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FROM:	David Swisher	**MVEIRB FILE:**	EA1011-001

PROJECT: Developer's Assessment Report
Thor Lake Project, NWT

ENCLOSED: 3 copies - Thor Lake Rare Earth Metals Baseline Project Environmental Baseline Report: Volume 3 – Aquatics and Fisheries (Final Report)
3 copies – Radioactivity Pathways Assessment for the Thor Lake Project, Northwest Territories

	As requested		**Mail**
X	**For your information**		**Courier**
	For your approval	X	**Hand delivered**
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COMMENTS: Please find enclosed three (3) copies each of the following reports:

- Stantec Inc. January 2011. Thor Lake Rare Earth Metals Baseline Project Environmental Baseline Report: Volume 3 – Aquatics and Fisheries (Final Report).
- SENES Consultants Ltd. