarized in Table 11A-4. The CPUE during the fall spawning survey is summarized in Table 11.2-6.

Caribou Lake Sub-Basin

Cisco (60) was the most abundant fish species captured in the Caribou Lake sub-basin. The highest abundance of cisco occurred in Caribou and Calf lakes (Table 11.2-10). Lake trout (48) was most abundant in Ridge Lake and present in low numbers in Caribou Lake and Calf/Judge Sissons Streams. Arctic grayling (35) was most abundant in Fox Lake. Arctic grayling were also present in low numbers in Crash and Caribou lakes and in the Calf/Judge Sissons Stream. Ninespine stickleback (20) was most abundant in Caribou Lake. Round whitefish (5) was only captured in Caribou Lake. Burbot (4) was present only in the lower portion of the sub-basin, in Caribou Lake and in Calf Lake.

Table 11.2-10 Summary of Fish Species and Numbers Captured During the 2007 to 2008 Surveys in the Caribou Lake Sub-Basin, by Type of Survey

Watercourse and Waterbody	Type of Survey	Fish Species					
		Arctic Grayling	**Burbot**	**Cisco**	**Lake Trout**	**Ninespine Stickleback**	**Round Whitefish**
Ridge Lake	fish community	0	0	0	35	0	0
	fall spawning	0	0	0	6	0	0
Cirque Lake	fish community	0	0	0	0	7	0
Crash Lake	fish community	2	0	0	0	0	0
Fox Lake	fish community	28	0	1	0	2	0
	fall spawning	0	0	0	0	0	0
Fox/Caribou Stream	spring spawning	0	0	0	0	0	0
Caribou Lake	fish community, chemistry	4	3	38	1	10	5
	fall spawning	0	0	0	0	0	0
Caribou/Calf Stream	spring spawning	0	0	0	0	0	0
Calf Lake	fish community	0	1	21	0	1	0
Calf/Judge Sissons Stream	spring spawning	1	0	0	6	0	0
Total		**35**	**4**	**60**	**48**	**20**	**5**

Judge Sissons Lake Sub-Basin

Lake trout (45) was the most abundant fish species captured in Judge Sissons Lake. Round whitefish (7) and Arctic grayling (7) were the next most abundant, followed by cisco and ninespine stickleback, and burbot (Table 11.2-11). The CPUE during the 2007 to 2009 fish community and fish chemistry surveys is summarized in Table 11A-4. The CPUE during the fall spawning survey is summarized in Table 11.2-6.

Table 11.2-11 Summary of Fish Species and Numbers Captured During the 2008 to 2009 Surveys in Judge Sissons Lake, by Type of Survey

Watercourse and Waterbody	Type of Survey	Fish Species					
		Arctic Grayling	Burbot	Cisco	Lake Trout	Ninespine Stickleback	Round Whitefish
Judge Sissons Lake	fish community, chemistry	7	1	2	39	2	7
	fall spawning	0	0	0	6	0	0
Total		**7**	**1**	**2**	**45**	**2**	**7**

Siamese Lake

Lake trout (6) was the only fish species captured in Siamese Lake (Table 11.2-12). Lake trout in spawning conditions were captured in fall 2008. The CPUE during the 2008 fish community and fish chemistry surveys is summarized in Table 11A-4.

Table 11.2-12 Summary of Fish Species and Numbers Captured During the 2008 Surveys in Siamese Lake, by Type of Survey

Watercourse and Waterbody	Type of Survey	Lake Trout
Siamese Lake	fish community, chemistry	4
	fall spawning	2
Total		**6**

11.2.3.2 Site Access Local Study Area

Baker Lake

Fish sampling at Site 1, in 2008, was limited by poor weather conditions on Baker Lake during the field program. Despite using two sampling methods (long-lining and gill nets) over a four hour period at Site 1, no fish were captured.

Fishing was more successful in 2009, with 56 captured at Site 2. Fish species represented in the catch included lake trout (24), lake whitefish (23), cisco (5), Arctic char (3), and Arctic grayling (1).

11.2.4 Fish Health

Fish captured were identified to species and an external or full health assessment was completed. The full health assessment involved both external and internal examinations and was done on fish that were being retained for metals analysis (tissue) or had died during capture. An exception to this occurred in the summer of 2008, when higher than normal water temperatures were experienced and fish were subject to heat stress. To reduce stress on the fish and lower the risk of mortalities, 22 fish were released without completing the health assessments. Due to time constraints during the 2009 stream crossing assessments, only weights and lengths were recorded for some fish.

During fish sampling completed between 2007 and 2010, a total of 995 fish from eight species were processed (Table 11.2-13). Fish health assessment (external only or full) were completed on 28 fish in 2007, 336 fish in 2008, 366 fish in 2009, and 8 fish in 2010. The detailed health results are presented in Attachment X.IX, Tables X.IX-1 to X.IX-16. Fish health observations will be discussed by species in the section below.

11.2.4.1 Arctic Grayling

External fish health assessments were conducted on 214 Arctic grayling captured in 2007, 2008 and 2009 (Table 11.2-13). Internal health assessments were carried out on 63 Arctic grayling (Table 11.2-13). The size range of Arctic grayling retained for the health assessments ranged from 57 to 362 mm fork length, with the smallest fish captured in End Grid Lake and the largest fish captured in Judge Sissons Lake (Attachment X.IX). Total body weight of the Arctic grayling ranged from 2.5 to 680 g, with the lightest fish captured in End Grid Lake and the heaviest fish in captured Fox Lake.

Table 11.2-13 Summary of the Fish Processed and the Fish Health Assessment Conducted Between 2007 and 2010

Fish Species	2007			2008			2009			2010	Total
	None	External	Full[(a)]	None	External	Full[(a)]	None	External	Full[(a)]	External	
Arctic grayling	0	9	1	0	40	52	5	102	10	0	**219**
Burbot	0	1	0	1	2	2	2	1	0	0	**9**
Cisco	0	1	0	5	3	67	20	17	0	0	**113**
Lake trout	0	1	0	10	66	54	1	15	5	0	**152**
Longnose sucker	0	0	0	0	0	0	4	0	0	0	**4**
Ninespine	0	15	0	2	6	0	199	120	0	0	**342**

Table 11.2-13 Summary of the Fish Processed and the Fish Health Assessment Conducted Between 2007 and 2010

Fish Species	2007			2008			2009			2010	Total
	None	External	Full(a)	None	External	Full(a)	None	External	Full(a)	External	
stickleback											
Round whitefish	0	0	0	4	1	43	0	7	0	0	**55**
Slimy sculpin	0	0	0	0	0	0	4	89	0	8	**101**
Total	**0**	**27**	**1**	**22**	**118**	**218**	**235**	**351**	**15**	**8**	**995**

(a) Full assessment includes external and internal health assessment.

The age of Arctic grayling sampled ranged from 1 to 10 years, with the youngest fish captured in Lower Lake and the oldest fish in Judge Sissons Lake. Younger fish (i.e., Age 1 to 3) were captured in Pointer, Rock, Knee, Shack, Lower, Fox, and Caribou lakes. All of these lakes were 3 m deep or less, suggesting that smaller fish were rearing in the shallow lakes in the study area. The older fish (i.e., Age 9 and 10) were captured in the deeper lakes in the local study area (Attachment X.IX).

Condition factor (K) of Arctic grayling ranged from 0.85 to 3.4. Fish with a low condition factor (i.e., K less than 1) were captured in Shack and Lower lakes. Fish with a higher condition factor (i.e., K between 1.5 and 2), were captured in Pointer, Shack, Lower, and Fox lakes.

Liver and gonad weights were collected in 2008 for Arctic grayling from Pointer, Mushroom, and Judge Sissons lakes. Liversomatic (LSI) and GSI indices were calculated. Fish with the lowest values were mainly from Pointer Lake (liver and gonad weights, and GSI), while fish with the highest values were mainly from Judge Sissons Lake (liver and gonad weights, and GSI). Mushroom Lake had the lowest value for LSI, while the highest LSI occurred for Arctic grayling from Pointer Lake.

Overall, the majority of the Arctic grayling processed were in good health and abnormalities or incidents of parasites were low (Attachment X.IX). The following abnormalities were observed:

- nine fish from Pointer, Mushroom, and Lunch lakes and from Calf/Judge Sissons Stream had minor to severe fin erosion;
- one fish from Calf/Judge Sissons Stream had moderate skin aberrations; and
- eight fish from Pointer, Mushroom, and Judge Sissons lakes had minor to severe parasite infestation, all of which were copepods on gills.

Internal health assessments were conducted in 2008 and the incidents of internal abnormalities were low. The following abnormalities were reported:

- one fish from Fox Lake had hemorrhaged gonads;
- one fish from Knee Lake had a fatty liver; and
- one fish from Mushroom Lake had a pale, discoloured, liver.

11.2.4.2 Burbot

External fish health assessments were conducted on 6 burbot captured in 2007, 2008, and 2009 (Attachment X.IX). Internal health assessments were carried out on 2 burbot (Table 11.2-13).

Size of burbot ranged from 70 to 219 mm total length, with the smallest fish captured in Andrew Lake and the largest fish captured in Caribou Lake. Total body weight of burbot in the sample ranged from 4 to 70 g. Fish captured in Lower and Judge Sissons lakes were also juvenile burbot based on length, but total body weights were not collected. Condition factor (K) of burbot ranged from 0.50 to 1.2, with the majority within the lower range (i.e., K less than 1).

Overall, all burbot processed were in good health and there were no abnormalities or incidents of parasites observed. Internal health assessments were conducted in 2008 and no internal abnormalities were observed.

11.2.4.3 Cisco

External fish health assessments were conducted on 88 cisco captured in 2007, 2008, and 2009 (Attachment X.IX). Internal health assessments were carried out on 67 cisco (Table 11.2-13).

Fork length of cisco ranged from 80 to 342 mm, with the smallest fish captured in Calf Lake and the largest fish captured in Caribou Lake (Attachment IX). Total body weight of cisco ranged from 30 to 600 g. Fish with total body weight less than 100 g were captured in Pointer, Cigar, Caribou, and Calf lakes, suggesting that these are rearing lakes for juvenile cisco. Larger fish, with total body weight greater than 500 g, were captured in Pointer and Caribou lakes (Attachment X.IX).

Condition factor of cisco ranged from 0.7 to 1.7. There was no clear pattern evident in the spatial distribution of condition factor values amongst lakes (Attachment X.IX).

Liver and gonad weights were collected in 2008 for cisco from Pointer and Caribou lakes. LSI and GSI indices were calculated. Fish with the lowest values were from Pointer Lake (liver and gonad weights, LSI and GSI), while fish with the highest values were primarily from Caribou Lake (liver and gonad weights, and GSI; Attachment X.IX).

Overall, the majority of the cisco processed were in good physical health and abnormalities or incidents of parasites were low (Attachment X.IX). The following abnormalities were observed:

- nine fish from Pointer, Caribou, and Judge Sissons lakes had minor to severe fin erosion; and
- one fish from Pointer Lake had hemorrhaging on fins.

Internal health assessments were conducted in 2008 and the incidents of internal abnormalities were low. The following abnormalities were reported:

- one fish from Pointer Lake had a fatty liver; and
- two fish from Calf Lake had discoloured livers.

11.2.4.4 Lake Trout

External fish health assessments were conducted on 141 lake trout captured in 2007, 2008, and 2009 (Attachment X.IX). Internal health assessments were carried out on 59 lake trout (Table 11.2-13).

The fork length of lake trout in the sample ranged from 174 to 810 mm; with the smallest fish captured in Judge Sissons Lake and the largest fish in Cigar Lake (Attachment X.IX). Total body weight of the lake trout ranged from 60 to 5,450 g. Fish with total body weight less than 200 g were captured in Ridge, Judge Sissons, and Siamese lakes, suggesting that these may also be rearing lakes for juvenile lake trout. Larger fish, with total body weight greater than 4,000 g, were captured in Mushroom, Cigar, and Judge Sissons lakes, in Lower/Judge Sissons Stream, and at road crossing 33 on the 2008 road alignment.

The age of captured lake trout ranged from 6 to 35 years, with the youngest fish captured in Siamese Lake and the oldest fish in Pointer Lake. Immature fish (i.e., Age less than 10) were captured in Ridge and Siamese lakes. The oldest fish (i.e., Age 30 to 35) were captured in Pointer, Ridge, and Siamese lakes. Condition factor of lake trout ranged from 0.41 to 1.86.

Liver and gonad weights were collected in 2008 for lake trout from Pointer, Mushroom, Judge Sissons, and Siamese lakes. LSI and GSI indices were calculated. Fish with the lowest values were mainly from Siamese Lake (liver and gonad weights, and LSI), while fish with the highest values were from Mushroom Lake. Judge Sissons Lake had the lowest value for the GSI (Attachment X.IX).

Overall, the majority of the lake trout processed were in relatively good physical health and abnormalities or incidents of parasites were moderate (Attachment X.IX). The following abnormalities were observed:

- three fish from the Northwest inflow of Pointer Lake, and road crossings 28 and 33 on the 2008 road alignment had body deformities, such as clubbed dorsal fin, bump on caudal fin, or lump on jaw;
- eleven fish from Pointer, Mushroom, Cigar, and Judge Sissons lakes were blind in one or both eyes;
- four fish from Judge Sissons Lake and Calf/Judge Sissons Stream had eroded gills, gill raker detached, or frayed gills;
- thirty-seven fish from Pointer, Mushroom, Cigar, Ridge, Caribou, Judge Sissons, and Siamese lakes, Mushroom/End Grid Stream, stream crossings NC28 and the Thelon River at the 2008 proposed road alignment had minor to severe fin erosion, or hemorrhaged fins;
- three fish from Ridge and Siamese lakes, and from Calf/Judge Sissons Stream had minor to moderate shortening of the opercle or the top of the opercle was cut;
- nine fish from Pointer, Mushroom, and Judge Sissons lakes, road crossing X33 on the 2008 road alignment, and from Shack/Lower Stream had minor skin aberrations, pale skin, or scars on body;
- two fish from Mushroom and Judge Sissons lakes had minor hindgut inflammation or reddening; and
- minor to moderate parasite infestation (e.g., copepods on gills, leaches on gills, and leaches on the skin) were present on thirty-six fish from a variety of waterbodies, including Pointer, Mushroom, Cigar, Caribou, Judge Sissons, and Siamese lakes, Shack/Lower Stream, Lower/Judge Sissons Stream, and Calf/Judge Sissons Stream, stream crossings NC28 and the Thelon River on the 2008 road alignment had.

Internal health assessments were conducted in 2008 and the incidents of internal abnormalities were low. The following abnormalities were reported:

- two fish from Pointer and Cigar lakes had minor to moderate parasite infestation, which were either segmented worm or nematode;
- two fish from Cigar and Judge Sissons lakes had hemorrhaged or atretic gonads;
- one fish from Judge Sissons Lake had a cyst on the kidney;
- one fish from Judge Sissons Lake had an enlarged gall bladder;
- four fish from Judge Sissons Lake had a fatty liver; and
- four fish from Pointer, Mushroom, and Cigar lakes had a discoloured liver.

Baker Lake

Length-frequency data indicate that Station 2 is utilized by larger lake trout ranging from 340 to 685 mm in length (Figure 11.2-1). Lake trout ranged from 7 to 17 years old; no 8-year-old fish were captured (Table 11.2-14; Attachment X.IX, Table IX-17). The largest lake trout captured was 17 years old and 685 mm in length. The absence of young age classes and small fish lengths of lake trout captured in Baker Lake in 2009 is likely a product of the selected sampling method and location. The floating gillnet was set in an area with limited cover and near the surface of the lake where smaller fish are less likely to be feeding and seeking refuge. Smaller fish are also less likely to become entangled in the larger size mesh of the gill net.

Table 11.2-14 Mean Fork Length and Standard Deviation for Lake Trout Age Classes at Station 2, Baker Lake, August 2009

Parameter	Age										
	7	8	9	10	11	12	13	14	15	16	17
Mean length (mm)	375	-	411.3	375	413	438.3	460	423.5	520	505	685
Standard Deviation	-	-	40.5	25.7	37.8	32.1	-	10.6	-	-	-
n	1	0	4	5	5	3	1	2	1	1	1

- = not applicable; mm = millimetres; n = number of lake trout.

Length and weight data for lake trout are provided in Attachment X.IX, Table X.IX-17. Figure 11.2-2 presents weight versus length results for lake trout captured at Site 2 in Baker Lake in 2009. Lake trout weight is well predicted by their length, as evidenced by the close fit of the data points (high R^2 value of 0.95). Growth appears to be positively allometric, in that body weight increases disproportionately with increasing length (i.e., longer fish appear to become more rotund in shape).

The population growth pattern was estimated using the Von Bertalanffy growth model. The fitted growth model demonstrated that the growth pattern for ages 7 through 17 is relatively slow or flat (Figure 11.2-3).

Mean relative fish condition (K) for captured lake trout in Baker Lake was 0.94. Fish condition is influenced by age of fish, sex, season, stage of maturation, fullness of gut, type of food consumed, amount of fat reserve, and degree of muscular development (Barnham and Baxter 1998). This condition factor represents a moderate overall fish condition (i.e., K greater than 0.9 and less than 1.0).

11.2.4.5 Lake Whitefish

Lake whitefish were only captured in Baker Lake. Length-frequency histograms of lake whitefish captured in Baker Lake in 2009 are presented in Figure 11.2-4. All captured lake whitefish were in the 0 to 3 year old range except for one 8 year old fish. No fish were captured between the age of 3 and 8 years old (Table 11.2-15; Attachment X.IX, Table X.IX-17). All captured lake whitefish, except for the one larger 8 year old, were captured in one gillnet panel with ¼” mesh. The largest specimen was 359 mm in length.

The population growth pattern was estimated using the Von Bertalanffy growth model (Figure 11.2-5). As the model is based on a small dataset primarily consisting of young fish, conclusions based on the model should be regarded with caution. Growth pattern for lake whitefish between the ages of 0 and 3, according to the model, is relatively constant.

Lake whitefish were not weighed at the time of sampling and therefore weight-length relationships and condition factors are not presented.

Table 11.2-15 Mean Fork Length and Standard Deviation for Lake Whitefish Age Classes at Site 2, Baker Lake, August 2009

Parameter	Age								
	YOY	1	2	3	4	5	6	7	8
Mean fork length (mm)	122	127.5	168	185.7	-	-	-	-	359
Standard Deviation	9.9	5.7	-	8.1	-	-	-	-	-
n	2	16	1	3	-	-	-	-	1

\- = not applicable; mm = millimetres; YOY = young-of-year; n = number of lake whitefish.

11.2.4.6 Ninespine Stickleback

External fish health assessments were conducted on 141 ninespine stickleback captured in 2007, 2008, and 2009 (Attachment X.IX). Internal fish health assessments were not conducted on this species.

Fork length of ninespine stickleback ranged from 27 to 67 mm, with the smallest fish captured in the Northeast inflow of Pointer Lake and the largest fish in Sik Sik Lake (Attachment X.IX).

Total body weight of ninespine stickleback ranged from 1 to 4 g, with the lightest and heaviest fish captured in Cirque Lake. Condition factor of ninespine stickleback ranged from 0.6 to 2. Fish within the lower range (i.e., K less than 1) were captured in Pointer, Sik Sik, and Cirque lakes, while fish in the higher range (i.e., K greater than 1.5) were captured in Pointer and Cirque lakes. Overall, the majority of the ninespine stickleback processed were in good physical health and no abnormalities or incidents of parasites were observed (Attachment X.IX).

11.2.4.7 Round Whitefish

External fish health assessments were conducted on 51 round whitefish captured in 2008 and 2009 (Attachment X.IX). Full health assessments were carried out on 43 round whitefish (Table 11.2-13).

Fork length of round whitefish ranged from 95 to 387 mm, with the smallest fish captured in Judge Sissons Lake and the largest fish in Mushroom Lake (Attachment X.IX). Total body weight of round whitefish in the sample ranged from 6.75 to 640 g.

The age of round whitefish in the sample ranged from 2 to 17 years old, with the youngest fish captured in Andrew, Lower, and Caribou lakes and the oldest fish in Caribou Lake. Condition factor ranged from 0.76 to 1.71. Fish within the lower range (i.e., K less than 1) were captured in Mushroom, Cigar, Andrew, and Judge Sissons lakes, while fish in the higher range (i.e., K greater than 1.5) were captured in Lower Lake.

Liver and gonad weights were collected in 2008 for round whitefish captured in Mushroom, Lower, Caribou, and Judge Sissons lakes. Fish with the lowest values were mainly from Caribou Lake (liver and gonad weights, and LSI), while fish with the highest values were mainly from Lower Lake (liver and LSI). A fish from Lower Lake had the lowest value for the GSI. Caribou Lake had the highest value for gonad weight, while the highest GSI value was recorded in a fish from Mushroom Lake (Attachment X.IX).

Overall, the majority of the round whitefish processed were in good physical health and abnormalities or incidents of parasites were low (Attachment X.IX). The following abnormalities were observed:

- two fish from Mushroom Lake had cataracts in both eyes;
- two fish from Mushroom Lake had a section of the gill missing;
- fourteen fish from Mushroom, Andrew, Lower, and Judge Sissons lakes had minor to moderate fin erosion or fin haemorrhaging;
- one fish from Mushroom Lake had minor skin aberrations; and
- eight fish from Mushroom and Cigar lakes had minor to moderate parasite infestations, all of which were copepods on gills.

Internal health assessments were conducted in 2008 and the incidents of internal abnormalities were low. The following abnormalities were reported:

- three fish from Mushroom Lake had shrunken or incomplete gonads;
- two fish from Mushroom Lake had granular kidney or discoloured kidney;
- one fish from Judge Sissons Lake had a fatty liver; and
- two fish from Mushroom Lake had a discoloured liver.

11.2.4.8 Slimy Sculpin

External fish health assessments were conducted on 97 slimy sculpin captured in 2009 and 2010 (Attachment X.IX). Internal fish health assessments were not conducted on this species.

Total length of slimy sculpin ranged from 34 to 110 mm, with the smallest fish captured at road crossing Km 17.2 and the largest fish in Willow/Judge Sissons Stream (Attachment X.IX). Total body weight of slimy sculpin ranged from 0.5 to 13 g, with the lightest fish captured at road crossing Km 145.3 and the heaviest fish captured in Willow/Judge Sissons Stream. Condition factor of slimy sculpin ranged from 0.4 to 3.5. Fish within the lower range (i.e., K less than 1) were captured in Willow/Judge Sissons Stream, stream crossings Km 17.2, 109.8, 145.3, and S13, while fish in the higher range (i.e., K greater than 1.5) were captured in stream crossings Km 11.3, 17.2, 145.3, and 145.4. Overall, the majority of the slimy sculpin processed were in good physical health and no abnormalities or incidents of parasites were observed (Attachment X.IX).

11.2.4.9 Observations on Summer Water Temperature

During the sampling session conducted in late July and early August 2008, field crews observed that lake trout and other species were experiencing mortality in the short-duration gill nets. Under normal conditions, lake trout can usually be caught in a gill net, processed, and successfully released. The Golder field crew attributed the high mortality rate of the lake trout to the high surface water temperature measured during summer 2008 (Table 11.2-16).

At the time of sampling, air temperatures were approaching 30°C and more than 50% of the lakes sampled had surface water temperatures above 15°C. End Grid, Cigar, Knee, and Lunch lakes had temperatures above 18°C (Table 11.2-16). Water temperatures were above the upper limit of the preferred temperature range for lake trout, cisco, and other fish species that prefer cooler water temperatures (Table 11.2-17). Therefore, the fish were likely physiologically stressed due to the unusually high temperatures.

Table 11.2-16 Range of Surface Water Temperatures Measured in Lakes During Summer Sampling, 2008 and 2009

Sub-Basin	Waterbody	2008		2009	
		Dates	Temperature (°C)	Dates	Temperature (°C)
Willow Lake	Pointer Lake	31July to 1 August	14.8 to 16.7; 14.7°C at 2.5 m	-	-
	Sik Sik Lake	-	-	22 July	13.3
	Rock Lake	30 July	13.5 to 13.7	22 July	12.4
	Willow Lake	-	-	22 July	12.9
Lower Lake	Mushroom Lake	23 to 25 July	16.0 to 17.9; 14.8°C at 8 m	-	-
	End Grid Lake	25 July	17.8 to 18.9	-	-
	Cigar Lake	22 July	17.0 to 18.3	-	-
	Knee Lake	22 July	17.5 to 18.6	-	-
	Lunch Lake	23 July	16.1 to 18.7 16.7 at 1 m	-	-
	Andrew Lake	26 July	15.9 to 16.2	-	-
	Shack Lake	27 July	11.8 to 13.5	-	-
	Lower Lake	28 to 29 July	10.3 to 13.8	-	-
Caribou Lake	Ridge Lake	5 August	14.2 to 14.3	-	-
	Fox Lake	3 August	15.8 to 16.6	-	-
	Caribou Lake	2 August	14.1 to 15.6; 15.0°C at 2.5 m	-	-
	Calf Lake	4 August	13.7 to 14.1	-	-
Judge Sissons Lake	Judge Sissons Lake	25 July to 1 August	10.6 to 15.2; 6.8°C at 18.7 m	22 July	5.6; 5.1°C at 19.5 m
Siamese Lake	Siamese Lake	4 to 5 August	14.4 to 14.8; 14.4 at 11 m	-	-

Note: temperature rounded to one decimal.
- = not applicable; °C = degrees Celsius; m = metres.

11.2.5 Fish Movements

In general, fish movements and migrations in the Kiggavik Project Area are related to the locations of suitable spawning, rearing and feeding habitats. As the streams and shallow lakes in the mine site LSA freeze to the bottom, fish also need to migrate into deeper waters for overwintering. A brief description of the migration patterns and timing for species captured and observed during the 2007, 2008, 2009, and 2010 field programs is presented below.

Table 11.2-17 Summary of Preferred Temperature Ranges and Upper Critical Ranges for Adult Fish Species Present in the Local Study Area

Fish Species	Temperature (°C)		Source
	Preferred	Upper Critical	
Arctic grayling	cool-water fish	- 22.5 to 24.5	Scott and Crossman 1998; Weber Scannell 1992
Burbot	15.6 to 18.3; 11.4	23.3 -	Scott and Crossman 1998; Weber Scannell 1992
Cisco	cool-water fish	17 to 18; 26 (for juvenile)	McPhail 2007; Scott and Crossman 1998
Lake trout	10 10 8 to 12; 10; 11.8	23.8 - 23.5 (for fry)	McPhail 2007 Scott and Crossman 1998 Weber Scannell 1992
Ninespine stickleback	warm to cold-water fish	-	Reist et al. 2006
Round whitefish	17.5	-	Weber Scannell 1992
Slimy sculpin	10 9 to 12	- 18.5 to 23.5	McPhail 2007 Otto and Rice 1977
°C = degree Celsius; - = not applicable.			

A total of 74 large-bodied fish captured between 2008 and 2009 were tagged, but none of the tagged fish were recaptured during the following years. The majority of the fish tagged came from the Lower Lake sub-basin with 23 lake trout (Table 11.2-18). In the Willow Lake sub-basin, two Arctic grayling, 12 lake trout, and two round whitefish were tagged, for a total of 16 fish (Table 11.2-18). In the Caribou Lake sub-basin, one Arctic grayling and 12 lake trout were tagged, for a total of 13 fish (Table 11.2-18). Fourteen more lake trout were tagged in Judge Sissons Lake; while five Arctic grayling and one lake trout were tagged in the Aniguq River, and two lake trout we tagged in Siamese Lake (Table 11.2-18).

Fish movements discussed below are based on the presence of fish in streams and lakes of each sub-basin during the study, the fish barriers observed, and the winter status of the lakes observed or expected (i.e., lakes shallower than 2 m would likely freeze to the bottom).

Table 11.2-18 Fish Tagged in the Mine Site Local Study Area Between 2008 and 2009

Sub-Basin	Waterbody/Watercourse	Arctic Grayling	Lake Trout	Round Whitefish	Total
Willow Lake	Northwest Inflow of Pointer Lake	0	2	0	**2**
	Pointer/Rock Stream	1	0	0	**1**
	Rock/Willow Stream	1	0	2	**3**
	Willow/Judge Sissons Stream	0	10	0	**10**
Lower Lake	Mushroom Lake	0	6	0	**6**
	Mushroom/End Grid Stream	0	2	0	**2**
	Cigar Lake	0	7	0	**7**
	Shack/Lower Stream	0	2	0	**2**
	Lower/Judge Sissons Stream	0	6	0	**6**
Caribou Lake	Ridge Lake	0	6	0	**6**
	Calf/Judge Sissons Stream	1	6	0	**7**
Judge Sissons Lake	Judge Sissons Lake	0	14	0	**14**
Aniguq River	Aniguq River	5	1	0	**6**
Siamese Lake	Siamese Lake	0	2	0	**2**
Total		**8**	**64**	**2**	**74**

11.2.5.1 Willow Lake Sub-Basin

Six streams and four lakes from the Willow Lake sub-basin were studied between 2007 and 2009 (Table 11A-5). Their potential for fish migration, overwintering, spawning, rearing, and feeding is presented below. From upstream to downstream, the streams and lakes are as follows:

- Northeast inflow of Pointer Lake flows south into Pointer Lake, which had no fish barrier observed.
- Upper Tributary to the Northeast Inflow of Pointer Lake flows south to the Northeast inflow of Pointer Lake, which has a poorly defined channel between the upper section and the downstream stream.

- Upstream Northwest Inflow of Pointer Lake flows south into Pointer Pond, in which slimy sculpin were present in June; however, fish presence is seasonal as the stream was dry in August.
- Pointer Pond is not expected to freeze to the bottom during winter, which offers overwintering and summer rearing habitat for the slimy sculpin captured in the inlet.
- Northwest inflow of Pointer Lake flows south into Pointer Lake, which had no fish barrier observed.
- Pointer Lake is not expected to freeze to the bottom during winter; however, the overwintering fish population would be limited to the deepest portion of the lake during winter as more than 50% of the volume of the lake would freeze to the bottom because of the shallow water depths in most of the lake.
- Pointer/Rock Stream flows south into Rock Lake, which had no fish barrier observed.
- Sik Sik Lake freezes to the bottom during winter months.
- Sik Sik/Rock Stream flows south into Rock Lake, but the channel is narrow and poorly defined (i.e., no visible channel). Successful migration upstream from Rock Lake would be expected only when water level is high enough to flood the area.
- Rock Lake freezes to the bottom during winter months.
- Rock/Willow Stream flows south into Willow Lake with no fish barrier observed.
- Willow Lake freezes to the bottom during winter months.
- Willow/Judge Sissons Stream flows south into Judge Sissons Lake, which had no fish barrier observed.

Arctic grayling were present in lakes and streams throughout the sub-basin excepted in Sik Sik Lake (Table 11A-5). Present in the most upstream and downstream lakes, Arctic grayling migrate freely throughout the sub-basin, except for Sik Sik Lake. Arctic grayling spawning was confirmed in two streams located between Pointer Lake and Willow Lake (refer to Section X11.2.5.5.1). Rearing and feeding habitats are available throughout the sub-basin, except for the Northeast inflow of Pointer Lake, Sik Sik Lake, and Sik Sik/Rock Stream, which have limited Arctic grayling habitat quality. Overwintering habitat is provided by Pointer Lake but Judge Sissons Lake is also easily accessible for this mobile species.

Burbot were present only in Pointer/Rock Stream (Table 11A-5). Present in the outlet of Pointer Lake, it would be expected that burbot are able to migrate freely between Pointer Lake and Judge Sissons Lake. Spawning and overwintering habitat may be limited to either Pointer Lake or Judge Sissons Lake; while rearing and feeding habitats are abundant in both lakes.

Cisco were present in Pointer Lake and in Rock/Willow Stream (Table 11A-5). Present in the most upstream lake, and in a stream section about halfway to Judge Sissons Lake, it would be expected that cisco can move between Pointer Lake and Judge Sissons Lake. Spawning and overwintering may be limited to either Pointer Lake or Judge Sissons Lake; while rearing and feeding could occur in both lakes.

Lake trout was present from the Northwest inflow of Pointer Lake down to the Willow/Judge Sissons Stream, but was absent in the shallow lakes (Table 11A-5). The absence of lake trout in Pointer Lake during 2008 and 2009 fall sampling was not expected, and may indicate that migration of adult fish from Pointer Lake to Judge Sissons Lake, for spawning and overwintering purposes, had occurred in August prior to the sampling session. Rearing and feeding habitats are likely limited to Pointer Lake and Judge Sissons Lake in the summer, because of the shallowness of Rock and Willow lakes and the inaccessibility of Sik Sik Lake.

Ninespine stickleback was present throughout the sub-basin except in the Northwest inflow of Pointer Lake and Rock Lake (Table 11A-5). Ninespine stickleback likely overwinter in Pointer Lake or Judge Sissons Lake. Ninespine stickleback likely migrate throughout the sub-basin early in the spring to spawn in the appropriate habitat, and rear and feed in all habitat available, before moving back to deeper lakes for the winter. Based on the sampling results, it could not be determined if ninespine stickleback can overwinter in Sik Sik Lake, or if there is an annual movement into the lake during periods of high water in the spring.

Round whitefish was present only in Pointer/Rock Stream and Rock/Willow Stream (Table 11A-5). Present in the outlet of Pointer Lake, it is thought that round whitefish migrate freely between Pointer Lake and Judge Sissons Lake. Spawning and overwintering may be limited to either Pointer Lake or Judge Sissons Lake; while rearing and feeding may occur in both lakes.

Slimy sculpin were only captured in Scotch Lake, the upper reach of the Northwest Inflow to Pointer Lake (above Pointer Pond), and Willow/Judge Sissons stream. They are also found downstream in Judge Sissons Lake (Tables 11A-1 and 11A-2). Slimy sculpin likely migrate short distances into small streams in the spring to spawn in the appropriate habitat, and rear and feed in all habitat available, before moving back to deeper lakes for the winter.

Slimy sculpin were present within the first 10 m of the upper reach of the Northwest Inflow of Pointer Lake (Table 11A-5). Spawning, rearing, and feeding activities are likely limited to that section of the stream where the fish was captured and Pointer Pond. As the upper reach is drying out in the summer, it is expected for slimy sculpin to mainly use Pointer Pond and occasionally use its inlet. Slimy sculpin likely overwinter in Pointer Pond.

11.2.5.2 Lower Lake Sub-Basin

The following streams and lakes from the Lower Lake sub-basin, and fish movement potential, were examined between 2007 and 2009 (Table 11A-6). From upstream to downstream, the streams and lakes are as follow:

- Mushroom Lake does not freeze to the bottom during winter, but ice cover was 2 m deep during winter 2009.

- Pond 1 to Pond 8 are expected to freeze to the bottom during winter months and defined channels were not observed between ponds to allow migration from the Mushroom/End Grid Stream.
- Mushroom/End Grid Stream flows south into End Grid Lake, with no fish barrier observed.
- End Grid Lake is expected to freeze to the bottom during winter months.
- End Grid/Shack Stream flows south into Shack Lake, with no fish barrier observed.
- Cigar Lake is not expected to freeze entirely to the bottom during winter, but more than 50% of the volume of the lake would freeze, limiting the fish population to the deepest section of the lake during winter.
- Cigar/Lunch Stream flows north into Lunch Lake, with no fish barrier observed.
- Knee Lake is expected to freeze to the bottom during winter months.
- Knee/Lunch Stream flows south into Lunch Lake, with no fish barrier observed.
- Lunch Lake is expected to freeze to the bottom during winter months.
- Lunch/Andrew Stream flows east into Andrew Lake, with no fish barrier observed.
- Andrew Lake freezes to the bottom during winter months.
- Andrew/Shack Stream flows east into Shack Lake, with no fish barrier observed.
- Shack Lake is expected to freeze to the bottom during winter months.
- Shack/Lower Stream flows east into Lower Lake, with no fish barrier observed.
- Lower Lake is expected to freeze to the bottom during winter months.
- Lower/Judge Sissons Stream flows north into Judge Sissons Lake, with no fish barrier observed.

Present in the most upstream and downstream lakes (Table 11A-6), Arctic grayling likely migrates freely throughout the sub-basin, including Cigar Lake since fish barriers were not observed in Cigar/Lunch Stream. Arctic grayling spawning was confirmed in two stream sections: Lunch/Andrew Stream and Andrew/Shack Stream (refer to Section X10.2.5.5.2). Rearing and feeding habitats are available throughout the sub-basin. Overwintering habitat is provided by Mushroom Lake and possibly Cigar Lake. Judge Sissons Lake is also easily accessible for this species.

Burbot were present in Cigar, Andrew, and Lower lakes (Table 11A-6). Burbot may migrate from Cigar Lake to Judge Sissons Lake. Spawning and overwintering activities may be limited to either Cigar or Judge Sissons lakes.

Cisco were present in Cigar and Andrew lakes (Table 11A-6); the most upstream lake and in a shallow lake downstream. It is anticipated that cisco migrates freely between Cigar Lake and Judge Sissons Lake. Spawning and overwintering habitat may be limited to either Cigar Lake, Mushroom Lake (cisco were present in this lake according to the historical data), or Judge Sissons Lake.

Lake trout were present in Mushroom Lake and its outlet (Mushroom/End Grid Stream), in Cigar Lake, the outlet of Knee Lake (Knee/Lunch Stream), Shack/Lower Stream, and in Lower/Judge Sissons Stream (Table 11A-6). There is potential for migration of lake trout throughout the sub-basin, as evidenced by their relatively widespread distribution. Lake trout spawning was confirmed in Cigar and Mushroom lakes (refer to Section 11.2.5.6). Overwintering habitat in the sub-basin may be limited to these same lakes and downstream in Judge Sissons Lake, due to the shallow depths of the majority of the lakes in the sub-basin.

Ninespine stickleback was present only in Lower Lake and in Lower/Judge Sissons Stream (Table 11A-6). As the smaller lakes likely freeze to the bottom, the ninespine stickleback likely overwinter in Judge Sissons Lake, migrate to Lower Lake to spawn, rear, and feed in Lower Lake before returning to Judge Sissons Lake for the winter. It is not clear why ninespine stickleback were not found upstream of Lower Lake, as there were no obvious barriers.

Round whitefish were present in the majority of the lakes (i.e., Mushroom, Cigar, Lunch, Andrew, and Lower lakes) (Table 11A-6). Based on the wide spread distribution, it is possible that round whitefish can migrate throughout the watershed. Spawning and overwintering may be limited to the deeper lakes (i.e., Mushroom Lake, Cigar Lake, and Judge Sissons Lake); while rearing and feeding activities may occur throughout the sub-basin during the open water period.

Slimy sculpin were not present in the Lower Lake sub-basin (Table 11A-6).

11.2.5.3 Caribou Lake Sub-Basin

The following streams and lakes from the Caribou Lake sub-basin were studied between 2007 and 2008 (Table 11A-7). From upstream to downstream, the streams and lakes are as follow:

- Ridge Lake is not expected to freeze to the bottom during winter.
- Ridge/Crash Stream flows west into Crash Lake. This stream was not sampled, but an aerial video was recorded and fish barriers were not observed.
- Cirque Lake is not expected to freeze to the bottom during winter.
- Cirque/Crash Stream flows west into Crash Lake. This stream was not sampled, but an aerial video was recorded and fish barriers were not observed.
- Crash Lake is expected to freeze to the bottom during winter months.
- Crash/Fox Stream flows south into Fox Lake. This stream was not sampled, but an aerial video was recorded and no obstacles to fish passage were observed.
- Fox Lake is not expected to freeze entirely to the bottom during winter, but fish populations are likely confined to the deepest section of the lake during winter.
- Fox/Caribou Stream flows south into Caribou Lake, with no fish barriers observed.
- Caribou Lake is not expected to freeze entirely to the bottom during winter. More than 50% of the volume of the lake would freeze to the bottom, limiting the fish population to the deepest section of the lake during winter.
- Caribou/Calf Stream flows south into Calf Lake, with no fish barriers observed.
- Calf Lake is expected to freeze to the bottom during winter months.

- Calf/Judge Sissons Stream flows east into Judge Sissons Lake, with no fish barriers observed.

Arctic grayling were present in three lakes (Crash, Fox, and Caribou lakes; Table 11A-7). Arctic grayling likely migrate freely throughout the lower half of the sub-basin, but may also migrate to Cirque Lake according to historical information. Although an Arctic grayling was captured in Calf/Judge Sissons Stream in spring 2008, spawning was not confirmed in any streams of the sub-basin (refer to Section X10.2.5.5.3). Rearing and feeding habitats are available throughout the sub-basin. Overwintering habitat is present in Cirque Lake and lower quality overwintering habitat may be present in Fox and Caribou lakes, as only a small volume of these lakes would remain ice free during winter months. Judge Sissons Lake is also easily accessible for this species and can provide overwintering habitat.

Burbot were present only in Caribou and Calf lakes (Table 11A-7). It is expected that burbot can migrate freely between Caribou Lake and Judge Sissons Lake, with critical habitats provided in either of these lakes.

Cisco were present in three lakes (Fox, Caribou, and Calf lakes; Table 11A-7) and can move between Fox Lake and Judge Sissons Lake. Spawning and overwintering may occur in Fox Lake or Caribou Lake, but more likely in Judge Sissons Lake as this species spawns late in the year (e.g., November), so fish would like have moved into Judge Sissons Lake before the streams started to freeze.

Lake trout were present from Ridge Lake to Calf/Judge Sissons Stream, but absent from Cirque, Crash, and Calf lakes (Table 11A-7). There is potential for migration of lake trout throughout the sub-basin, as evidenced by their relatively widespread distribution. Lake trout spawning was confirmed in Ridge Lake (refer to Section 11.2.5.6.1). Overwintering habitat may be limited to Ridge Lake and Judge Sissons Lake, with some potential overwintering habitat available in the deeper portions of Fox and Caribou lakes.

Ninespine stickleback was found throughout the sub-basin except in Ridge and Crash lakes (Table 11A-7).

Round whitefish were present only in Caribou Lake (Table 11A-7) but may migrate freely between Caribou Lake and Judge Sissons Lake.

11.2.5.4 Judge Sissons Lake

Judge Sissons Lake is a deep lake with a maximum depth of 19.7 m (Table 11A-8). The variety of habitats in the lake would likely accommodate spawning preferences for all lake spawning species and tributaries provide habitat for stream spawning species.

Arctic grayling were present in Judge Sissons Lake (Table 11A-8). After overwintering in Judge Sissons Lake, Arctic grayling are expected to migrate to tributaries in the early spring to spawn. Spawning was confirmed in Pointer/Rock Stream, Rock/Willow Stream, Lunch/Andrew Stream, and Andrew/Shack Stream (refer to Section 11.2.5.5). Rearing and feeding activities may occur within the lake as well as in other lakes and streams surrounding Judge Sissons Lake.

Burbot were present in Judge Sissons Lake (Table 11A-8) and may utilize the lake for all life history functions.

Cisco were present in Judge Sissons Lake (Table 11A-8) and also likely use the lake for rearing, feeding, spawning and overwintering.

Lake trout were present in Judge Sissons Lake (Table 11A-8). After overwintering, lake trout may remain in the lake for rearing, feeding and spawning. Based on observations and fish captured in the spring, it is thought that some lake trout migrate into shallow lakes and tributaries to feed.

Ninespine stickleback and round whitefish were present in Judge Sissons Lake (Table 11A-8). After overwintering in Judge Sissons Lake, round whitefish may rear, feed, and spawn in the lake, or may migrate to the tributaries.

Slimy sculpin were not captured in Judge Sissons Lake between 2007 and 2009, but were historically reported to be present in the lake (Table 11A-1). It is likely that slimy sculpin are resident to Judge Sissons Lake, as they tend to exhibit limited migratory movements and would likely not move out of the lake.

11.2.5.5 Arctic Grayling Spawning Movements

Spring spawning surveys were undertaken in 2008 and 2009, in an attempt to identify Arctic grayling spawning habitat. The objectives of the 2008 spring sampling were to map habitat for the entire length of stream in the three major basins northwest of Judge Sissons Lake and to sample the streams for Arctic grayling. As the fish sampling was done between June 16 and 27, 2008, it is likely that most spawners had already moved out of the stream. The 2009 spawning survey was conducted a bit later than the previous survey from June 24 to July 3, 2009 and water levels and ice conditions were better for sampling.

Stream sampling in the spring of 2009 was done over a period of several days. A Fyke net, blocking most of the stream, was employed to capture some adult Arctic grayling upstream migrants. Kick netting was conducted in areas with suitably sized substrates (i.e., areas with sand, gravel or small cobble), to collect eggs and confirm spawning locations.

The following discussions are based on the data collected in 2008 and 2009.

Willow Lake Sub-Basin

In 2008, Arctic grayling were observed in Rock/Willow Stream only. As these fish were not captured, the sex and maturity could not be verified.

In 2009, Arctic grayling spawning activities were confirmed in two streams: Pointer/Rock Stream and Rock/Willow Stream (Table 11.2-19). Ripe male and female Arctic grayling were captured and eggs were recovered by kick netting, confirming that spawning was occurring. The eggs were collected in 0.3 to 0.7 m water depth, with velocities between 0.4 and 1.0 m/s. The spawning substrate consisted of primarily gravel or cobble, with some sand. Two additional streams were identified with potential spawning habitat (Northeast Inflow of Pointer Lake and Sik Sik/Rock Stream), but spawning use could not be confirmed.

Lower Lake Sub-Basin

In 2008, Arctic grayling were observed in Mushroom/End Grid Stream (maturity unknown) and in End Grid/Shack Stream (juvenile). The sex and maturity could not be verified.

In 2009, only two streams were sampled, Lunch/Andrew Stream and Andrew/Shack Stream (Table 11.2-19). Arctic grayling spawning activities were confirmed in both of these streams. A total of three male Arctic grayling in ripe condition were captured, as well as seven fish in unknown condition (i.e., eggs or milt could not be expressed when pressure was applied to the abdomen). A large number of eggs (215) were recovered by kick netting, with the majority collected downstream of Andrew Lake. The eggs were collected in 0.1 to 0.6 m water depth, with velocity between 0.2 and 0.8 m/s. The spawning substrate varied greatly, but in general consisted of cobble, with some sand, gravel, or boulder.

Caribou Lake Sub-Basin

In 2008, two streams (Fox/Caribou Stream and Caribou/Calf Stream) were identified as having with potentially suitable spawning habitat; however, Arctic grayling were not captured or observed in either (Table 11.2-19).

11.2.5.6 Fall Spawning Surveys

The objective of the 2008 fall spawning survey was to assess fall fish movements and spawning activities, and to collect supplemental fish for chemistry analysis in lakes within the Project area. Although the fall sampling program targeted lake trout, other fall spawning species such as round whitefish, cisco, and Arctic char might be expected to be captured.

Table 11.2-19 Summary of Data Collected During the Arctic Grayling Spring Spawning Surveys in 2008 and 2009

Sub-Basin	Watercourse	2008[b]	2009		2009 Egg Sampling, Range[a] of Habitat Information		
			Fish[b]	Number of Eggs	Depth (m)	Substrate Type[c]	Velocity (m/s)
Willow Lake	Northeast inflow of Pointer Lake	0	0	no habitat	-	-	-
	Northwest inflow of Pointer Lake	0	0 (12)	0	-	-	-
	Pointer/Rock Stream	0	1 M-RP	9	0.3-0.7	Gr/Co/Sa	0.4-0.8
	Sik Sik/Rock Stream	0	0	no habitat	-	-	-
	Rock/Willow Stream	0	4 M-RP, 1 F-RP, 1 U-U	3	0.3-0.4	Co/Gr	0.7-1.0
	Willow/Judge Sissons Stream	0	4 (1): 4 U-IM	0	-	-	-
Lower Lake	Mushroom/ End Grid Stream	0	-	-	-	-	-
	End Grid/ Shack Stream	0[d]	-	-	-	-	-
	Cigar/Lunch Stream	0	-	-	-	-	-
	Knee/Lunch Stream	0	-	-	-	-	-
	Lunch/ Andrew Stream	0	1 M-RP	44	0.4-0.5	Co/Sa/Gr; Co/Sa/Bo	0.4-0.8
	Andrew/ Shack Stream	0	2 M-RP, 7 U-U	171	0.1-0.6	Sa/Co/Gr; Co/Gr/Bo; Co/Bo	0.2-0.6
	Shack/Lower Stream	0	-	-	-	-	-
	Lower/Judge Sissons Stream	0	-	-	-	-	-
Caribou Lake	Fox/Caribou Stream	0	-	-	-	-	-
	Caribou/Calf Stream	0	-	-	-	-	-
	Calf/Judge Sissons Stream	1 U-U	-	-	-	-	-

Note:	Ridge/Crash, Cirque/Crash. and Crash/Fox streams were not sampled in 2008 due to time restrictions.
(a)	Range of parameters where eggs were captured. Values rounded to 1 decimal.
(b)	Sex and maturity of processed fish
(c)	Substrate type was limited to the three substrates most represented in the area where eggs were captured.
(d)	Juvenile Arctic grayling were observed in the stream.
#	= number of adult fish captured (number of fish observed in parenthesis); m = metre; m/s = metre per seconds; Sa = sand; Gr = gravel; Co = cobble; Bo = Boulder; - = not applicable; M = male, F = female, U = unknown; RP = ripe, IM = immature.

Mine Site Local Study Area

No spawning information was collected during previous surveys of the lakes in the mine site LSA. The 2008 spawning survey was conducted from August 26 to September 10, 2008. The survey was limited to lakes where lake trout were captured in 2007 or where they were historically reported. Spawning was confirmed through the capture of ripe lake trout.

Willow Lake Sub-Basin

In 2008, lake trout were not captured in the Willow Lake sub-basin during the fall spawning survey. In Pointer Lake, lake trout were captured in fall 2007 and summer 2008, but were absent from the catch in fall 2008 and fall 2009 (Table 11.2-20). Due to its shallow depth (i.e., maximum depth of 3.0 m), it seems likely that lake trout move out of the lake to spend the winter in the deeper Judge Sissons Lake.

Table 11.2-20 Summary of the Lake Trout Fall Spawning Habitat Information

		Fish Captured		Habitat Information[a]		
Sub-Basin	Waterbody	Fish	Sex and Maturity[b]	Secchi Depth (m)	Substrate Type	Water Temperature at Surface (°C)
Willow Lake	Pointer Lake	0	-	-	-	-
	Willow Lake	0	-	-	-	-
Lower Lake	Mushroom Lake	2	1 M-RP; 1 U-U	1.6 (bottom)	Co/Bo	7.9
	Cigar Lake	5	1 M-RP; 4 U-U	3.6 (bottom)	Co/Bo; Co/Sa	7.3
	Knee Lake	0	-	-	-	-
	Lunch Lake	0	-	-	-	-
	Andrew Lake	0	-	-	-	-
	Shack Lake	0	-	-	-	-

Table 11.2-20 Summary of the Lake Trout Fall Spawning Habitat Information

Sub-Basin	Waterbody	Fish Captured		Habitat Information[a]		
		Fish	Sex and Maturity[b]	Secchi Depth (m)	Substrate Type	Water Temperature at Surface (°C)
	Lower Lake	0	-	-	-	-
Caribou Lake	Ridge Lake	6	1 M-RP; 5 U-U	-	-	6.6
	Fox Lake	0	-	-	-	-
	Caribou Lake	0	-	-	-	-
Judge Sissons Lake	Judge Sissons Lake	6	1 M-RP; 5 U-U	3.9 (bottom)	Co/Bo	10.7
Siamese Lake	Siamese Lake	2	1 M-RP; 1 U-U	1.5 (bottom)	Bo/Co; Co/Gr	8.6

(a) Parameters where lake trout in spawning condition were captured.
(b) Sex and maturity of processed fish.
m = metre; °C = degree Celcius; Sa = sand; Gr = gravel; Co = cobble; Bo = Boulder; - = not applicable; M = male; U = unknown; RP = ripe.

Lake trout were not captured in Willow Lake in fall 2007 and fall 2008; however, were captured in an upstream tributary in 2009. Therefore, it appears that lake trout may be moving through the lake on a seasonal basis. As the maximum depth of the lake is 2 m, lake trout would not likely spawn in this lake.

Lower Lake Sub-Basin

In 2008, seven lakes were sampled in the Lower Lake sub-basin in the fall (Table 11.2-20). No lake trout were present in five of the lakes (Knee, Lunch, Andrew, Shack, and Lower lakes) Andrew Lake was frozen to the bottom during sampling in winter 2009. The other four lakes are also expected to freeze to the bottom during the winter. Therefore, the lake trout population of these five lakes appear to be transient and spawning probably does not occur in these lakes.

Two ripe male lake trout were captured in Mushroom Lake and in Cigar Lake in 2008 (Table 11.2-20). The habitat and site characteristics where these two fish were captured was:

- maximum depth from 1.6 to 3.6 m;
- substrate contained a majority of cobble with either boulder or sand; and
- surface water temperature ranged between 7.3ºC and 7.9ºC.

Caribou Lake Sub-Basin

In 2008, lake trout spawning was confirmed in Ridge Lake, a deep overwintering lake, when a male in ripe condition was captured (Table 11.2-20). Two other lakes (i.e., Fox and Caribou lakes) yielded no lake trout during the fall spawning survey (Table 11.2-20). The lake trout population of these two lakes is likely transient as lake trout were captured in Caribou Lake during summer 2008, in Ridge Lake (located upstream) and in Calf/Judge Sissons Steam (located downstream). The maximum depth of these two lakes ranged from 2.6 to 2.7 m and use by spawning lake trout is unlikely.

Judge Sissons Lake

In 2008, lake trout spawning was confirmed in Judge Sissons Lake when a ripe male was captured (Table 11.2-20). The habitat and site characteristics where this fish was captured was as follows:

- maximum depth of 3.9 m;
- substrate with a majority of cobble with boulder; and
- surface water temperature of 10.7ºC.

In fall 2009, five female lake trout were captured during the chemistry survey. Two females were in pre-spawning condition and three females were in a developing condition. This information confirms that lake trout spawn in Judge Sissons Lake; however, they may not spawn on a yearly basis.

Siamese Lake

A male lake trout in ripe condition was captured during the 2008 spawning survey (Table 11.2-20). The habitat information and conditions where this fish was captured were:

- maximum depth of 1.5 m;
- substrate contained a majority of boulder and cobble, or cobble and gravel; and
- surface water temperature was 8.6ºC.

Site Access Local Study Area

Although lake trout were captured in Baker Lake (McLeod et al. 1976), it was noted that sampling likely terminated before onset of spawning in late fall. Potential spawning habitat was noted in the western portion of Baker Lake.

About one-quarter of the female Arctic char captured during the 1975 program contained re-absorbing eggs from a previous spawning attempt (McLeod et al. 1976). No spawning or rearing areas were identified within the lake and very few juvenile fish were captured, suggesting spawning occurred outside Baker Lake.

During the Baker Lake survey, several gravid cisco were captured; however, no ripe fish were obtained by mid September, suggesting that spawning probably occurs during freeze up and under ice (McLeod et al. 1976).

During the 1975 Baker Lake survey, several schools of YOY round whitefish were observed in Baker Lake at the mouth of the Thelon River, suggesting that the area may be used as spawning or nursery habitat (McLeod et al. 1976).

11.2.6 Fish Tissue and Bone Chemistry

Fish tissue sampling for metals and radionuclides was undertaken from a variety of fish species between 1980 and 1990. During the 2008 to 2009 sampling periods, Arctic grayling, cisco, lake trout and round whitefish were retained for metals and radionuclide analysis (Table 11.2-21). The majority of the historical chemistry data was from composite flesh samples, while the recent analyses used individual fish separated in flesh and bone. The following sections provide a summary of the historical and current chemistry analysis. Consumption guidelines from Canada (Lockhart et al. 2005) and from Food Standards Australia New Zealand (FSANZ 2009) were included with historical and recent data for comparison.

11.2.6.1 Historical Summary

Fish tissue samples from Arctic char, Arctic grayling, and lake trout were analyzed for metals and some radionuclides during the sampling sessions undertaken between 1980 and 1990 (Attachment X.X, Table X.X-1 to Table X.X-4). The following provides a brief summary of results.

Arctic Char

Concentrations of trace metals in Arctic char from Baker Lake were low, with the exceptions of arsenic, mercury and selenium. The concentration of arsenic in composite sample B (8.0 µg/g)[9] was above the consumption guideline of 2.0 µg/g. The concentration of mercury in both composite samples (0.5 µg/g) were above the consumption guidelines of 0.2 µg/g (Lockhart et al. 2005). The

[9] All concentrations are in wet weight, unless indicated otherwise.

concentration of selenium in the two Baker Lake composite samples was 1.80 micrograms per gram (µg/g), which is higher than selenium concentrations reported for Arctic grayling and lake trout in the previous studies (Attachment X.X, Table X.X-1 and Table X.X-2).

Table 11.2-21 Summary of Waterbodies and Fish Species Sampled for Tissue Chemistry Between 1980 and 2009

Sub-Basin	Waterbody	Arctic Char	Arctic Grayling	Cisco	Lake Trout	Round Whitefish
Willow Lake	Felsenmeer Lake	-	1986	-	1986	-
	Escarpment Lake	-	-	-	1986	-
	Lin Lake	-	1986	-	-	-
	Pointer Lake	-	1988; 2008[a]	2009[a]	1989; 2008[a]	
	Willow Lake	-	1986		1986	-
Lower Lake	Mushroom Lake		2008[a]	-	1990; 2008[a]	2008[a]
	Cigar Lake	-	-	-	1990	-
	Andrew Lake	-	1990	-	-	-
	Lower Lake	-	1990	-	-	2008[a]
Caribou Lake	Ridge Lake	-	-	-	1986	-
	Caribou Lake	-	1986; 2008[a]	-	1986; 2008[a]	2008[a]
Judge Sissons Lake	Judge Sissons Lake	-	2008[a], 2009[a]	-	1980; 2008[a], 2009[a]	2008[a]
Baker Lake	Baker Lake	1989, 2009[b]	-	-	2009[b]	-
Source: [a] = Golder; [b] = Nunami Stantec; - = not applicable						

Arctic Grayling

The concentrations of trace metals in Arctic grayling were low and close to the detection limit with several exceptions (Attachment X.X, Table X.X-2). The concentration of arsenic was above consumption guidelines of 2 µg/g wet weight for all Arctic grayling from 1986 (i.e., Felsenmeer, Lin, Willow, and Caribou lakes), while other samples (i.e., 1988 and 1990) were below detection limits. The detection limit of cadmium for historical samples was 0.1 µg/g, which is above the current consumption guideline of 0.005 µg/g. Cadmium concentration in two samples from Pointer Lake (0.1 and 0.6 µg/g) were above consumption guidelines. The concentration of lead was above the consumption guideline of 0.5 µg/g for one fish from Pointer Lake. Concentrations of mercury in fish from Andrew and Lower lakes were also above consumption guidelines of 0.5 µg/g (Attachment X.X, Table X.X-2).

Concentrations of radionuclides were below detection limits for all parameters with the exception of Po-210 and Ra-226. In 1990, concentrations of Po-210 in Arctic grayling flesh from Andrew and Lower lakes ranged from 0.002 to 0.004 Bq/g. In 1988, concentrations of Ra-226 in bone of Arctic grayling from Pointer Lake ranged from 0.015 to 0.017 Bq/g (Attachment X.X, Table X.X-3).

Lake Trout

In general, concentrations of trace metals in lake trout were low and close to the detection limit. The level of arsenic was above guidelines for lake trout from Escarpment Lake in 1986, while arsenic concentrations in lake trout from other lakes sampled in 1986, 1988 and 1990 were below detection limits. The detection limit of cadmium for historical samples was 0.1 µg/g, which is above the current consumption guideline of 0.005 µg/g. Most samples were below the detection limit; however, the concentration of cadmium for one fish from Judge Sissons Lake in 1980 was 0.036 µg/g, which was above the consumption guideline limits. Lead concentrations were below the consumption guideline for all lake trout sampled between 1986 and 1990. Concentrations of mercury in fish from Pointer Lake in 1989, Mushroom and Cigar lakes in 1990, Caribou Lake in 1986, and Judge Sissons Lake in 1980 were also above consumption guidelines of 0.5 µg/g (Attachment X.X, Table X.X-1).

Concentrations of radionuclides were below detection limits in most of the lake trout sampled between 1980 and 1990. Concentration of Pb-210 in one fish from Judge Sissons Lake (1980), concentrations of Po-210 in lake trout from Mushroom and Cigar lakes (1990), and concentration of Th-230 in fish from Cigar Lake (1990) were above the detection limit (0.001 Bq/g). In 1980, detectable levels of Ra-226 was found in all lake trout from Judge Sissons Lake and ranged from 0.003 to 0.013 Bq/g. In 1990, Ra-226 was detectable at the detection limit (0.0004 Bq/g) in a composite sample from Cigar Lake (Attachment X.X, Table X.X-4).

11.2.6.2 Recent Sampling Period 2008 to 2009

Fish tissue (flesh) and bone were analysed on Arctic grayling and lake trout in 2008 and 2009; round whitefish was analysed only in 2008; and cisco was analysed only in 2009 (Attachment X.X, Tables X.X-5 to X.X-8). Tissue and liver samples from Arctic char captured in Baker Lake were also sampled. Summary statistics for Baker Lake fish processed in 2009 are presented in Table 11.2-22, 2008 Arctic grayling flesh and bone statistics are in Tables 11A-9 and 11A-10, 2008 lake trout flesh and bone statistics are in Tables 11A-11 and 11A-12, 2008 round whitefish flesh and bone statistics are in Tables11A-13 and 11A-14, and 2009 statistics for Arctic grayling, cisco, and lake trout are in Tables 11.2-23 to 11.2-25.

Table 11.2-22 Summary of Mean Metal Concentrations in Fish Tissue, Baker Lake, August 2009[(a)]

Analyte	Lake Trout		Arctic Char	
	Mean (mg/kg wet weight)	**Reference Value (± SD)**	**Mean[(b)] (mg/kg wet weight)**	**Reference Value (± SD)**
Liver Tissue				
Aluminum[(c)]	4.3	2.2 (3.51)	1.116	2.03 (1.83)
Arsenic[(c)]	0.02	0.03 (0.01)	0.026	0.03 (0.01)
Barium[(c)]	0.03	0.28 (0.09)	<0.01	0.26 (0.12)
Cadmium[(c)]	0.116	0.28 (0.09)	0.28	63.6 (44.8)
Copper[(c)]	8.841	13.6 (6.71)	12.33	14.4 (18.8)
Iron[(c)]	150.25	382 (237)	746 (520)	216 (136)
Lead[(c)]	0.004	0.3 (0.12)	0.003	0.33 (0.21)
Manganese[(c)]	1.294	1.19 (0.47)	1.086	1.55 (0.79)
Molybdenum[(e)]	0.117	16	0.17	16
Nickel[(c)]	0.015	1.41 (0.46)	0.016	1.32 (0.62)
Selenium[(d)]	0.943	1.0	1.63	1.0
Strontium	0.271	none	0.127	none
Thallium[(f)]	0.053	0.27	0.027	0.27
Zinc[(c)]	28.083	28 (2.87)	123.3 (30.0)	30.2 (7.19)
Muscle Tissue				
Mercury[(c)]	0.18	0.26 (0.04)	0.083333	0.11 (0.12)
Radionuclides				
	Mean (Bq/g)	**Reference Value**	**Mean (Bq/g)**	**Reference Value**
Lead-210	0.00165	none	0.001	none
Polonium-210	0.00043	none	0.0003	none
Radium-226	0.0000735	none	0.000073	none
Thorium-230	<0.01	none	<0.01	none

(a) Individual samples that were below detection limits were given a value of one-half of the detection limit. Where the detection limit differed between samples of the same analyte at one site, the highest value was used to calculate the mean.
(b) Values in parentheses indicate mean values from which outliers were not considered (values which were an order of magnitude greater than all other values).
(c) Metal concentrations in bold exceeded levels (plus one standard deviation) in Rieberger (1992).
(d) Metal concentrations in bold exceeded BC MoE Tissue Quality Guidelines (2006) for human consumption of edible tissue.
(e) Metal concentrations in bold exceeded levels in ERED 2008 for sockeye salmon (*Oncorhynchus nerka*).
(f) Metal concentrations in bold exceeded levels in ERED 2008 for Atlantic salmon (*Salmo salar*).
(g) Value in parentheses represents the mean metal concentration without outliers.
< = less than; mg/kg = milligrams per kilogram; SD = standard deviation; Bq/g = Becquerels per gram.

Arctic Char

Concentrations of total iron and zinc in Arctic char liver tissue exceeded the Rieberger average for uncontaminated lakes (Rieberger 1992) at Station 1 in Baker Lake. As well, selenium exceeded BC tissue quality guidelines (BCMoE 2006) and molybdenum concentrations exceeded ERED toxicity values specified for sockeye salmon (ERED 2008). As with lake trout, mean concentrations of aluminum, copper, iron, and zinc were highest for Arctic char liver samples collected at site 1 (Table 11.2-22).

Mean mercury concentrations in Arctic char muscle tissue at Station 1 did not exceed Rieberger averages (Rieberger 1992) and were below BCMoE recommended levels for human consumption (0.1 to 0.5 mg/kg) (BCMoE 2006). Only three Arctic char muscle samples were analyzed for mercury levels. Mercury concentrations ranged between 0.06 and 0.11 mg/kg. Due to the small sample size (3), the relationship between fish length and mercury concentrations was not examined.

Concentrations of Th-228 and Th-230 were below detection limits in flesh and bone from Baker Lake Arctic char. Pb-210, Polonium-210, and Ra-226 were detected in flesh and bone samples from three Arctic char captured in Baker Lake. Pb-210 concentrations ranged from below detection limits to 0.003 Bq/g, Polonium-210 concentrations ranged from 0.001 to 0.002 Bq/g, and Ra-226 concentrations ranged from 0.0008 to 0.002 Bq/g.

Arctic Grayling

In general, concentrations of trace metals in flesh and bone of Arctic grayling in 2008 were similar between lakes. Many of the chemistry parameters were near or below detection limits (Table 11A-9, Table 11A-10). The concentration of arsenic and lead in flesh were below guidelines for all lakes. The concentration of cadmium in Arctic grayling from Mushroom Lake (0.005 µg/g) was equal to the consumption guideline. Variations in flesh of Arctic grayling among lakes were observed for aluminum, barium, strontium, and uranium, while variations in bone were observed for barium and strontium. Higher concentrations of aluminum, barium, and strontium were measured in flesh samples from Pointer and Caribou lakes (Table 11A-9). Higher concentrations of barium in bone were measured in samples from Pointer Lake, and higher concentrations of strontium in bone were measured in samples from Pointer and Mushroom lakes (Table 11A-10). Concentrations of uranium in flesh were highest in Judge Sissons Lake (0.010 to 0.16 µg/g), followed by Pointer and Caribou lakes (0.003 and 0.023 µg/g), and concentrations at or below detection limit in Mushroom Lake (Table 11A-9).

Concentrations of radionuclides were below detection limits in flesh and bone from Arctic grayling for Th-228, Th-230, and Th-232 (Table 11A-9, Table 11A-10). Concentration of Pb-210 was detected in flesh from Pointer Lake and in bone from Judge Sissons Lake. Polonium-210 was detected in flesh and bone from at least one fish from all four lakes; detectable concentrations ranged from 0.0009 to

0.002 Bq/g in flesh and from 0.001 to 0.005 Bq/g in bone (Table 11A-9, Table 11A-10). Detectable concentrations of Ra-226 ranged from 0.0001 to 0.002 Bq/g in flesh and from 0.001 to 0.008 Bq/g in bone from at least one fish from all four lakes (Table 11A-9, Table 11A-10).

In 2009, chemistry analysis was completed on Arctic grayling flesh and bone from Judge Sissons Lake only. The concentration of arsenic, cadmium, and lead in flesh of Arctic grayling were below guidelines (Attachment X.X, Table X.X-7). Variation between flesh and bone was limited. Many of the chemistry parameters were near or below detection limits (Table 11.2-23). Concentrations of cobalt, copper, iron, and selenium were similar in bone and flesh samples. Concentrations of nickel were detected in bones, but were near or below detection limit in flesh samples. Higher concentrations of aluminum, barium, manganese, strontium, titanium, and zinc were observed in bone samples compared to flesh samples. Concentrations of all radionuclides were near or below detection limits in flesh and bone from Arctic grayling except for Pb-210 in bone and Po-210 in flesh and bone (Table 11.2-23). Concentrations of Pb-210 ranged from 0.003 to 0.051 Bq/g in bone. Concentrations of Po-210 were slightly above detection limits (0.0002 to 0.0010 Bq/g) and mean concentration was similar in flesh and bone samples.

Comparison of metal and radionuclides between 2008 (n = 2 fish) and 2009 (n = 5 fish) in Judge Sissons Lake shows similar values between the years except for aluminum, lead, and uranium concentrations in flesh samples and strontium and zinc concentrations in bone samples. In 2008, concentrations of aluminum, lead, and uranium were detected for all flesh samples, while concentrations were near or below detection limits in 2009. In 2009, concentrations of strontium and zinc were more than twice the minimum value from 2008.

Cisco

In 2009, chemistry analysis was completed on cisco flesh and bone from Pointer Lake only. Many of the chemistry parameters were near or below detection limits (Table 11.2-24). The concentrations of arsenic, cadmium, and lead in flesh of cisco were below guidelines (Table 11.2-24). Concentrations of cobalt, copper, and selenium were similar in bone and flesh samples. Concentrations of nickel were detected in bones and were near or below detection limits in flesh samples. Higher concentrations of aluminum, arsenic, barium, iron, manganese, strontium, titanium, and zinc were observed in bone samples compared to flesh samples. Concentrations of all radionuclides were near or below detection limits in flesh and bone from cisco, except for Pb-210 and Po-210 (Table 11.2-24). Concentrations of Pb-210 were slightly lower in flesh samples (less than 0.001 to 0.045 Bq/g) than in bone samples (0.012 to 0.12 Bq/g). Concentrations of Po-210 were low (ranging from less than 0.0005 to 0.005 Bq/g) and similar between flesh and bone samples.

Lake Trout

In general, concentrations of trace metals in flesh and bone of lake trout in 2008 were similar between lakes. Many of the chemistry parameters were near or below detection limits (Table 11A-11, Table 11A-12). Concentrations of arsenic, cadmium, and lead in flesh were detected, but below guidelines for all lakes. Arsenic, cadmium, and lead in bone was near or below detection limit (Table 11A-11, Table 11A-12). Concentrations of barium, selenium, and uranium in the flesh of lake trout varied between lakes, while variations in bone concentrations were observed for aluminum and boron. Higher concentrations of barium in flesh were found in Pointer and Judge Sissons lakes (Table 11A-11). Concentrations of selenium in flesh were highest in Mushroom Lake (0.30 to 0.44 µg/g); followed by Judge Sissons Lake (0.26 to 0.33 µg/g); and Pointer and Caribou lakes (range: 0.20 to 0.25 µg/g). The highest concentration of 0.02 µg/g uranium in lake trout flesh occurred in Pointer Lake, whereas the mean uranium concentration in fish from other lakes was 0.002 µg/g (Table 11A-11). The only detected concentration of boron in bone was measured in a sample from Judge Sissons Lake (Table 11A-12).

Concentrations of Pb-210, Th-228, and Pb-232 were below detection limits in flesh from lake trout (Table 11A-11). Thorium-228 and Th-232 were below detection limits in bone samples (Table 11A-12). Lead-210 was detected in bone from Mushroom Lake (Table 11A-12). Polonium-210 was detected in flesh from at least one fish from all lakes except Caribou Lake; detectable concentrations ranged from 0.0002 to 0.0004 Bq/g in flesh and from 0.0007 to 0.002 Bq/g in bone (Table 11A-11, Table 11A-12). Concentrations of Ra-226 and Th-230 were detected in flesh samples from Mushroom Lake (Table 11A-11), while Ra-226 was detected in bone samples from Pointer and Judge Sissons lakes, and Th-230 was detected in bone samples from Judge Sissons Lake (Table 11A-12).

In 2009, chemistry analysis was completed on lake trout flesh and bone from Judge Sissons Lake only. Many of the chemistry parameters were near or below detection limits (Table 11.2-25). The concentrations of arsenic, cadmium, and lead in the flesh of lake trout were below guidelines, but concentrations of mercury in flesh (n = 4 fish) were higher than guidelines (Table 11.2-25). Variation between flesh and bone was limited. Concentrations of copper, and selenium were similar in bone and flesh samples. Concentrations of nickel were detected in bones and were near or below detection limits in flesh samples. Higher concentrations of aluminum, arsenic, barium, cobalt, iron, manganese, strontium, titanium, and zinc were observed in bone samples compared to flesh samples. Concentrations of all radionuclides were near or below detection limits in flesh and bone from lake trout except for Po-210 in bone and Ra-226 in flesh and bone (Table 11.2-25). Concentrations of Po-210 ranged from 0.0006 to 0.003 Bq/g in bone. Concentrations of Ra-226 were low in flesh samples, but higher in bone samples (ranging from 0.0009 to 0.002 Bq/g).

Comparison of metal and radionuclides between lake trout captured in Judge Sissons Lake from 2008 (n = 5 for flesh and bone samples) and 2009 (n = 5 for flesh samples and n = 4 for bone samples) shows similar values between the years, except for aluminum and Ra-226 concentrations in flesh samples, and for arsenic and strontium concentrations in bone samples. In 2008, concentrations of aluminum were detected for all flesh samples, while concentrations were near or below detection limits in 2009. In 2009, concentrations of Ra-226 in flesh samples and arsenic in bone samples were detected, while concentrations were near or below detection limits in 2008. In 2009 concentrations of strontium were about twice the minimum value from 2008.

Baker Lake

Several lake trout were also captured in Baker Lake in 2009 and analyzed for metals and radionuclides. Concentrations of all metals were below Rieberger averages plus one standard deviation for uncontaminated lakes (Rieberger 1992). The remaining metals tested did not exceed the ERED value. Mean concentrations of aluminum, copper, iron, and zinc were highest for lake trout liver samples (Table 11.2.-22).

Mean mercury concentrations in lake trout muscle tissue at Station 1 did not exceed Rieberger averages (Rieberger 1992) and were below maximum BCMoE recommended levels for human consumption (0.1 to 0.5 mg/kg) (BCMoE 2006). While the majority of mercury levels ranged from 0.1 mg/kg to 0.26 mg/kg wet weight, there was one sample with a value of 0.47 mg/kg, which is near the BCMoE upper limit for human consumption. This sample was from a larger, 14 year-old lake trout (400 mm, 675 g). The relationship between mercury levels in lake trout muscle tissue and fish length was examined for fish captured at Site 1. The expected, generally increasing trend in mercury concentration with fish size was not evident (R^2 = 0.0853). Likewise, there was no correlation between fish age and mercury levels for lake trout captured at site 1 (R^2 = 0.0027).

Concentrations of Th-228 and Th-230 were below detection limits in flesh and bone from Baker Lake lake trout. Pb-210, Polonium-210, and Ra-226 were detected in flesh and bone samples from several lake trout captured in Baker Lake. Pb-210 concentrations ranged from below detection limits to 0.015 Bq/g, Polonium-210 concentrations ranged from below detection limits to 0.004 Bq/g, and Ra-226 concentrations ranged from below detection limits to 0.003 Bq/g.

Round Whitefish

Concentrations of most of the trace metals in flesh and bone of round whitefish captured in 2008 were similar between lakes and generally low (i.e., near detection limits). The concentrations of arsenic, cadmium, and lead in flesh were below guidelines for all lakes, while concentrations in bone were near or below the detection limit. Higher concentrations of aluminum, barium, copper, lead, silver, and strontium, uranium, and zinc were present in the flesh of fish from Caribou Lake. The highest concentration of selenium occurred in fish from Mushroom Lake (Table 11A-13). Higher concentrations of boron and zinc in bone were found in samples from Lower Lake, while higher concentrations of manganese, selenium, strontium, and uranium in bone were found measured in samples from Mushroom Lake (Table 11A-14). Uranium was detectable from at least one fish in each of the lakes sampled, except Lower Lake. Uranium concentrations ranged from below detection limits in Lower Lake to a maximum of 0.28 µg/g in a fish from Caribou Lake.

Concentrations of Pb-210, Ra-226, Th-228, Th-230, and Th-232 were below detection limits in flesh from round whitefish sampled in 2008 (Table 11A-13). Concentrations of Th-228, Th-230, and Th-232 were not detected in bone samples (Table 11A-14). Polonium-210 was detected in flesh and bone from at least one fish from all four lakes sampled in 2008. Concentrations of Po-210 ranged from 0.0003 to 0.001 Bq/g in flesh and from 0.002 to 0.007 Bq/g in bone (Table 11A-13, Table 11A-14). Radium-226 was also detectable in bones samples in at least one fish from Mushroom, Lower, and Caribou lakes. Concentrations of Ra-226 ranged from 0.002 to 0.003 Bq/g (Table 11A-14).

11.3 Summary

The Traditional Land Use study conducted as part of the environmental assessment baseline indicates that portions of Judge Sissons Lake, Caribou Lake, Sleek Lake and Siamese Lake were traditionally used for fishing and hunting. Fishing in the Judge Sissons Lake area was concentrated near the outlet of the lake and in the southeast arm of the lake. In addition, the two lake-like widenings of the Aniguq River immediately downstream of Judge Sissons Lake were also fished. Fish were used to augment food supplies for humans and dog teams, when caribou were not abundant. The subsistence fisheries in the Project area focused on lake trout, lake whitefish, and Arctic grayling.

The results of the aquatic sampling programs have found the species composition of fish communities is similar in lakes and streams in the mine site and site access LSAs. Seven species of fish have been captured in the LSA, including Arctic grayling, burbot, cisco, lake trout, ninespine stickleback, round whitefish, and slimy sculpin. Four additional species have been captured in Baker Lake, including Arctic char, fourhorn sculpin, lake whitefish, and longnose sucker.

Fish are widely distributed in the lakes and streams of the mine site LSA. Arctic grayling and lake trout are the most widely dispersed species and the species found in the highest abundance. Other species occur in lesser numbers and their distribution is much more restricted. For example, species such as ninespine stickleback, slimy sculpin, and burbot were generally restricted to the lower portions of each sub-basin, close to Judge Sissons Lake. These species may overwinter in Judge Sissons Lake and then move into the lower lakes of the sub-basins to feed and rear during the open water period.

Fish distribution appears to vary seasonally and is influenced by overwintering conditions. The majority of the lakes in the mine site LSA are shallow and freeze to the bottom in the winter. Therefore, fish appear to be moving into the deeper lakes for overwintering, particularly Judge Sissons Lake. There is a movement of fish into the streams in the early spring for spawning and feeding purposes. These seasonal movements are exemplified by results in the Willow Lake sub-basin. Arctic grayling and lake trout were captured in streams and lakes during the spring and summer sampling; however, these species were absent in the catch from late August and early September.

Fish health assessments found that all species present were in good health. Observations of external or internal abnormalities and parasites were generally low.

Arctic grayling spawning was confirmed in the Willow Lake and Lower Lake sub-basins, with several specific areas identified where eggs were found in 2009. Ripe lake trout were found in Ridge, Cigar, Judge Sissons, Mushroom, and Siamese lakes. These five lakes are deep enough to have overwintering fish populations; therefore, it is likely that overwintering lake trout populations occur in these lakes.

Fish tissue chemistry results indicate that most metals and radionuclides were at or below detection limits. There were few individual exceedances of consumption guidelines for arsenic, cadmium, mercury, and lead. Selenium appeared to be at higher concentrations in fish captured in Mushroom Lake.

Table 11.2-2 Fishing Effort for the Fish Community and Fish Chemistry Surveys, 2007 to 2010

Waterbody/Watercourse	Season and Year	Angling (hour)	Backpack Electrofishing Time (seconds)	Gill Netting Time (hour)	Gill Netting Total Net Length (metres)	Minnow Trapping (hour)	Fish Species Captured	Fish Species Observed
Willow Lake Sub-Basin								
NEPRL	spring 2010	-	3,968	-	-	-	-	-
T-NEPRL	spring 2010	-	4,938	-	-	-	-	-
U-NWPRL	spring 2010	-	3,585	-	-	-	slimy sculpin	slimy sculpin
Pointer Pond	spring 2010	1.22	-	-	-	-	-	-
Pointer Lake	fall 2007	-	-	12.20	120	519.20	Arctic grayling, cisco, lake trout, ninespine stickleback	Arctic grayling
	summer 2008	4.50	-	42.08	270	67.02	Arctic grayling, cisco, lake trout, ninespine stickleback	-
	fall 2009	4.07	-	17.15	540	-	cisco	-
Sik Sik Lake	fall 2007	-	-	12.60	120	175.00	ninespine stickleback	-
Rock Lake	summer 2008	-	-	10.30	270	25.22	Arctic grayling	-
Willow Lake	fall 2007	-	-	7.40	120	11.80	Arctic grayling	ninespine stickleback
subtotal		*9.79*	*12,491*	*101.73*	*1,440*	*798.24*		
Lower Lake Sub-Basin								
Mushroom Lake	summer 2008	1.50	-	6.90	405	140.28	Arctic grayling, lake trout, round whitefish	lake trout
Pond 1	spring 2010	0.50	1,429	-	-	78.30	-	-
Pond 2	spring 2010	0.73	1,254	-	-	69.35	-	-
Pond 3	spring 2010	0.80	1,206	-	-	220.52	-	-
Pond 4	spring 2010	0.53	1,394	-	-	84.13	-	-
Pond 5	spring 2010	0.70	1,440	-	-	202.07	-	-
Pond 6	spring 2010	0.32	1,245	-	-	60.18	-	-
Pond 7	spring 2010	0.27	1,326	-	-	59.08	-	-
Pond 8	spring 2010	0.50	1,277	-	-	13.83	-	-
End Grid Lake	fall 2007	-	-	5.70	60	29.80	Arctic grayling	-
	summer 2008	-	-	3.50	135	93.10	no fish captured	-
Cigar Lake	summer 2008	-	-	5.95	270	101.75	burbot, cisco, lake trout, round whitefish	lake trout
Knee Lake	summer 2008	0.75	-	18.83	135	131.00	Arctic grayling	Arctic grayling
Lunch Lake	summer 2008	0.67	-	4.02	135	136.73	Arctic grayling, round whitefish	Arctic grayling
Andrew Lake	fall 2007	-	-	13.60	120	40.90	burbot	-
	summer 2008	-	-	43.92	270	90.63	Arctic grayling, round whitefish	-
	fall 2009	-	-	45.20	270	90.78	Arctic grayling, burbot, cisco	-
Shack Lake	fall 2007	-	-	16.10	120	42.90	no fish captured	-

Table 11.2-2 Fishing Effort for the Fish Community and Fish Chemistry Surveys, 2007 to 2010

Waterbody/Watercourse	Season and Year	Angling (hour)	Backpack Electrofishing	Gill Netting		Minnow Trapping (hour)	Fish Species	
			Time (seconds)	Time (hour)	Total Net Length (metres)		Captured	Observed
	summer 2008	-	-	11.02	270	28.80	Arctic grayling	-
Lower Lake	fall 2007	-	-	16.30	240	47.70	Arctic grayling	Arctic grayling
	summer 2008	1.63	-	89.05	540	231.60	Arctic grayling, burbot, ninespine stickleback, round whitefish	-
subtotal		*8.90*	*10,571*	*280.09*	*2,970*	*1,993.43*		
Caribou Lake Sub-Basin								
Ridge Lake	fall 2007	0.50	-	15.70	120	46.10	no fish captured	-
	summer 2008	-	-	4.76	270	-	lake trout	-
Cirque Lake	fall 2007	-	-	14.40	120	42.30	ninespine stickleback	-
	fall 2008	0.73	-	3.00	135	-	no fish captured	-
Crash Lake	fall 2007	-	-	7.80	60	43.40	Arctic grayling	-
Fox Lake	fall 2007	-		12.10	120	40.80	no fish captured	-
	summer 2008	-	-	58.83	270	73.75	Arctic grayling, cisco, ninespine stickleback	-
Caribou Lake	summer 2008	-	-	46.02	270	118.77	Arctic grayling, burbot, cisco, lake trout, ninespine stickleback, round whitefish	-
Calf Lake	summer 2008	-	-	10.52	270	97.02	burbot, cisco, ninespine stickleback	-
subtotal		*1.23*	*0*	*173.13*	*1,635*	*462.14*		
Judge Sissons Lake Sub-Basin								
Judge Sissons Lake	summer 2008	25.95	-	8.27	675	378.57	Arctic grayling, burbot, cisco, lake trout, ninespine stickleback, round whitefish	lake trout
	fall 2009	1.53	-	3.07	135	-	Arctic grayling, lake trout	lake trout
subtotal		*25.95*	*0*	*8.27*	*675*	*378.57*		
Siamese Lake Sub-Basin								
Siamese Lake	summer 2008	4.62	-	5.13	270	-	lake trout	-
Aniguq River								
Aniguq River	fall 2009	23.13	-	-	-	-	Arctic grayling, lake trout	Arctic grayling, lake trout
Total		**72.39**	**23,062**	**395.22**	**5,355**	**3170.24**		

Notes: Individual gill nets used in fall 2007 were 60 m long, with 6 panels of 10 m each of the following mesh sizes: 2.5, 3.8, 5.1, 7.6, 10.2, 12.7 cm.
Individual gill nets used in summer and fall 2008 and 2009 were 135 m long, with 9 panels of 15 m each of the following mesh sizes: 1.9, 3.8, 6.4, 7.6, 8.9, 10.2, 11.4, 12.7, 14.0 cm.
\- = not applicable, NEPRL = Northeast Inflow of Pointer Lake Stream; T-NEPRL = Tributary to the NEPRL; NWPRL = Northwest Inflow of Pointer Lake.

Table 11.2-4 Fishing Effort for the Fish Survey of Watercourses Crossed by Proposed Access Road Corridors, 2008 to 2009

New Crossing ID (EBA)	Crossing ID (Golder)	Season and Year	Angling (hour)	Backpack Electrofishing (seconds)	Observation (hour)	Fish Species	
						Captured	Observed
Northern Road Crossings							
Km 2.0	NC31 Stream	spring 2009	-	-	3.00	-	Arctic grayling
Km 6.7	NC30 Stream	summer 2009	-	-	3.80	Arctic grayling	unidentified species
Km 11.3	NC29 Stream	summer 2009	-	2,783	-	Arctic grayling, slimy sculpin	unidentified species
Km 15.6	NC27 Stream	summer 2009	-	758	-	ninespine stickleback	-
Km 17.2	NC26 Stream	summer 2009	-	1,763	-	Arctic grayling, ninespine stickleback, slimy sculpin	slimy sculpin
Km 100.2	NC24 Stream	summer 2009	-	302	-	-	-
Km 107.8	NC23 Stream	summer 2009	-	578	-	-	-
Km 108.8	NC34 Stream	spring 2009	-	-	3.67	-	-
Km 109.8	NC22.5 Stream	summer 2009	-	505	-	Arctic grayling, ninespine stickleback, slimy sculpin	Arctic grayling
alternate NC22	NC22 Stream	spring 2009	-	-	4.00	-	-
alternate NC21	NC21 Stream	spring 2009	-	-	4.00	-	-
alternate NC20	NC20 Stream	spring 2009	-	-	4.33	-	-
alternate NC17	NC17 Stream	summer 2009	-	1,269	-	-	-
Km 127.5	NC16 Stream	summer 2009	-	1,109	-	Arctic grayling, ninespine stickleback, slimy sculpin	Arctic grayling, ninespine stickleback, slimy sculpin
Km 129.2	NC15 Stream	summer 2009	-	820	-	Arctic grayling, burbot	slimy sculpin
Km 145.3	NC13 Stream	summer 2009	-	463	8.50	Arctic grayling, ninespine stickleback, round whitefish, slimy sculpin	unidentified species
Km 147.1	NC12 Stream	summer 2009	-	211	-	ninespine stickleback, slimy sculpin	-
Km 147.6	NC11.5 Stream	summer 2009	-	363	-	-	-
Km 157.3	NC10 Stream	summer 2009	-	312	-	ninespine stickleback	-
Km 157.7	NC09 Stream	summer 2009	-	643	5.33	Arctic graying, longnose sucker, ninespine stickleback	unidentified species
Km 172.2	NC03 Stream	summer 2009	-	468	-	-	-
Km 174.8	Thelon River	fall 2008	4.08	-	-	lake trout	-
		summer 2009	1.00	818	-	Arctic grayling, lake trout	Arctic grayling, slimy sculpin
alternate EC30	EC30 Stream	fall 2009	-	-	2.00	-	-
alternate EC22	EC22 Stream	fall 2009	-	-	4.43	-	ninespine stickleback, unidentified species
Km 193.3	EC21 Stream	fall 2009	-	-	5.25	-	-
Km 195.1	EC20 Stream	fall 2009	-	-	7.00	-	-
Km 197.5	EC19 Stream	fall 2009	-	-	5.25	-	-

Table 11.2-4 Fishing Effort for the Fish Survey of Watercourses Crossed by Proposed Access Road Corridors, 2008 to 2009

New Crossing ID (EBA)	Crossing ID (Golder)	Season and Year	Angling (hour)	Backpack Electrofishing (seconds)	Observation (hour)	Fish Species	
						Captured	Observed
Km 203.0	EC10 Stream	fall 2009	-	-	4.40	-	ninespine stickleback, unidentified species
Km 209.4	EC4 Stream	fall 2009	-	-	16.55	-	-
Km 212.2	EC3 Stream	fall 2009	-	-	11.43	-	-
Km 213.1	EC2 Stream	fall 2009	-	-	14.47	-	Arctic grayling
Winter Road Crossings							
alternate W1	W1 Stream	summer 2009	-	126	-	-	ninespine stickleback
alternate W2	W2 Stream	summer 2009	-	1,365	-	ninespine stickleback	slimy sculpin, unidentified species
alternate W3	W3 Stream	summer 2009	-	866	-	-	ninespine stickleback
alternate W5	W5 Stream	summer 2009	-	703	-	-	-
alternate W6	W6 Stream	summer 2009	-	396	-	-	-
Southern Road Crossings							
S03	S03 Stream	fall 2009	-	754	-	Arctic grayling, ninespine stickleback, slimy sculpin	ninespine stickleback
S05	S05 Stream	fall 2009	-	873	-	burbot, ninespine stickleback	ninespine stickleback
S11	S11 Stream	fall 2009	-	343	-	ninespine stickleback	ninespine stickleback
S13	S13 Stream	fall 2009	-	846	-	ninespine stickleback, slimy sculpin	Arctic grayling
S14	S14 Stream	fall 2009	-	1,067	-	Arctic grayling, ninespine stickleback	-
Other Road Crossings							
alternate X28	X28 Stream	fall 2008	3.33	-	-	lake trout	-
alternate X33	X33 Stream	fall 2008	3.13	-	-	lake trout	-

\- = not applicable.

Table 11.2-7 Catch-Per-Unit-Effort for the Fish Survey at Watercourses Crossed by Proposed Access Road Corridors, 2008 to 2009

New Crossing ID (EBA)	Crossing ID (Golder)	Season and Year	Fish Species	Angling (hours)	Angling		Backpack Electrofishing (seconds)	Backpack Electrofishing	
					# Fish Captured	CPUE (# fish/hr)		# Fish Captured	CPUE (# fish/100 s)
alternate X28	X28	fall 2008	lake trout	3.33	9	2.70	-	-	-
alternate X33	X33	fall 2008	lake trout	3.13	1	0.32	-	-	-
Km 11.3	NC29	summer 2009	Arctic grayling	-	-	-	2,783	1	0.04
			slimy sculpin	-	-	-		3	0.11
Km 15.6	NC27	summer 2009	ninespine stickleback	-	-	-	758	1	0.13
Km 17.2	NC26	summer 2009	Arctic grayling	-	-	-	1,763	14	0.79
			ninespine stickleback	-	-	-		2	0.11
			slimy sculpin	-	-	-		43	2.44
Km 100.2	NC24	summer 2009	no fish captured	-	-	-	302	0	0
Km 107.8	NC23	summer 2009	no fish captured	-	-	-	578	0	0
Km 109.8	NC22.5	summer 2009	Arctic grayling	-	-	-	505	26	5.15
			ninespine stickleback	-	-	-		1	0.20
			slimy sculpin	-	-	-		4	0.79
alternate NC17	NC17	summer 2009	no fish captured	-	-	-	1,269	0	0.00
Km 127.5	NC16	summer 2009	Arctic grayling	-	-	-	1,109	6	0.54
			ninespine stickleback	-	-	-		12	1.08
			slimy sculpin	-	-	-		5	0.45
Km 129.2	NC15	summer 2009	Arctic grayling	-	-	-	820	1	0.12
			burbot	-	-	-		1	0.12
Km 145.3	NC13	summer 2009	Arctic grayling	-	-	-	463	16	3.46
			ninespine stickleback	-	-	-		5	1.08
			slimy sculpin	-	-	-		19	4.10
			round whitefish	-	-	-		4	0.86
Km 147.1	NC12	summer 2009	ninespine stickleback	-	-	-	211	46	21.80
			slimy sculpin	-	-	-		1	0.47
Km 147.6	NC11.5	summer 2009	no fish captured	-	-	-	363	0	0
Km 157.3	NC10	summer 2009	ninespine stickleback	-	-	-	312	5	1.60

Table 11.2-7 Catch-Per-Unit-Effort for the Fish Survey at Watercourses Crossed by Proposed Access Road Corridors, 2008 to 2009

New Crossing ID (EBA)	Crossing ID (Golder)	Season and Year	Fish Species	Angling (hours)	Angling		Backpack Electrofishing (seconds)	Backpack Electrofishing	
					# Fish Captured	CPUE (# fish/hr)		# Fish Captured	CPUE (# fish/100 s)
Km 157.7	NC09	summer 2009	Arctic grayling	-	-	-	643	1	0.16
			ninespine stickleback	-	-	-		13	2.02
			longnose sucker	-	-	-		4	0.62
Km 172.2	NC03	summer 2009	no fish captured	-	-	-	468	0	0
Km 174.8	Thelon River	fall 2008	lake trout	4.08	1	0.25	-	-	-
		summer 2009	Arctic grayling	1.00	1	1.00	818	3	0.37
			lake trout		1	1.00		0	0
alternate W1	W1	summer 2009	no fish captured	-	-	-	126	0	0
alternate W2	W2	summer 2009	ninespine stickleback	-	-	-	1,365	2	0.15
alternate W3	W3	summer 2009	no fish captured	-	-	-	866	0	0
alternate W5	W5	summer 2009	no fish captured	-	-	-	703	0	0
alternate W6	W6 S	summer 2009	no fish captured	-	-	-	396	0	0
S03	S03	fall 2009	Arctic grayling	-	-	-	754	4	0.53
			ninespine stickleback	-	-	-		20	2.65
			slimy sculpin	-	-	-		1	0.13
S05	S05	fall 2009	ninespine stickleback	-	-	-	873	9	1.03
			burbot	-	-	-		1	0.11
S11	S11	fall 2009	ninespine stickleback	-	-	-	343	327	95.34
S13	S13	fall 2009	ninespine stickleback	-	-	-	846	7	0.83
			slimy sculpin	-	-	-		11	1.30
S14	S14	fall 2009	Arctic grayling	-	-	-	1,067	1	0.09
			ninespine stickleback	-	-	-		38	3.56

- = not applicable; CPUE = catch-per-unit-effort; # = number; # fish/h = number of fish per hour; # fish/100 s = number of fish per hour per 100 seconds.

Table 11.2-23 Summary of Chemistry Results for Flesh and Bone of Arctic Grayling Captured in Judge Sissons Lake in the Kiggavik Project Area, Fall 2009

Parameter	Unit[(a)]	Flesh							Bone						
		n	Mean	Median	SD	SE	Min	Max	n	Mean	Median	SD	SE	Min	Max
Physical Properties															
Ash	%	5	1.0	1.2	0.41	0.18	0.47	1.42	5	17.42	18.43	2.248	1.005	13.42	18.61
Moisture	%	5	75.2	75.5	1.052	0.4703	73.43	76.20	5	62.40	60.92	4.938	2.208	58.82	70.82
Metals															
Aluminum	µg/g	5	-	-	-	-	<0.01	0.18	5	0.44	0.42	0.15	0.069	0.29	0.69
Antimony	µg/g	5	-	-	-	-	<0.02	<0.02	5	-	-	-	-	<0.05	<0.05
Arsenic	µg/g	5	-	-	-	-	<0.01	<0.01	5	-	-	-	-	<0.02	0.05
Barium	µg/g	5	0.2	0.2	0.2	0.08	0.05	0.52	5	55	53	15	6.6	39	75
Beryllium	µg/g	5	-	-	-	-	<0.002	<0.02	5	-	-	-	-	<0.01	<0.01
Boron	µg/g	5	-	-	-	-	<0.2	<0.2	5	-	-	-	-	<0.5	<0.5
Cadmium	µg/g	5	-	-	-	-	<0.002	<0.002	5	-	-	-	-	<0.01	<0.01
Chromium	µg/g	5	-	-	-	-	<0.1	<0.1	5	-	-	-	-	<0.2	<0.2
Cobalt	µg/g	5	0.008	0.006	0.004	0.002	0.005	0.013	5	0.03	0.03	0.02	0.007	0.01	0.04
Copper	µg/g	5	0.50	0.36	0.26	0.12	0.24	0.80	5	0.36	0.36	0.079	0.035	0.26	0.47
Iron	µg/g	5	4.4	3.6	2.0	0.89	2.2	6.5	5	5.7	5.1	1.4	0.64	4.6	8.1
Lead	µg/g	5	-	-	-	-	<0.002	<0.002	5	0.02	0.01	0.01	0.006	<0.01	0.04
Manganese	µg/g	5	0.1	0.1	0.06	0.03	0.08	0.23	5	12	6.5	9.9	4.4	3.6	27
Mercury	µg/g	0	-	-	-	-	-	-	0	-	-	-	-	-	-
Molybdenum	µg/g	5	-	-	-	-	<0.02	<0.02	5	-	-	-	-	<0.05	<0.05
Nickel	µg/g	5	-	-	-	-	<0.01	0.01	5	0.08	0.07	0.04	0.02	0.03	0.13
Selenium	µg/g	5	0.2	0.2	0.046	0.020	0.16	0.25	5	0.2	0.2	0.07	0.03	0.09	0.28
Silver	µg/g	5	-	-	-	-	<0.002	<0.002	5	-	-	-	-	<0.01	<0.01
Strontium	µg/g	5	0.47	0.48	0.32	0.14	0.15	0.90	5	133	134	25.9	11.6	93	160
Thallium	µg/g	5	-	-	-	-	<0.01	<0.01	5	-	-	-	-	<0.02	<0.02
Tin	µg/g	5	-	-	-	-	<0.01	<0.01	5	-	-	-	-	<0.02	<0.02
Titanium	µg/g	5	0.084	0.09	0.009	0.004	0.07	0.09	5	0.27	0.24	0.098	0.044	0.16	0.40
Uranium	µg/g	5	-	-	-	-	<0.001	<0.001	5	-	-	-	-	<0.01	0.01
Vanadium	µg/g	5	-	-	-	-	<0.02	<0.02	5	-	-	-	-	<0.05	<0.05
Zinc	µg/g	5	6.9	6.6	1.2	0.5	5.6	8.6	5	53.80	56	13.773	6.160	34	69

Table 11.2-23 Summary of Chemistry Results for Flesh and Bone of Arctic Grayling Captured in Judge Sissons Lake in the Kiggavik Project Area, Fall 2009

Parameter	Unit[a]	Flesh							Bone						
		n	Mean	Median	SD	SE	Min	Max	n	Mean	Median	SD	SE	Min	Max
Radionuclides															
Lead-210	Bq/g	5	-	-	-	-	<0.001	0.002	5	0.02	0.009	0.02	0.009	0.003	0.051
Polonium-210	Bq/g	5	0.0005	0.0004	0.0004	0.0002	<0.0002	0.0010	5	0.0005	0.0006	0.0003	0.0001	<0.0005	0.0008
Radium-226[b]	Bq/g	5	-	-	-	-	<0.00005	<0.001	5	0.003	0.004	0.002	0.0007	<0.002	0.004
Thorium-228	Bq/g	5	-	-	-	-	<0.00007	<0.002	5	-	-	-	-	<0.004	<0.004
Thorium-230	Bq/g	5	-	-	-	-	<0.00007	<0.002	5	-	-	-	-	<0.004	<0.004
Thorium-232	Bq/g	5	-	-	-	-	<0.00007	<0.002	5	-	-	-	-	<0.004	<0.004

Notes: When results were less than detection limit summary statistics were calculated using half the detection limit. If detection frequency was ≥50%, then non-detect values were replaced with one half the detection limit to calculate summary statistics. If detection frequency was <50%, then only minimum and maximum values are presented.

(a) All results were in wet weight.

(b) Highest detected value in flesh was 0.00005 Bq/g.

Moisture = moisture content by percent weight; ash = ash content by percent weight; µg/g = microgram per gram; Bq/g = Becquerels per gram; % = percent; n = number of samples; SD = standard deviation; SE = standard error; Min = minimum; Max = maximum; - = not applicable; < = less than.

Table 11.2-24 Summary of Chemistry Results for Flesh and Bone of Cisco Captured in Pointer Lake in the Kiggavik Project Area, Fall 2009

Parameter	Unit[a]	Flesh							Bone						
		n	Mean	Median	SD	SE	Min	Max	n	Mean	Median	SD	SE	Min	Max
Physical Properties															
Ash	%	5	1.42	1.37	0.291	0.130	1.08	1.75	5	12.1	14.3	4.99	2.23	6.69	16.54
Moisture	%	5	73.16	74.02	2.368	1.059	70.27	75.67	5	62.40	59.31	5.674	2.537	57.13	69.11
Metals															
Aluminum	µg/g	5	-	-	-	-	<0.01	0.05	5	0.58	0.58	0.22	0.10	0.34	0.94
Antimony	µg/g	5	-	-	-	-	<0.02	<0.02	5	-	-	-	-	<0.05	<0.05
Arsenic	µg/g	5	0.03	0.03	0.015	0.007	0.02	0.05	5	-	-	-	-	<0.02	0.15
Barium	µg/g	5	0.58	0.28	0.63	0.28	0.060	1.6	5	61	53	24	11	40	92
Beryllium	µg/g	5	-	-	-	-	<0.002	<0.002	5	-	-	-	-	<0.01	<0.01
Boron	µg/g	5	-	-	-	-	<0.2	<0.2	5	-	-	-	-	<0.5	<0.5
Cadmium	µg/g	5	-	-	-	-	<0.002	<0.002	5	-	-	-	-	<0.01	<0.01
Chromium	µg/g	5	-	-	-	-	<0.1	<0.1	5	-	-	-	-	<0.2	<0.2
Cobalt	µg/g	5	0.006	0.003	0.006	0.003	0.002	0.02	5	0.03	0.03	0.02	0.01	0.01	0.06
Copper	µg/g	5	0.36	0.36	0.092	0.041	0.22	0.47	5	0.37	0.44	0.13	0.060	0.16	0.48
Iron	µg/g	5	3.1	2.9	0.57	0.26	2.4	3.8	5	5.6	5.5	0.44	0.20	5.3	6.4
Lead	µg/g	5	-	-	-	-	<0.002	0.003	5	0.02	0.02	0.004	0.002	0.02	0.03
Manganese	µg/g	5	0.15	0.13	0.077	0.034	0.080	0.28	5	12	10	7.4	3.3	4.5	22
Mercury	µg/g	0	-	-	-	-	-	-	0	-	-	-	-	-	-
Molybdenum	µg/g	5	-	-	-	-	<0.02	<0.02	5	-	-	-	-	<0.05	<0.05
Nickel	µg/g	5	-	-	-	-	<0.01	0.03	5	0.09	0.09	0.03	0.01	0.05	0.12
Selenium	µg/g	5	0.19	0.19	0.029	0.013	0.15	0.23	5	0.21	0.22	0.037	0.017	0.15	0.25
Silver	µg/g	5	-	-	-	-	<0.002	<0.002	5	-	-	-	-	<0.01	<0.01
Strontium	µg/g	5	1.5	0.95	1.48	0.66	0.18	3.9	5	108	89	35	16	75	150
Thallium	µg/g	5	-	-	-	-	<0.01	<0.01	5	-	-	-	-	<0.02	<0.02
Tin	µg/g	5	-	-	-	-	<0.01	<0.01	5	-	-	-	-	<0.02	<0.02
Titanium	µg/g	5	0.08	0.08	0.008	0.004	0.07	0.09	5	0.26	0.29	0.06	0.03	0.17	0.32
Uranium	µg/g	5	-	-	-	-	<0.001	<0.001	5	-	-	-	-	<0.01	<0.01
Vanadium	µg/g	5	-	-	-	-	<0.02	<0.02	5	-	-	-	-	<0.05	<0.05
Zinc	µg/g	5	12	10	3.2	1.4	9.4	16	5	45	44	17	8	26	72

Table 11.2-24 Summary of Chemistry Results for Flesh and Bone of Cisco Captured in Pointer Lake in the Kiggavik Project Area, Fall 2009

Parameter	Unit[(a)]	Flesh							Bone						
		n	Mean	Median	SD	SE	Min	Max	n	Mean	Median	SD	SE	Min	Max
Radionuclides															
Lead-210	Bq/g	5	0.02	0.02	0.02	0.009	<0.001	0.045	5	0.078	0.090	0.041	0.018	0.012	0.12
Polonium-210	Bq/g	5	0.0006	0.0005	0.0002	0.0001	0.0005	0.001	5	0.002	0.002	0.002	0.0008	<0.0005	0.005
Radium-226	Bq/g	5	-	-	-	-	<0.00005	0.0012	5	-	-	-	-	<0.002	0.003
Thorium-228	Bq/g	5	-	-	-	-	<0.0001	<0.002	5	-	-	-	-	<0.004	<0.005
Thorium-230	Bq/g	5	-	-	-	-	<0.0001	<0.002	5	-	-	-	-	<0.004	<0.005
Thorium-232	Bq/g	5	-	-	-	-	<0.0001	<0.002	5	-	-	-	-	<0.004	<0.005

Notes: When results were less than detection limit summary statistics were calculated using half the detection limit.
If detection frequency was ≥50%, then non-detect values were replaced with one half the detection limit to calculate summary statistics.
If detection frequency was <50%, then only minimum and maximum values are presented.
(a) All results were in wet weight.
Moisture = moisture content by percent weight; ash = ash content by percent weight; µg/g = microgram per gram; Bq/g = Becquerels per gram; % = percent; n = number of samples; SD = standard deviation; SE = standard error; Min = minimum; Max = maximum; - = not applicable; < = less than.

Table 11.2-25 Summary of Chemistry Results for Flesh and Bone of Lake Trout Captured in Judge Sissons Lake in the Kiggavik Project Area, Fall 2009

Parameter	Unit[a]	Flesh							Bone						
		n	Mean	Median	SD	SE	Min	Max	n[b]	Mean	Median	SD	SE	Min	Max
Physical Properties															
Ash	%	5	1.3	1.2	0.21	0.095	0.95	1.52	5	20.01	21.22	3.178	1.421	15.81	23.54
Moisture	%	5	76.24	77.24	2.704	1.209	72.04	79.13	5	54.37	54.14	1.204	0.5382	53.10	55.77
Metals															
Aluminum	µg/g	5	-	-	-	-	<0.01	0.05	4	0.29	0.21	0.21	0.10	0.13	0.59
Antimony	µg/g	5	-	-	-	-	<0.02	<0.02	4	-	-	-	-	<0.05	<0.05
Arsenic	µg/g	5	0.03	0.03	0.01	0.002	0.03	0.04	4	0.08	0.075	0.017	0.009	0.06	0.10
Barium	µg/g	5	0.02	0.01	0.01	0.004	<0.01	0.03	4	9.2	8.9	1.3	0.63	8.1	11
Beryllium	µg/g	5	-	-	-	-	<0.002	<0.002	4	-	-	-	-	<0.01	<0.01
Boron	µg/g	5	-	-	-	-	<0.2	<0.2	4	-	-	-	-	<0.5	<0.5
Cadmium	µg/g	5	-	-	-	-	<0.002	<0.002	4	-	-	-	-	<0.01	0.01
Chromium	µg/g	5	-	-	-	-	<0.1	<0.1	4	-	-	-	-	<0.2	<0.2
Cobalt	µg/g	5	0.005	0.004	0.002	0.001	0.003	0.007	4	0.02	0.03	0.01	0.005	0.01	0.03
Copper	µg/g	5	0.25	0.19	0.16	0.071	0.12	0.52	4	0.12	0.12	0.032	0.016	0.09	0.16
Iron	µg/g	5	3.5	3.9	0.69	0.31	2.5	4.1	4	6.8	5.8	2.9	1.5	4.4	11
Lead	µg/g	5	-	-	-	-	<0.002	<0.002	4	0.01	0.01	0.009	0.004	<0.01	0.02
Manganese	µg/g	5	0.1	0.1	0.01	0.003	0.06	0.08	4	6.7	7.3	2.1	1.1	3.8	8.3
Mercury	µg/g	5	0.69	0.57	0.24	0.107	0.45	0.95	5	0.38	0.42	0.13	0.056	0.17	0.48
Molybdenum	µg/g	5	-	-	-	-	<0.02	<0.02	4	-	-	-	-	<0.05	<0.05
Nickel	µg/g	5	-	-	-	-	<0.01	0.01	4	0.06	0.06	0.01	0.006	0.05	0.08
Selenium	µg/g	5	0.26	0.26	0.036	0.016	0.21	0.30	4	0.20	0.18	0.056	0.028	0.16	0.28
Silver	µg/g	5	-	-	-	-	<0.002	<0.002	4	-	-	-	-	<0.01	<0.01
Strontium	µg/g	5	0.1	0.1	0.03	0.01	0.05	0.12	4	69	69	4.7	2.3	63	74
Thallium	µg/g	5	-	-	-	-	<0.01	<0.01	4	-	-	-	-	<0.02	<0.02
Tin	µg/g	5	-	-	-	-	<0.01	<0.01	4	-	-	-	-	<0.02	<0.02
Titanium	µg/g	5	0.1	0.1	0.01	0.002	0.06	0.07	4	0.24	0.24	0.033	0.017	0.20	0.28
Uranium	µg/g	5	-	-	-	-	<0.001	<0.001	4	-	-	-	-	<0.01	<0.01
Vanadium	µg/g	5	-	-	-	-	<0.02	<0.02	4	-	-	-	-	<0.05	<0.05
Zinc	µg/g	5	4.7	4.1	1.4	0.65	3.5	6.9	4	28	28	0.50	0.25	28	29

Table 11.2-25 Summary of Chemistry Results for Flesh and Bone of Lake Trout Captured in Judge Sissons Lake in the Kiggavik Project Area, Fall 2009

Parameter	Unit[(a)]	Flesh							Bone						
		n	Mean	Median	SD	SE	Min	Max	n[(b)]	Mean	Median	SD	SE	Min	Max
Radionuclides															
Lead-210	Bq/g	5	-	-	-	-	<0.001	0.001	5	-	-	-	-	<0.002	0.004
Polonium-210	Bq/g	5	-	-	-	-	<0.0002	0.0005	5	0.0017	0.0020	0.0009	0.0004	0.0006	0.003
Radium-226	Bq/g	5	0.0001	0.0001	0.00009	0.00004	<0.00006	0.0002	5	0.0014	0.0010	0.0006	0.0003	0.0009	0.002
Thorium-228	Bq/g	5	-	-	-	-	<0.0001	<0.001	5	-	-	-	-	<0.002	<0.002
Thorium-230[(c)]	Bq/g	5	-	-	-	-	<0.0001	<0.001	5	-	-	-	-	<0.002	0.002
Thorium-232	Bq/g	5	-	-	-	-	<0.0001	<0.001	5	-	-	-	-	<0.002	<0.002

Notes: When results were less than detection limit summary statistics were calculated using half the detection limit.
If detection frequency was ≥50%, then non-detect values were replaced with one half the detection limit to calculate summary statistics.
If detection frequency was <50%, then only minimum and maximum values are presented.
(a) All results were in wet weight.
(b) A lake trout had not enough bone sample left to re-run the ICP metal scan.
(c) Highest detected value in flesh was 0.0001 Bq/g.

Moisture = moisture content by percent weight; ash = ash content by percent weight; µg/g = microgram per gram; Bq/g = Becquerels per gram; % = percent; n = number of samples; SD = standard deviation; SE = standard error; Min = minimum; Max = maximum; - = not applicable; < = less than

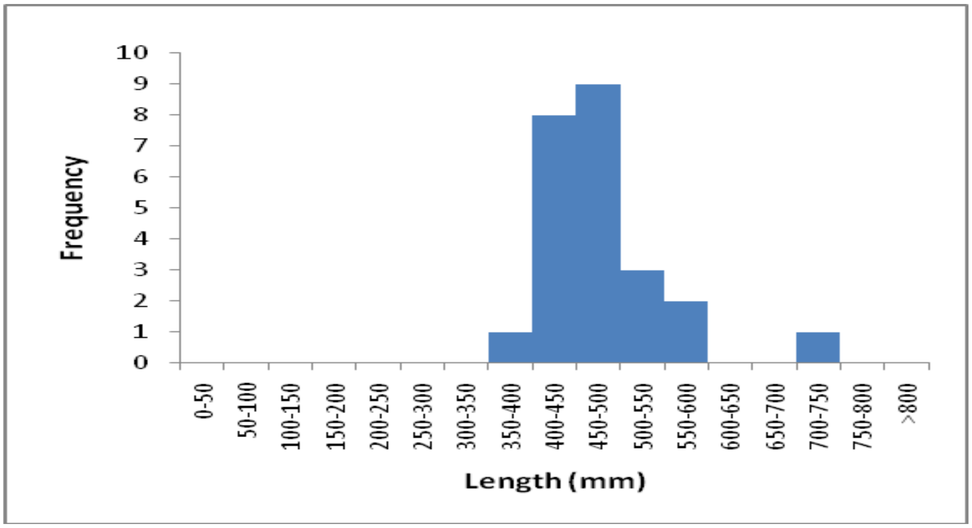

Figure 11.2-1 Length-Frequency Distribution of Captured Lake Trout, Baker Lake, August 2009

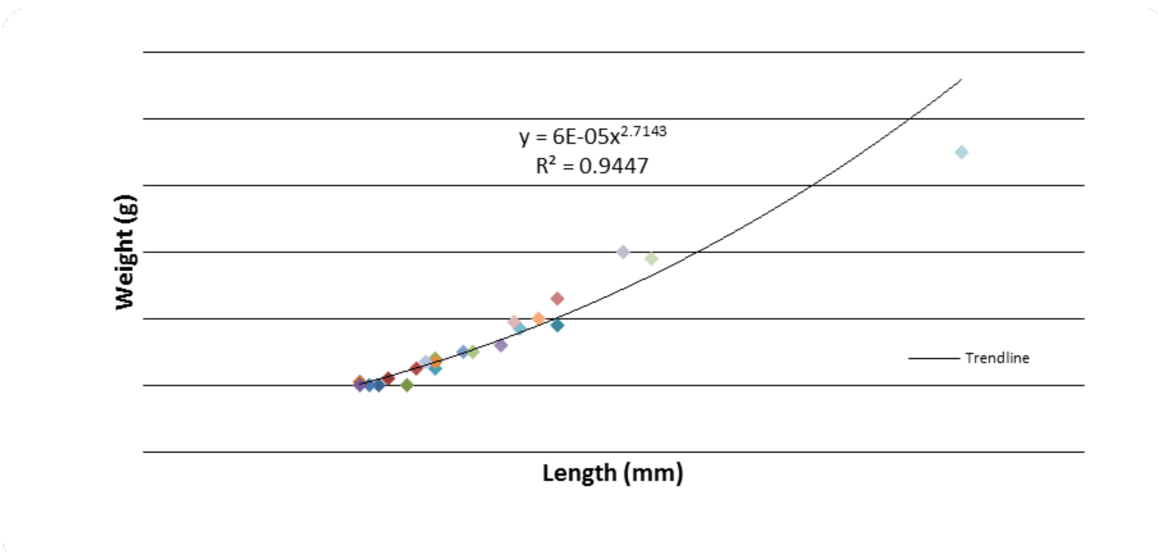

Figure 11.2-2 Length-Weight Relationship of Captured Lake Trout, Baker Lake, August 2009

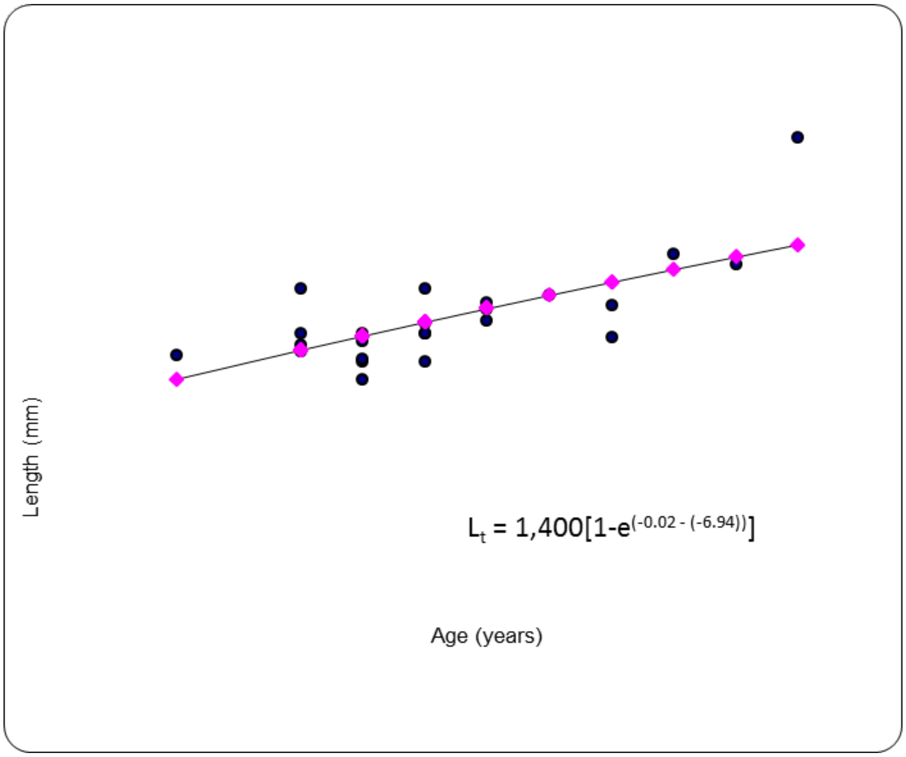

Figure 11.2-3 Growth Pattern of Captured Lake Trout, Baker Lake, August 2009

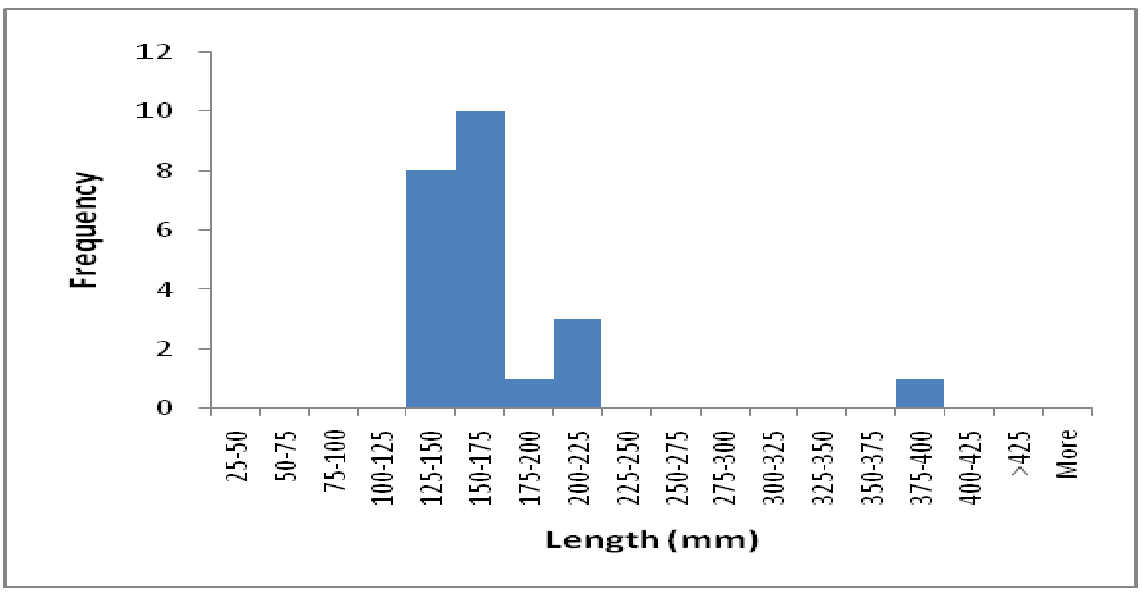

Figure 11.2-4 Length-Frequency Distribution of Captured Lake Whitefish, Baker Lake, August 2009

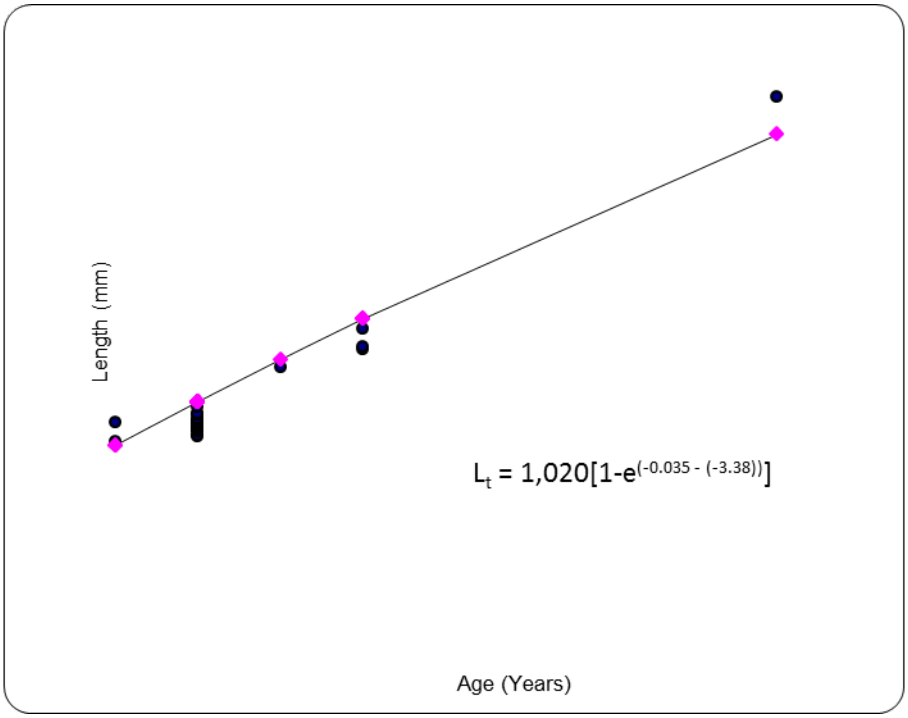

Figure 11.2-5 Growth Pattern of Captured Lake Whitefish, Baker Lake, August 2009

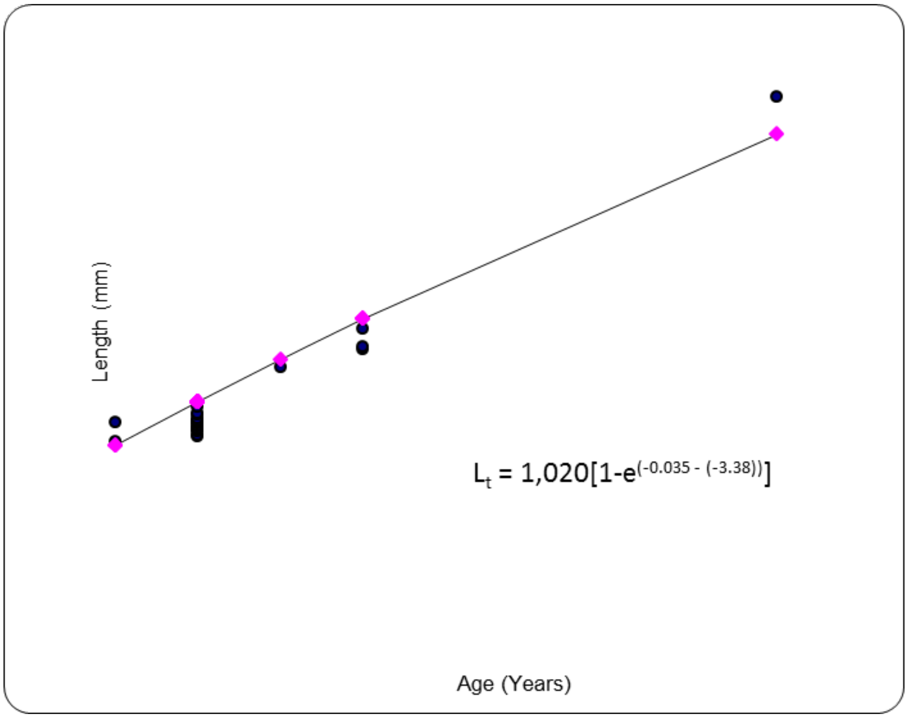

Figure 11.2-5 Growth Pattern of Captured Lake Whitefish, Baker Lake, August 2009

12 Summary

Assessments of all major aspects of the aquatic environment were undertaken in support of the development of the proposed Kiggavik Project (the Project). Field investigations were undertaken during the period between 2007 and 2010 to augment data from past studies in the mine site LSA. The recent studies included assessments of water, sediment, aquatic plant and fish tissue chemistry, and characterization of plankton, benthic invertebrate, and fish communities in lakes and streams in the mine site and site access LSAs. Fish habitat and fish spawning migrations and habitat were also documented. The majority of the Project footprint is to be located in the Judge Sissons Lake watershed and the proposed access road crosses a number of watersheds between Baker Lake and Judge Sissons Lake.

Peak stream flows in this region are a result of spring melt, which can account for the majority of the volume of total annual runoff. In winter, streams freeze completely to channel bottoms, and begin to flow again during spring runoff overtop the anchor ice. Lake ice reaches a depth of approximately two metres. As a result, many shallow lakes freeze completely, and a portion of the volume of larger lakes is frozen by late winter. The majority of the lakes in the LSA are less than 3 m in depth, although several of the larger lakes are between 10 and 20 m deep.

Lakes and streams in the LSA are characterized by low ionic strength and neutral to alkaline pH. Total hardness concentrations indicate that the waters are very soft to soft in hardness. Measured nutrient concentrations are typical of oligotrophic waterbodies in subarctic regions. Baseline water quality parameters were generally less than the SSWQO and CWQG; however, some parameters (e.g., aluminum, ammonia, cadmium, chromium, copper, iron, and lead) were found at higher levels in several lakes and streams during some sampling periods. Radionuclides were generally not detected or were detected near the analytical detection limits.

Total metal concentrations in sediments were similar among studied lakes. The concentrations of most metals in lake sediments were mostly below the ISQG, with the exception of arsenic, and chromium. Copper and zinc concentrations occasionally exceeded the ISQG as well. Radionuclides were detected in almost all sediment samples, except those from Baker Lake, and were generally reported at concentrations below 0.3 Bq/g dw.

Phytoplankton, zooplankton and benthic invertebrate communities in lakes, and periphyton and benthic invertebrate communities in streams within the Project area were generally characterized by low to moderate density and diversity typical of unproductive Canadian Shield waters. Several unique taxa were identified within various waterbodies; however, none of these are federally or territorially listed species at risk.

The fish sampling program documented fish communities in the LSA typical of those found within this general region of the Arctic. Seven species of fish were captured including Arctic grayling, burbot, cisco, lake trout, ninespine stickleback, round whitefish, and slimy sculpin. Four additional species have been captured in Baker Lake, including Arctic char, fourhorn sculpin, lake whitefish, and longnose sucker. Artic char do not occur in the Judge Sissons Lake watershed and also appear to be absent from the Aniguq River.

Fish are widely distributed in the lakes and streams of the mine site LSA. Arctic grayling and lake trout are the most widely dispersed species, and the species found in the highest abundance. Other species occur in lesser numbers and their distribution is much more restricted. Fish distribution appears to vary seasonally and is influenced by overwintering conditions. The majority of the lakes in the LSA are shallow and freeze to the bottom in the winter. Fish appear to be moving into the deeper lakes for overwintering, particularly Judge Sissons Lake. Fish move out of the deeper lakes into the streams in the early spring for spawning and feeding purposes. Fish tissue chemistry results indicate that most metals and radionuclides were at or below detection limits, with only a few individual exceedances of consumption guidelines for arsenic, cadmium, mercury and lead.

Fish habitat mapping was completed for 29 waterbodies (20 lakes and nine ponds) within the mine site LSA. In addition, fish habitat assessments were completed at five sites within Baker Lake. Fish habitat assessments were also completed on the entire length of 19 stream reaches in the mine site LSA. Run and riffle habitat were the dominant habitat types in most streams, with flats also being common. Cobble was observed as the dominant substrate in 11 streams, with boulders and organic matter being dominant in several others.

Fish habitat assessments were also conducted for streams crossed by the proposed road access, including 37 stream crossings along the proposed North All-Weather Access Road (west of the Thelon River), 16 stream crossings along the North All-Weather Access Road (east of the Thelon River), six stream crossings along the proposed Winter Access Road corridor, and 18 stream crossings along the proposed South All-Weather Access Road. Many of the assessed watercourses were undefined, seasonal in nature, or had dry channels. Small streams were generally characterized by organic substrate and low habitat diversity. Large streams or rivers contained more instream and overhead cover and had a greater diversity of substrates and habitat types present. Fish were present in streams with a bankful width of 2 m or more.

13 References

13.1 Literature Cited

Alfonso, N.R. 2004. Evidence of Two Morphotypes of Lake Trout, Salvelinus Namaycush, from Great Bear Lake, Northwest Territories, Canada. Environmental Biology of Fishes. 71: 21-32.

Anderson, R.O. and R.M. Neumann. 1996. Length, Weight, and Associated Structural Indices. In B.R. Murphy and D.W. Willis (ed.). Fisheries Techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Anton, A. and H. C. Duthie. 1981. Use of Cluster Analysis in the Systematics of the Algal Genus Cryptomonas. Canadian Journal of Botany. 59: 992-1002.

AREVA (AREVA Resources Canada Inc.). 2008. The Kiggavik Project: Project Proposal. AREVA Resources Canada Inc. Saskatoon, SK. 297 pp.

Babaluk, J.A., S.J. Sandstrom, J.D. Reist, and J.D. Johnson. 1997. A Preliminary Assessment of the Fish Populations in Five Lakes on Banks Island, Northwest Territories, 1993 - 1994. Fisheries Joint Management Committee. Fisheries and Oceans Canada, Winnipeg, MB.

Barnham, C. and A. Baxter. 1998. Condition Factor, K, for Salmonid Fish. Australian Department of Natural Resources and Environment. Fisheries Notes Series No. FN0005. 3 pp.

BEAK (BEAK Consultants Limited). 1987. Kiggavik Preliminary Environmental Study Report 1986 – 1987. BEAK Consultants Limited, Toronto, ON.

BEAK. 1990. Kiggavik Uranium Project, Environmental Assessment, Supporting Document No. 4: The Aquatic Environment. BEAK Consultants Limited, Toronto, ON.

BEAK. 1992a. Aquatic Baseline Survey: Andrew Lake and Kiggavik Study Areas, 1990/1991. BEAK Consultants Limited, Toronto, ON.

BEAK. 1992b. Aquatic Wildlife Impacts Responses to FEARO Questions. Submitted December 1992.

Bengtsson, Å. and B.-E. Bengtsson. 1983. A Method to Registrate Spinal and Vertebral Anomalies in Fourhorn Sculpin, Myoxocephalus quadricornis L. (Pisces). Aquilo Serie Zoologica. 22: 61-64.

Bishop, F.G. 1971. Observations on the Spawning Habits and Fecundity of the Arctic Grayling. The Progressive Fish-Culturist. 33: 12-19.

Bjoru, B. and O.T. Sandlund. 1995. Differences in Morphology and Ecology within a Stunted Arctic Char Population. Nordic Journal Freshwater Research. 71: 163-172.

Bond, W.A. and R.N. Erickson. 1989. Summer Studies of the Nearshore Fish Community at Phillips Bay, Beaufort coast, Yukon. Canadian Technical Report for Fisheries and Aquatic Sciences No. 1676. 102 pp.

Botterell, H.H., A. Duncan, Z.M. Gliwicz, E. Grygierczyk, A. Herzig, A. Hillbricht-Illakowska, H. Kurasawa, P. Larsson, and T. Weglenska. 1976. A Review of some Problems in Zooplankton Production Studies. Norwegian Journal of Zoology. 24: 319-456.

Breeser, S.W., F.D. Stearns, M.W. Smith, R.L. West, and J.B. Reynolds. 1988. Observations of Movements and Habitat Preferences of Burbot in an Alaskan Glacial River System. Transactions of the American Fisheries Society. 117: 506-509.

Brönmark, C. and L.-A. Hansson. 1998. The Biology of Lakes and Ponds. Oxford University Press. New York, New York. 216 pp.

Brooks, J.L. 1957. The Systematics of North American Daphnia. Vol. XIII. Connecticut Academy of Arts and Sciences, New Haven, Connecticut. 180 pp.

Camburn, K.E, and D.F. Charles. 2000. Diatoms of Low-Alkalinity Lakes in the Northeastern United States. Academy of Natural Sciences of Philadelphia, Philadelphia, PA. 152 pp.

Canter-Lund, H, and J.W.G. Lund. 1995. Freshwater Algae – their Microscopic World Explored. BioPress Ltd., Bristol, UK, 360 pp.

Clifford, H. 1991. Aquatic Invertebrates of Alberta. University of Alberta Press. 538 pp.

CCAC (Canadian Council on Animal Care). 2005. Guidelines on: the Care and Use of Fish in Research, Teaching and Testing. Canadian Council on Animal Care, Ottawa, ON.

CCME (Canadian Council of Ministers of the Environment). 2001. Canadian Sediment Quality Guidelines for the Protection of Aquatic Life: Introduction. Canadian Environmental Quality Guidelines, 2007. Canadian Council of Ministers of the Environment, Winnipeg, MB.

CCME. 2002. Canadian Sediment Quality Guidelines for the Protection of Aquatic Life. Canadian Environmental Quality Guidelines, 2002. Canadian Council of Ministers of the Environment, Winnipeg, MB.

CCME. 2007. Canadian Water Quality Guidelines for the Protection of Aquatic Life. Canadian Environmental Quality Guidelines, 2007. Canadian Council of Ministers of the Environment, Winnipeg, MB.

Chapman P.M., W.J. Adams, M.L. Brooks, C.G. Delos, S.N. Luoma, W.A. Maher, H.M. Ohlendorft, T.S. Presser, D.P. Shaw. 2009. Ecological Assessment of Selenium in the Aquatic Environment: Summary of a SETAC Pellston Workshop. Society of Environmental Toxicology and Chemistry (SETAC), Pensacola, FL.

Chengalath, R.C., C.H. Fernando and M.G. George. 1971. The Planktonic Rotifera of Ontario with Keys to Genera and Species. University of Waterloo Biology Series, Waterloo, ON. 40 pp.

Clark, M.J.R. (editor). 2003. British Columbia Field Sampling Manual. Water, Air and Climate Change Branch, Ministry of Water, Land and Air Protection, Victoria, BC, Canada. 312 pp.

Communications Directorate. 1991. Lake Trout. Underwater World Factsheet. DFO, Ottawa, Ontario. Cat. No. FS 41-33/50-1990E. 6 pp.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2003. COSEWIC Assessment and Update Status Report on the Fourhorn Sculpin Myoxocephalus Quadricornis (Freshwater Form) in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 24 pp.

Craig, P.C. and J. Wells. 1976. Life History Notes for a Population of Slimy Sculpin (Cottus cognatus) in an Alaskan Arctic Stream. Journal of the Fisheries Research Board of Canada. 33: 1639-1642.

Cumberland Resources Ltd. 2004. Meadowbank Gold Project. Draft Environmental Impact Statement. Part 1: Report. 216 pp.

Davis, C.L., L.M. Carl and D.O. Evans. 1997. Use of a Remotely Operated Vehicle to Study Habitat and Population Density of Juvenile Lake Trout. Transactions of the American Fisheries Society. 126: 871-875.

Dickman, M. 1991. Failure of an Environmental Impact Assessment to Predict the Impact of Mine Tailings on Canada's Most Northerly Hypersaline Lake. Environmental Impact Assessment Review. 11: 171-180.

Dickman, M. 1995. An Isolated Population of Fourhorn Sculpins (Myoxocephalus Quadricornis, Family Cottidae) in a Hypersaline High Arctic Canadian Lake. Hydrobiologia. 312(1): 27-35.

Downing, J.A. and F.H. Rigler. 1984. A Manual on Methods for the Assessment of Secondary Productivity in Fresh Waters. Blackwell Scientific Publications. 501 pp.

EBA (EBA Engineering Consultants Ltd.). 2010. Kiggavik Project Haul Road Report. Prepared for AREVA Resources Canada Inc. by EBA Engineering Consultants Ltd., Vancouver, BC.

Ecometrix Incorporated. 2006. Kiggavik Environmental Baseline Data Summary and Potential Data Gaps. November 2006. Prepared for AREVA Resources Canada Inc. Saskatoon, SK.

Edmondson, W.T. 1966. Freshwater Biology. 2nd Edition. John Wiley and Sons, New York, N.Y. 1248 pp.

Environment Canada. 2002. Metal Mining Guidance Document for Aquatic Environmental Effects Monitoring. Environment Canada, Ottawa, ON.

Evans, C.E., J.D. Reist and C.K. Minns. 2002. Life History Characteristics of Freshwater Fishes Occurring in the Northwest Territories and Nunavut, with Major Emphasis on Riverine Habitat Requirements. Canadian Manuscript Report of Fisheries and Aquatic Sciences No 2614. 169 p.

Fallis, B.W., S.M. Harbicht, and B.J. MacKenzie. 1987. A Preliminary Study of the Limnology and Biology of Garrow Lake, Northwest Territories, an Arctic Meromictic Lake. Department of Fisheries and Oceans, Winnipeg, MB. Unpublished Data. 55 pp.

Findlay, D.L. and H.J. Kling. 1976. A Species List and Pictorial Reference to the Phytoplankton of Central and Northern Canada. Fisheries and Environment Canada, Fisheries and Marine Service, Manuscript Report No. 1503. 619 pp.

Ford, B.S., P.S. Higgins, A.F.Lewis, K.L. Cooper, C.M. Watson, G.L. Ennis, and R.L. Sweeting, 1995. Literature Reviews of the Life History, Habitat Requirements and Mitigation/Compensation Strategies for Thirteen Sport Fish Species in the Peace, Liard and Columbia River Drainages of British Columbia. Canadian Manuscript Report of Fisheries and Aquatic Sciences No 2321. 342 p.

Gibbons, W.N., M.D. Munn and M.D. Paine. 1993. Guidelines for Monitoring Benthos in Freshwater Environments. Report prepared for Environment Canada, North Vancouver, B.C. by EVS Consultants, North Vancouver, BC. 81 pp.

Goodyear, C.S., T.A. Edsall, D.M. Ormsby, G.D. Moss and P.E. Polanski. 1982. Atlas of the Spawning and Nursery Areas of Great Lakes Fishes. Volume 13: Reproductive Characteristics of Great Lakes Fishes. U.S. Fish and Wildlife Service, Washington DC FWS/OBS-82/52. 124 pp.

Gray, M.A., R.A. Cunjak, and K.R. Munkittrick. 2004. Site Fidelity of Slimy Sculpin (Cottus Cognatus): Insights from Stable Carbon and Nitrogen Analysis. Canadian Journal of Fisheries and Aquatic Sciences. 61: 1717-1722.

Geitler L. 1932. Cyanophyceae. Edited by Rabenhorst. Kryptogamenflora von Deutschland. Österreich und der Schweiz, Vol. 14. Akademische Verlagsgesellschaft, Leipzgi. 1196 pp.

Grothe, D.W. and D.R. Grothe. 1977. An Illustrated Key to the Planktonic Rotifers of the Laurentian Great Lakes. U.S. Environmental Protection Agency, Chicago, IL. 53 pp.

Gyselman, E.C. 1994. Fidelity of Anadromous Arctic Char (Salvelinus Alpinus) to Nauyuk Lake, N.W.T., Canada. Canadian Journal of Fisheries and Aquatic Sciences. 51: 1927-1934.

Hamilton, P. 1990. The Revised Edition of a Computerized Counter for Plankton, Periphyton and Sediment Diatom Analysis. Hydrobiologia. 194: 23-30.

Hammar, J., E. Bergstrand and O. Enderlein. 1996. Why Do Juvenile Fourhorn Sculpin, Triglopsis Quadricornis, Appear in the Pelagic Habitat at Night? Environmental Biology of Fishes. 46: 185-195.

Huber-Pestalozzi, G. 1983. Das Phytoplankton des Süβwassers. Systematik und Biologie. 7 Teil, 1 Halfte. Chlorophyceae (Grünalgen), Ordnung: Chlorococcales von J. Komárek und B. Fott. Die Binnengewäser (Band XVI). E. Schweizerbart’sche Verlagsbuchhandlung (Nägele u Obermiller), Stuttgart. 1044 pp.

Huber-Pestalozzi, G. 1982. Das Phytoplankton des Süβwassers. Systematik und Biologie. 8 Teil, 1 Halfte. Conjugatophyceae Zygnematales und Desmidiales von Kurt Förster, Pfronten/Allgäu Die Binnengewäser (Band XVI). E. Schweizerbart’sche Verlagsbuchhandlung (Nägele u Obermiller), Stuttgart. 543 pp.

Huber-Pestalozzi, G. 1972. Das Phytoplankton des Süβwassers. Systematik und Biologie. 6 Teil, Chlorophyceae (Grünalgen), Ordnung: Tetrasporales von B. Fott. Die Binnengewäser (Band XVI). E. Schweizerbart’sche Verlagsbuchhandlung (Nägele u Obermiller), Stuttgart. 47 pp.

Huber-Pestalozzi, G. 1961. Das Phytoplankton des Süβwassers. Systematik und Biologie. 5 Teil, Chlorophyceae (Grünalgen), Ordnung: Volvocales Die Binnengewäser (Band XVI). E. Schweizerbart'sche Verlagsbuchhandlung (Nägele u Obermiller). Stuttgart. 728 pp.

Hunter, J.G. 1970. Production of Arctic Char (Salvelinus Alpinus Linnaeus) in a Small Arctic Lake. Fisheries Research Board of Canada Technical Report No. 231. 190 pp.

Hunter, J.G. 1976. Arctic Char and Hydroelectric Power in the Sylvia Grinnell River. Fisheries Research Board of Canada Manuscript Report No. 1376. 21 pp.

Jamet, J.-L. 1995. Reproduction, Condition and Food of Adult Arctic Char (Salvelinus Alpinus, L.) in Lake Pavin (Massif Central, France). Hydrobiologia 300/301: 279-288.

Johnson, L. 1980. The Arctic Charr Salvelinus Alpinus. Edited by E.K. Balon. Charrs, salmonid fishes of the genus Salvelinus. Dr. W. Junk bv Publishers. The Hague, Netherlands. p. 15-98.

Johnson, L. 1989. The Anadromous Arctic Charr, Salvelinus Alpinus, of Nauyuk Lake, N.W.T., Canada. Edited by H. Kawanabe, Fumio Yamazaki, and David L. G. Noakes. Proceedings of the International Symposium on Charrs and Masu Salmon. Physiological Ecology of Japan Spec. Vol. 1. Editorial Office, Kyoto, Japan. pp. 201-227.

Komárek, J. and K. Anagnostidis. 2005. Cyanoprokaryota 2. Teil: Oscillatoriales. In B. Bridel; G.L. Gastner and M.S. Krienitz (ed.). Süßwasserflora von Mitteleuropa 19/2. London, Elsevier. pp. 1-759.

Komárek J. and K. Anagnostidis. 1998a. Cyanoprokaryota. Part 1: Chroococcales. In H. Ettl et al. (ed.). Süswasserflora von Mitteleuropa. B Spektrum Akademischer Verlag. Volume 19/1. Gustav Fischer. 584 pp.

Komárek J. and K. Anagnostidis. 1998b. Cyanoprokaryota. Part 2: Oscillatoriales. In B. Büdel et al. (ed.) Süswasserflora von Mitteleuropa. Elsevier Spektrum Akademischer Verlag. Volume Band 19/2. 757 pp.

Krammer, K. and H. Lange-Bertalot. 1986. Bacillariophyceae. 1. Teil: Naviculaceae. In H. Ettl et al (ed.). Süswasserflora von Mitteleuropa. Begründet von A. Pascher. Band 2/1. Stuttgart-Jena. 876 pp.

Krammer, K. and H. Lange-Bertalot. 1991a. Bacillariophyceae. 3 Teil: Centrales, Fragilariaceae, Eunotiaceae .In H. Ettl et al.(ed.). Süswasserflora von Mitteleuropa. Begründet von A. Pascher Band 2/3. Stuttgart-Jena. 576 pp.

Krammer, K. and H. Lange-Bertalot. 1991b. Bacillariophyceae. 4 Teil: Achnanthaceae Kritische Ergänzungen zu Navicula (Lineolatae) und Gomphonema. In H. Ettl et al: (ed.). Süswasserflora von Mitteleuropa. Band 2/4. Stuttgart-Jena. 437 pp.

Krammer, K. and H. Lange-Bertalot. 1988. Bacillariophyceae. 2 Teil: Bacillariaceae, Epithemiaceae, Surirellaceae. In H. Ettl et al: (ed.). Süswasserflora von Mitteleuropa. Begründet von A. Pascher Band 2/2. Stuttgart-Jena. 596 pp.

Krammer, K. and H. Lange-Bertalot. 1986. Bacillariophyceae. 1. Teil: Naviculaceae. In H. Ettl et al. (ed.): Süswasserflora von Mitteleuropa. Begründet von A. Pascher. Band 2/1. Stuttgart-Jena. 876 pp.

Kristofferson, A.H. 1988. Stock Status of Arctic Char in the Hornaday River, Northwest Territories. AFSAC Background Document. 15 pp.

Lawrence, M. and Davies, S. 1978. Aquatic Resources Survey – Keewatin and Franklin Districts. AIPP Report 1978. Fisheries and Marine Service. 108 pp.

Lee, S.D., C.R. Gilbert, C.H. Hocutt, R.E. Jenkins, D.E. McAllister and J.R. Stauffer Jr. 1980. Atlas of North American Freshwater Fishes. North Carolina State Museum of Natural History, Biological Survey Publication 1980-12. 854 p.

Lock, M.A., R.R. Wallace, J.W. Costerton, R.M. Ventullo, and S.E. Charlton. 1984. River Epilithon: Towards a Structural-Functional Model. Oikos. 42: 10-22.

Lockhart, W.L., G.A. Stern, G. Low, M. Hendzel, G. Boila, P. Roach, M.S. Evans, B.N. Billeck, J. DeLaronde, S. Friesen, K. Kidd, S. Atkins, D.C.G. Muir, M. Stoddart, G. Stephens, S. Stephenson, S. Harbicht, N. Snowshoe, B. Grey, S. Thompson, N. DeGraff. 2005. A History of Total Mercury in Edible Muscle of Fish from Lakes in Northern Canada. Science of the Total Environment. 351-352: 427-463.

Luecke, C. and P. MacKinnon. 2008. Landscape Effects on Growth of Age-0 Arctic Grayling in Tundra Streams. Transaction of the American Fisheries Society. 137: 236-243.

MacDonald, G. and Stewart, D.B. 1980. Arctic Land Use Research Program 1979: a Survey of the Aquatic Resources of the Central Keewatin Region of the Northwest Territories. Canadian Department of Indian Northern Affairs Environmental Study No. 17. 111 pp.

MacDonell, D.S. (North/South Consultants Inc.) 1997. Hornaday River-Paulatuk, NT. Arctic Charr Spawning Location Study-August-September 1997. Prepared for the Department of Fisheries and Oceans, Inuvik, NT, Canada. 21 pp.

Mackay, W.C., G.R. Ash, and H.J. Norris. 1990. Fish Ageing Methods for Alberta. R.L.& L. Environmental Services Ltd. Edmonton, AB. 113 pp.

Marcus, M.D., W.A. Hubert and S.H. Anderson. 1984. Habitat Suitability Index Models: Lake Trout (Exclusive of the Great Lakes). U.S. Fisheries Wildlife Biological Service Program FWS/OBS 82/10.84. 12 pp.

Mardsen, J.E., J.M. Casselman, T.A. Edsall, R.F. Elliott, J.D. Fitzsimons, W.H. Horns, B.A. Manny, S.C. McAughey, P.S. Sly and B.L. Swanson. 1995. Lake Trout Spawning Habitat in the Great Lakes – a Review of Current Knowledge. Journal of Great Lakes Research 21 (Supplement 1): 487-497.

Martin, N.V. and C.H. Oliver. 1980. The Lake Char, Salvelinus Namaycush. Edited by E.K. Balon. Charrs: salmonid fishes of the genus Salvelinus. Dr. W. Junk bv Publishers, The Hague, Netherlands. p. 205-277.

McKee, P.M., W. Swodgrass, B.R. Hart, H.C. Duthie, H. McAndrews, and W. Keller. 1987. Sedimentation Rates and Sediment Core Profiles of U 238 and TH 232 Decay Chain Radionuclides in a Lake Affected by Uranium Mining and Milling. Canadian Journal of Fisheries and Aquatic Science. Vol. 44.

McLeod, C.L., P.J. Wiebe, and R.A. Mohr (Renewable Resources Consulting Services Ltd.). 1976. An Examination of Aquatic Ecosystems in the Baker Lake – Lower Thelon River, N.W.T., Area in Relation to Proposed Polar Gas Pipeline Development. Prepared for PolarGas Environmental Program. 267 pp.

McNeely, R.N., V.P. Neimanis and L. Dwyer. 1979. Water Quality Sourcebook. A Guide to Water Quality Parameters. Inland Waters Directorate, Water Quality Branch, Environment Canada, Ottawa, ON.

McPhail, J.D. and C.C. Lindsey. 1970. Freshwater Fishes of Northwestern Canada and Alaska. Fisheries Research Board of Canada Bulletin No. 173. 381 p.

McPhail. J.D. 1997. Review of Burbot (Lota Lota) Life History and Habitat Use in Relation to Compensation and Improvement Opportunities. Canadian Manuscript Report of Fisheries and Aquatic Sciences 2397. 37 p.

McPhail, J.D. 2007. The Freshwater Fishes of British Columbia. The University of Alberta Press. 620 p.

Mecklenburg, C.W., T.A. Mecklenburg and L.K. Thorsteinson. 2002. Fishes of Alaska. American Fisheries Society. Bethesda, MD. 1037 pp.

Mitchell, P.A. and E.E. Prepas (eds.). 1990. Atlas of Alberta Lakes. The University of Alberta Press. Edmonton, AB. 690 pp.

Mohr, L.C. 1984. The General Ecology of the Slimy Sculpin (Cottus Cognatus) in Lake 302 of the Experimental Lakes Area, Northwestern Ontario. Canadian Technical Report Fisheries and Aquatic Sciences No. 1227. 16 pp.

Mohr, L.C. 1985. Depth Distribution of the Slimy Sculpin (Cottus Cognatus) in a Small Lake in Northwestern Ontario. Canadian Technical Report Fisheries and Aquatic Sciences No. 1374. 13 pp.

Moore, J.W. 1975. Distribution, Movements, and Mortality of Anadromous Arctic Char, Salvelinus Alpinus L., in the Cumberland Sound Area of Baffin Island. Journal of Fish Biology 7: 339-348.

Morrow, J.E. 1980. Freshwater Fishes of Alaska. Alaskan Northwest Publishing Company. Anchorage, Alaska. 248 pp.

Mousseau, T.A. and N.C. Collins. 1987. Polygyny and Nest Site Abundance in the Slimy Sculpin. Canadian Journal of Zoology 65: 2827-2829.

Muus, B.J. and P. Dahlstrøm. 1999. Freshwater Fish. Scandinavian Fishing Year Book, Denmark. 224 pp.

MWLAP (BC Ministry of Water, Land and Air Protection), 2003. British Columbia Field Sampling Manual. BC Ministry of Water, Land and Air Protection, Victoria, BC.

Myers, G.S.1949. Usage of Anadromous, Catadromous and Allied Terms for Migratory Fishes. Copeia 2: 89-97.

Normandeau, D.A. 1969. Life History of the Round Whitefish Prosopium Cylindraceum (Pallas), of Newfound Lake, Bristol, New Hampshire. Transactions of the American Fisheries Society 98: 7-13.

Northcote, T.G. 1995. Comparative Biology and Management of Arctic and European Grayling (Salmonidae, Thymallus). Reviews in Fish Biology and Fisheries 5: 141-194.

Otto, R.G., J.O. Rice. 1977. Responses of a Freshwater Sculpin (Cottus Cognatus Gracilis) to Temperature. Transactions of the American Fisheries Society 106: 89-94.

Parker, H.H. and L. Johnson. 1991. Population Structure, Ecological Segregation and Reproduction in Non-Anadromous Arctic Char, Salvelinus Alpinus (L.) in Four Unexploited Lakes in the High Arctic. Journal of Fish Biology 38: 123-147.

Patrick, R. and C. Reimer. 1975. The Diatoms of the United States, Exclusive of Alaska and Hawaii. Academy of Natural Sciences of Philadelphia, Philadelphia, PA.

Pauly, D. 1984. Fish Population Dynamics in Tropical Waters: a Manual for Use with Programmable Calculators. ICLARM Studies and Reviews 8, 325 pp. International Center for Living Aquatic Resources Management, Manila, Philippines.

Peck, J.W. 1982. Extended Residence of Young-of-the-Year Lake Trout in Shallow Water. Transactions of the American Fisheries Society 111: 775-778.

Pennak, R.W. 1978. Freshwater Invertebrates of the United States. 2nd Edition. John Wiley and Sons. Toronto, ON. 803 pp.

Prescott, G.W. 1982. Algae of the Western Great Lakes. Otto Koeltz Science Publishers. 977 pp.

Pritchard, A.L. 1930. Spawning Habits and Fry of the Cisco (Leucichthys Artedi) in Lake Ontario. Contr. Can. Biol. Fish. NS 6: 225-240.

Reist, J.D., J.A. Babluk and M.A. Papst. 2001. Biodiversity, Life History and Management of the Anadromous Fish of the Western Canadian Arctic. (unpublished report). 93 pp.

Reist, J.D., F.J. Wrona, T.D. Prowse, M. Power, J.B. Dempson, R.J. Beamish, J.R. King, T.J. Carmichael, C.D. Sawatzky. 2006. General Effects of Climate Change on Arctic Fishes and Fish Populations. Ambio 35 (7): 370-380.

Richardson, E.S., J.D. Reist and C.K. Minns. 2001. Life History Characteristics of Freshwater Fishes Occurring in the Northwest Territories and Nunavut, with Major Emphasis on Lake Habitat Requirements. Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 2569. 146 pp.

Rieberger, K. 1992. Metal Concentrations in Fish Tissue from Uncontaminated BC Lakes. Ministry of Environment, Lands and Parks, Victoria, BC.

Rosenberg, D.M. and V.H. Resh. 1993. Introduction to Freshwater Biomonitoring and Benthic Macroinvertebrates. In D.M. Rosenberg and V.H. Resh (eds.) Freshwater biomonitoring and benthic macroinvertebrates. Chapman and Hall, New York, NY.

Rott, E. 1981. Some Results from Phytoplankton Counting Inter-Calibrations. Schweiz Z. Hydrol. 24: 15-24.

Ryder, R.A. and J. Pisendorfer. 1992. Food, Growth, Habitat, and Community Interactions of Young-of-the-Year Burbot, Lota Lota L., in a Precambrian Shield Lake. Hydrobiologia. 243/244: 211-227.

Saffran, K.A. and D.O. Trew. 1996. Sensitivity of Alberta Lakes to Acidifying Deposition: An Update of Maps with Emphasis on 109 Northern Lakes. Water Management Division, Alberta Environmental Protection. Edmonton, AB.

SE (Saskatchewan Environment). 2006. Surface Water Quality Objectives, Interim Edition. EPB 356. Saskatchewan Environment, Regina, SK.

Schmidt, D., and W.J. O'Brien. 1982. Planktivorous Feeding Ecology of Arctic Grayling (Thymallus Arcticus). Canadian Journal of Fisheries and Aquatic Sciences. 39: 475-482.

Scott, D.C. and R.R. Wheaton. 1954. A Study of Great Slave Lake at the Spawning Time of Lake Trout, Cristivomer Namaycush and Whitefish, Coregonus Clupeaformis in 1953 with a Similar Study in 1952 as an Appendix. Fisheries Research Board of Canada Manuscript Report of Biological Stations No. 565. 28 pp.

Scott, W.B. and E.J. Crossman. 1998. Freshwater Fishes of Canada. Canadian Bulletin of Fisheries and Aquatic Sciences 184. Reprinted by Galt House Publications Ltd., Oakville, Ontario. 966 pp. ISBN: 0-9690653-9-6.

Scott, W.B. and M.G. Scott. 1988. Atlantic Fishes of Canada. Canadian Bulletin of Fisheries and Aquatic Sciences No. 219. 731 pp.

SENES Consultants Limited. 2008. Screening Level Environmental Effects Assessment Proposed Kiggavik Project. Prepared for AREVA Resources Canada Inc, Saskatoon SK. Submitted July 2008. 241 pp.

Sellers, T.J., B.R. Parker, D.W. Schindler and W.M. Tonn. 1998. Pelagic Distribution of Lake Trout (Salvelinus Namaycush) in Small Canadian Shield Lakes with Respect to Temperature, Dissolved Oxygen, and Light. Canadian Journal of Fisheries and Aquatic Sciences. 55: 170-179.

Skuja, H. 1949. Zur Siisswasseralgenflora Burmas. Nova Ada Regia Societatis Scientiarum Upsaliensis. 14: 1-188.

Sly, P.G. and D.O. Evans. 1996. Suitability of Habitat for Spawning Lake Trout. Journal of Aquatic Ecosystem Health. 5: 153-175.

Starmach, K. 1985. Chrysophyceae und Haptophyceae. In Ettl, H. et al. (eds.): Süswasserflora von Mitteleuropa. Begründet von A. Pascher Band 1. VEB Gustav Fischer Verlag, Jena. 515 pp.

Stemberger, R.S. 1979. A Guide to Rotifers of the Laurentian Great Lakes. US Environmental Protection Agency, Environmental Monitoring Support Lab, Cincinnati, Ohio. 182 pp.

Stemberger, R.S. and J.J. Gilbert. 1987. Planktonic Rotifer Defences. In W.C. Kerfoot and A. Sih (ed.). Predation: Direct and Indirect Impacts on Aquatic Communities. University Press of New England, Hanover, NH. p. 227-239.

Stewart, D.B., R.A. Ratynski, L.M.J. Bernier and D.J. Ramsey. 1993. A Fishery Development Strategy for the Canadian Beaufort Sea-Amundsen Gulf Area. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1910. 127 p.

Stockner, J.G. and A.C. Costella. 1980. The Paleolimnology of Eight Sockeye Salmon (Oncorhynchus Nerka) Nursery Lakes in British Columbia, Canada. Canadian Technical Report of Fisheries and Aquatic Science. No. 979.

Suchanek, P.M., R.L. Sundet, and M.N. Wenger. 1984. Resident Fish Habitat Studies. In Alaska Department of Fish and Game Susitna Hydro Aquatic Studies. In D.C. Schmidt, S.S. Hale, D.L. Crawford and P.M. Suchanek (ed.). Report No. 2: Resident and Juvenile Anadromous Fish Investigations (May - October 1983). Anchorage, Alaska. Part 6. 40 pp.

Thibodeau, M.L. and J.R.M. Kelso. 1990. An Evaluation of Putative Lake Trout (Salvelinus Namaycush) Spawning Sites in the Great Lakes. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1739.

Thompson, P.A., J. Kurias, S. Mihok. 2004. Derivation and Use of Sediment Quality Guidelines for Ecological Risk Assessment of Metals and Radionuclides Released to the Environment from Uranium Mining and Milling Activities in Canada. Environmental Monitoring and Assessment. 110: 71-85.

Thorp, J.H. and A.P. Covich. 1991. Ecology and Classification of North American Freshwater Invertebrates. Academic Press. 911 pp.

Tikkanen, T. 1986. Kasviplantonopas. Suomen Luonnosuojelun Tuki Oy. 278 pp.

Walters, V. 1955. Fishes of Western Arctic America and Eastern Arctic Siberia. Bulletin of the American Museum of Natural History 106 (5): 259-371.

WEF (Water Environment Federation). 2005. Standard Methods for the Examination of Water and Wastewater. American Water Works Association. 1368 pp. ISBN: 0-87553-047-8.

Weber Scannell, P.K. 1992. Influence of Temperature on Freshwater Fishes: a Literature Review with Emphasis on Species in Alaska. Technical Report 91-1. Alaska Department of Fish & Game. 47 pp.

Wehr, J.D. and R.G. Sheath (eds). 2003. Freshwater Algae of North America: Ecology and Classification. Academic Press, New York. 918 pp.

Wetzel, R.G. 2001. Limnology 3rd edition. Elsevier Science Academic Press, New York. 1006 pp.

Whitford, L.A. and G.J. Schumacher. 1984. A Manual of Freshwater Algae. Sparks Press, N.C. 337 pp.

Wootton, R.J. 1976. The Biology of Sticklebacks. Academic Press. London. 387 pp.

Wootton, R.J. 1984. A Functional Biology of Sticklebacks. University of California Press, Berkley and Los Angles, California. 265 pp.

Wrona, F.J., J.M. Culp, and R.W. Davies. 1982. Macroinvertebrate Subsampling: a Simplified Apparatus and Approach. Canadian Journal of Fisheries and Aquatic Sciences. 39: 1051-1054.

13.2 Internet Sites

Environment Canada. 2009. *State of the Environment Infobase, Northern Arctic Ecozone*. Available at: http://www.ecozones.ca/english. Accessed December 7, 2009.

GoC (Government of Canada). 2008. *Species at Risk Act. Public Registry*. Available: http://www.sararegistry.gc.ca/background/default_e.cfm. Accessed December 2008

MoE (BC Ministry of Environment). 2006. *British Columbia Approved Water Quality Guidelines 2006 edition*. Water Quality Section, Water Management Branch, Environment and Resource Management Branch. Available at: http://www.env.gov.bc.ca/wat/wq/BCguidelines/approv_wq_guide/approved.html. Accessed November 2008.

NRCAN (Natural Resources Canada). 2009. *The Atlas of Canada*. Available at: http://atlas.nrcan.gc.ca/site/english/index.html. Accessed November 2009.

Paterson, M. 2002. *Ecological Monitoring and Assessment Network (EMAN) Protocols for Measuring Biodiversity: Zooplankton in Fresh Waters*. Available at: www.eman-rese.ca/eman/ecotools/protocols/freshwater. Environment Canada, Ottawa, ON. Accessed: February 2004.

Prasad, M.N.V. 2009 . *Emerging Phytotechnologies for Remediation of Heavy Metal Contaminated/Polluted Soil and Wate*r. 24 p. Article available at internet: http://wgbis.ces.iisc.ernet.in/energy/lake2006/programme/programme/proceedings/fullpaper_pdfs/%20M%20N%20V%20Prasad.pdf

United States Environmental Protection Agency. *Environmental Residue Effects Database* (ERED). 2008. Available: http://www.wes.army.mil/el/ered/. Accessed November 2008.

13.3 Personal Communications

McLeod, C. 2008. Senior Fisheries Biologist, Golder Associates Ltd., Edmonton, AB, telephone communication December 23, 2009.

Stanley, L. 2008. Email and attachments outlining sample preparation and quality control methods. January 23 and 24 2008.

Zloty, J. 2008. Email communication, February 28, 2008.

14 Glossary

Adfluvial	Life history strategy in which adult fish spawn and juveniles subsequently rear in streams but migrate to lakes for feeding as subadults and adults.
Alevin	Newly hatched salmonids before the yolk sac is absorbed.
Alkalinity	A measurement (expressed in milligrams per litre of calcium carbonate) of the capacity of water to neutralize acids. The concentration is measured based on the presence of naturally available bicarbonate, carbonate, and hydroxide ions.
Ammonia-nitrogen	The overall concentration of nitrogen in both the ionized (NH4+) and molecular (NH3) forms of dissolved ammonia. The ammonia concentration is reported as nitrogen, where the weight of the nitrogen is ignored in the analysis.
Anadromous	Applied to the migratory behaviour of fish that spend most of their lives in sea, but then migrate to fresh water to spawn.
Anoxia	The complete depletion of dissolved oxygen (DO) in the aquatic environment.
Backwater	Discrete, localized area of variable size exhibiting reverse flow direction; generally produced by bank irregularities; velocities variable but generally lower than main flow; substrate similar to adjacent channel with higher percentage of fines.
Bankful width (also channel width)	Horizontal distance along a transect line from bank to bank at the bankful stage, measured at right angles to the direction of flow. Multiple channel widths are summed to represent total channel width.
Baseline	A surveyed or predicted condition that serves as a reference point on which later surveys are coordinated or correlated.
Bathymetric map	A map depicting the depth contours of the bottom of any water body.

Bathymetry	The measurement of underwater depth.
Benthic invertebrate communities	Animals with no backbone or internal skeleton that inhabit the bottom substrates of freshwater habitats; also referred to as "benthic macroinvertebrates" because of their large size, with some species reaching a few centimetres in length
Becquerel	A unit of measure of radioactive decay, equal to one disintegration per second.
Berm	Transitional zone between the foreshore and the backshore.
	Natural or artificial levee, dike, shelf, ledge, groyne, or bench along a streambank that may extend laterally along the channel or parallel to the flow to contain the flow within the streambank.
Bioaccumulation	The accumulation of a chemical substance in an organism such that the amount in the organism is greater than the amount lost. Bioconcentration refers to uptake from water, whereas bioaccumulation refers to uptake from both water and food.
Bioavailable	Available for uptake by an aquatic organism
Biochemical oxygen demand (BOD)	A measurement of the relative oxygen requirement of a water sample.
Boulder garden	Significant occurrence of large boulders providing significant instream cover; always in association with an overall channel unit such as a riffle (e.g., RF/BG) or run (e.g., R1/BG).
Brackish	Water with a salt content greater than freshwater but less than seawater.
Buffering capacity	The capacity of water to receive inputs of acids or bases without changing pH.

Canadian Water Quality Guidelines (CWQG) for the protection of aquatic life	Guidelines established by the Canadian Council of Ministers of the Environment and used to assess the potential effects of the concentration of different water quality parameters upon aquatic life (e.g., fish, aquatic plants, and benthic invertebrates).
Cascade	Extremely high gradient and velocity; extremely turbulent with entire water surface broken; may have short vertical sections, but overall is passable to fish; armoured substrate; may be associated with chute. Highly turbulent series of short falls and small scour basins, with very rapid water movement as it passes over a steep channel bottom with gradients exceeding 8%. Most of the water surface is broken by short, irregular plunges creating whitewater, frequently characterized by very large substrates, and a well-defined stepped longitudinal profile that exceeds 50% in supercritical flow.
Channel unit	Relatively homogeneous areas of a channel that differ in depth, velocity, and substrate characteristics from adjoining areas, creating different habitat types in a stream channel.
Chlorophyl *a*	Primary photosynthetic pigment contained in phytoplankton.
Concentration	Quantifiable amount of a chemical in environmental media, such as water or sediment.
Condition factor (K)	Description of the plumpness and, by inference, the well-being of individual fish. K is believed to reflect the nutritional state or well-being of an individual fish. The K value will be 1.0 for fish whose weight is equal to the cube of its length.
Conductivity	A measure of the ability of water to carry an electrical current. This measurement is directly related to the amount of positively and negatively charged ions in the water and can be correlated with the concentration of total dissolved solids (TDS).
Desiccate	Desiccation is the process of dehydration or drying up.
Diel	A 24-hour period that includes both day and night.

Dissolved oxygen	The amount of free oxygen dissolved in water, usually expressed in milligrams per litre (mg/L), parts per million (ppm), or percent of saturation (%). Adequate concentrations of dissolved oxygen are necessary for fish and other aquatic organisms.
Dissolved organic carbon (DOC)	The dissolved portion of organic carbon in water; it is made up of humic substances and partly degraded plant and animal materials.
Dry weight	Weight of element (fish or macrohytes) after moisture was removed.
Duplicate field sample	A second sample collected at the same time and from the same location, repeating the same collection procedure as the original sample. The sample is used to detect variability at a sampling station and to verify the field sampling method.
Duplicate laboratory sample	A field sample that is split into two samples by the laboratory and tested separately. These samples are used to assess the reproducibility of the laboratory results (i.e., laboratory method and analyses).
Ecozone	An area of the earth's surface that represents a large ecological zone and has characteristic landforms and climate. An area of the earth's surface that is representative of a broad-scale ecological unit characterized by particular abiotic (non-living) and biotic (living) factors (e.g., prairie, boreal plain).
Effluent	Discharge of liquid into a water body or emission of a gas into the environment. Usually composed of waste material.
Ekman or Ponar grab sampler	Cube-shaped mechanical device with a spring-loaded opening that is lowered to the bottom of a waterbody and triggered to close thereby collecting a sample of the bottom sediment.
Electrofishing	Use of a direct current (DC) or alternating current (AC) electric field to attract, immobilize and capture fish.

Esker	A long, sinuous, steep-sided, narrow-crested ridge which consists of cross-bedded sands and gravels. It is laid down by glacial meltwater either at the retreating edge of an ice sheet, or in an ice-walled tunnel.
Estuary	That part of a river or stream or other body of water having unimpaired connection with the open sea, where the sea water is measurably diluted with freshwater derived from land drainage.
Eutrophic	Trophic state classification for lakes characterized by high productivity and nutrient inputs.
Fecundity	An assessment of the reproductive products that can be produced by an organism (e.g., the number of eggs produced annually by a female fish).
Field blank	A sample that is prepared in the field using ultrapure, distilled, or deionized water provided by the laboratory. These samples are treated in the field in the same way as the field samples. They are used to detect sample contamination during the collection, shipping, and analysis of samples.
Flat	Area characterized by low velocity and near-laminar flow; differentiated from pool habitat by high channel uniformity; more depositional than shallow run habitat. Level landform composed of unconsolidated sediments, usually mud or sand, that may be elongated or irregularly shaped and continuous with the shore, that is covered with shallow water or may be periodically exposed.
Floy Tag	Small, plastic identification tag inserted into the back of the fish near the dorsal fin.
Foreshore	Land along the edge of a water body. Portion of land between the high water mark and the low water mark.
Fork length (FL)	The distance from the tip of the snout to the tip of the middle caudal ray.

Fyke Net	A passive capture device in which a lead net directs fish into a trap through a series of funnels. A fish can readily find its way into the trap through the funnels, but not out of it.
Foreshore	Land along the edge of a water body. Portion of land between the high water mark and the low water mark.
Grab sample	A single sample collected at a particular time and place that represents the composition of the water or sediment only at that time and place.
Gonadosomatic index (GSI)	An index of the proportion of reproductive tissue in the body of the fish to total body weight. It is believed to be an indicator of fish health in that a fish with a comparatively low GSI for its species is considered to not have sufficient energy available for proper gonad growth.
Groundwater	That part of the subsurface water that occurs beneath the water table, in soils and geologic formations that are fully saturated.
Guidelines for Canadian Drinking Water Quality (GCDWQ)	Guidelines issued by the Canadian Council of Ministers of the Environment that are used to assess the suitability of water for human consumption.
Habitat type	Aggregation of land or aquatic units having equivalent structure, function, and responses to disturbance and capable of maintaining similar animal or plant communities. Habitat types include refuge or cover habitat, over wintering or deeper water habitat, spawning habitat, and foraging habitat.
Hardness	A characteristic of water caused by the presence of positively charged ions such as calcium, magnesium, iron, and manganese. This parameter is expressed in milligrams per litre of calcium carbonate.
Hypolimnion	The lower, cooler, non-circulating water in a thermally stratified lake in summer.
Interim Sediment Quality Guidelines (ISQG)	Recommended maximum concentration of a chemical in sediment, indicated to be protective of aquatic organisms.

Interstitial space	Spaces or openings in substrates that provide habitat and cover for benthos.
Kemmerer water sampler	Specialized device to taking water samples at discrete depths
Lacustrine	Pertaining to lakes, reservoirs, wetlands, or any standing waterbody with a total surface area exceeding 8 ha.
Lentic	Relating to still water, such as ponds and lakes.
Life stage	The series of developmental changes undergone by an organism between birth and death. The life stages of a fish include egg, fry, juvenile, and adult stages.
Limnology	The study of open fresh and more rarely saline water bodies, specifically lakes and ponds (both natural and man-made), including their physical, chemical, and biological properties. Limnology traditionally is closely related to hydrobiology, which is concerned with the application of the principles and methods of physics, chemistry, geology, and geography to ecological problems.
Limnology (vertical) profile	An in situ measurement consisting of taking readings of physical parameters or samples at certain depth increments in a water column of a lake.
Littoral	Shallow shore area (less than 6 m deep) of a water body where light can usually penetrate to the bottom and that is often occupied by rooted macrophytes.
Liversomatic index (LSI)	An indicator of fish health. Energy is stored in the liver in the form of glycogen and the relative size of the liver is believed to correlate with nutritional state of the fish. The ratio of liver weight (g) versus total body weight, expressed as a percentage of total body weight.
Lotic	Relating to running water such as streams and rivers

Macrophyte	A plant that can be seen without the aid of optics, general used to categorize aquatic plants. Aquatic macrophytes can be divided into emergent, floating, free-floating, nonpersistent emergent, rheophyte, and submerged.
Marine	Of, or pertaining to, the ocean and associated seas.
Matrix spike	A laboratory produced sample containing a known concentration of a given parameter to measure the accuracy of laboratory equipment.
Mesotrophic	Trophic state classification for lakes characterized by moderate productivity and nutrient inputs (particularly total phosphorus).
Method blank	A laboratory grade, pure water sample that is subjected to all laboratory procedures. This is used to detect possibility of cross-contamination between samples in the laboratory.
Method detection limit (DL)	The lowest concentration at which individual measurement results for a specific analyte are statistically different from a blank (that may be zero) with a specified confidence level for a given method and representative matrix.
Milt	The milky white fluid extruded by male fish during spawning activity. It contains the sperm.
Moraine	The ridges of rock debris or till deposits around the margins of glaciers.
Morphology	Physical attributes of a water body and the methods for measuring those attributes.
Morphometry	A set of linear, area, and volumetric parameters of a waterbody or watershed that describe geometric features and provide a background for a hydrologic description of a waterbody or drainage area. The physical shape of a water body, such as a stream, lake, or reservoir.
Nitrate + nitrite	The sum of the concentrations of nitrate and nitrite.

Nutrients	Environmental substances (elements or compounds) such as nitrogen or phosphorus, which are necessary for the growth and development of plants and animals.
Oligotrophic	Trophic state classification for lakes characterized by low productivity (i.e., little aquatic plant or animal life) and low nutrient inputs (particularly total phosphorus).
Open water conditions	The period of time when the surface of a waterbody is completely free of ice.
Otolith	Otoliths are small particles, composed of a combination of a gelatinous matrix and calcium carbonate in the viscous fluid of the saccule and utricle of the inner ear, that increases throughout the life of the fish. There is less growth in winter and more in summer, which results in the appearance of rings that resemble tree rings. By counting the rings, it is possible to determine the age of the fish in years.
Passive integrated transponder (PIT) tag	Microchip implanted in a fish to identify the fish remotely through the use of radio frequencies. PIT tags have no battery so the microchip remains inactive until read with a scanner. The scanner sends a low frequency signal to the microchip within the tag providing the power needed to send its unique code back to the scanner and positively identify the animal. PIT tags are designed to last the life of the animal providing a reliable, long term identification method.
Pathway (flow)	Flow preferred path in a drainage area.
Pelagic zone	Open water areas of lakes, reservoirs, or seas away from the shore.
Periphyton	A term used to describe the algal community that grows attached to the substrate (generally rocks) in streams and lakes.

Permafrost	The permanently frozen ground which occupies some 26 per cent of the Earth's land surface under thermal conditions where temperatures below 0ºC have persisted for at least two consecutive winters and the intervening summer. Permanently frozen ground (subsoil). Permafrost areas are divided into more northern areas in which permafrost is continuous, and those more southern areas in which patches of permafrost alternate with unfrozen ground.
pH	The negative log of the concentration of the hydronium ion. The pH is a measure of the acidity or alkalinity of all materials dissolved in water, expressed on a scale from 0 to 14, where 7 is neutral, values below 7 are acidic, and values over 7 are alkaline.
Photic zone	The depth at which light is sufficient to allow photosynthesis by phytoplankton (generally estimated at twice the Secchi depth).
Phytoplankton	Open-water, algal component (i.e., non-vascular, photosynthetic plants)
Picocurie	A unit of measure of radioactive decay. One trillionth of a Curie, which is approximately 2.2 disintegrations per minute.
Plankton	A general term referring to small, usually microscopic, organisms that live suspended in open water
Pool	Discrete portion of channel featuring increased depth and reduced velocity relative to riffle/run habitats; formed by channel scour. Aquatic habitat in a stream with a gradient less than 1% that is normally deeper and wider that aquatic habitats immediately above and below it.
Predator	An animal that catches, kills, and eats its prey.
Producer	In an ecosystem, an organism that is able to manufacture food from simple inorganic substances (e.g., a green plant or phytoplankton).
Probable Effects Level (PEL)	Concentration of a chemical in sediment above which adverse effects on an aquatic organism are likely.

Quality Assurance / Quality Control procedures	Procedures used by field personnel and laboratories to ensure data quality.
Radionuclide	An isotope of artificial or natural origin that exhibits radioactivity.
Rapid	Extremely high velocity; deeper than riffle; substrate extremely coarse (i.e., cobble and boulder); instream cover in pocket eddies and associated with substrate.
	Moderately steep stream area (4-8% gradient) with supercritical flow between 15 and 50%, rapid and turbulent water movement, surface with intermittent whitewater with breaking waves, coarse substrate, with exposed boulders at low flows, and a somewhat planar longitudinal profile.
Redd	A collective term for the sequential series of nests dug by a single female salmonid.
Root	The lower part of a plant, usually underground, by which the plant is anchored and through which water and mineral nutrients enter the plant.
Run	Moderate to high velocity; surface largely unbroken; usually deeper than riffle; substrate size depend on hydraulics. Run habitat can be differentiated into one of four types: deep/slow, deep/fast, shallow/slow, or shallow/fast.
	Swiftly flowing stream reach with a gradient greater than 4%, little to no surface agitation, waves, or turbulence, no major flow obstructions, approximately uniform flow, substrates of variable particle size, and water surface slope roughly parallel to the overall stream gradient.
Sacfry	Recently hatched fish larvae that are still in possession of the yolk sac.
Saskatchewan Surface Water Quality Objectives (SSWQO)	Objectives adopted by Saskatchewan Environment and used to assess the potential effects of the concentration of different water quality parameters upon aquatic life.

Secchi depth	A parameter used to determine the clarity of surface waters. The measurement is made with a “Secchi” disk, a black and white disk that is lowered into the water and the depth is recorded at which it is no longer visible. A secchi depth recording of 1 m indicates that the device was last visible at 1 m below the surface. High secchi depth readings indicate clearer water that allows sunlight to penetrate to greater depths. Low readings indicate turbid water which can reduce the passage of sunlight to bottom depths. Limited light penetration can be a factor in diminished aquatic plant growth beneath the surface, thus reducing the biological re-aeration at lower depths.
Sediment	Solid material that is transported by, suspended in, or deposited from water. It originates mostly from disintegrated rocks; it also includes chemical and biochemical precipitates and decomposed organic material, such as humus. The quantity, characteristics and cause of the occurrence of sediment in streams are influenced by environmental factors. Some major factors are degree of slope, length of slope soil characteristics, land usage and quantity and intensity of precipitation.
Sedimentation rate	The rate at which sediment is deposited in a waterbody such as a lake or stream.
Shelf	Sandbank or submerged area of rock in a water body or bedrock underlying an alluvial deposit.
Shoot	The upper part of a plant, usually above ground, through which light energy is collected.
Shoreline development Index (DL)	Ratio of a lakes shoreline length (L) to the circumference of a circle having the same area (A) as the lake: $$DL = \frac{L}{2(\pi A)^{½}}$$
Snye	Discrete section of non-flowing water connected to a flowing channel only at its downstream end; generally formed in a side-channel or behind a peninsula.

Soluble	Referring to a substance that can be easily dissolved in a solvent such as water.
Specific conductivity (See also Conductivity).	A conductivity reading normalized to a temperature of 25ºC. This allows valuable comparisons to be made.
Stratification	The separation of lakes into layers: well mixed top layer, middle layer (see Thermocline), and a bottom layer. In freshwater lakes, stratification usually occurs as a result of temperature effects that cause changes in water density. Stratification may also affect vertical changes in water quality.
Sub-basin	Surface area of a watershed drained by a tributary to a larger stream that is bounded by ridges or other hydrologic divides and is located within the larger watershed drained by the larger stream.
Sympatric	Applied to species or other taxa with ranges that overlap.
Thermocline	Generally, a gradient of temperature change, but applied more particularly to the zone of rapid temperature change between the warm surface waters (epilimnion) and cooler deep waters (hypolimnion) in a thermally stratified lake in summer.
Total dissolved solids (TDS)	The dissolved matter found in water comprised of mineral salts and small amounts of other inorganic and organic substances.
Total Kjeldahl nitrogen (TKN)	The sum of organic nitrogen and ammonia.
Total length (TL)	Refers to the distance from the tip of the snout to the posterior end of the caudal fin.
Total organic carbon	A measure of the concentration of organic carbon in water or sediment, it is determined by the oxidation of the organic matter into carbon dioxide. Organic matter in soils, aquatic vegetation, and aquatic organisms are major sources of organic carbon.
Total suspended solids (TSS)	A measurement of the concentration of particulate matter found in water.

Trip blank	A water sample prepared by the laboratory and shipped to the field sampling location and then subsequently returned to the laboratory unaltered. These samples are used to detect sample contamination during preparation, preservation, or transport between field and laboratory.
Trophic state	Eutrophication is the process by which lakes are enriched with nutrients, increasing the production of rooted aquatic plants and algae. The extent to which this process has occurred is reflected in a lake's trophic classification or state: oligotrophic (nutrient poor), mesotrophic (moderately productive) and eutrophic (very productive and fertile).
Turbidity	Refers to the relative clarity of a water body. It is a measure of the extent to which light penetration in water is reduced from suspended materials such as clay, mud, organic matter, colour, or plankton.
Under ice conditions	The period of year when the lakes are partially or completely covered with ice.
Volatile	Referring to a substance that can be easily changed from solid or liquid form to a vapour.
Watershed	Region or area drained by surface and groundwater flow in rivers, streams, or other surface channels. A smaller watershed can be wholly contained within a larger watershed.
Wetted width	Width of a water surface measured perpendicular to the direction of flow at a specific discharge. Widths of multiple channels are summed to represent the total wetted width.
Zooplankton	Microscopic animals that float, drift or swim weakly, and includes crustaceans (i.e., Cladocera [cladocerans], Calanoida, and Cyclopoida) and rotifers.

Table 14.0-1 Table of Fish Names

Scientific Name	Common Name
Catostomus catostomus	longnose sucker
Coregonus artedi	cisco
C. clupeaformis	lake whitefish
Cottus cognatus	slimy sculpin
Myoxocephalus quadricornis	fourhorned sculpin
Lota lota	burbot
Prosopium cylindraceum	round whitefish
Pungitius pungitius	ninespine stickleback
Salvelinus alpinus	Arctic char
S. namaycush	lake trout
Thymallus arcticus	Arctic grayling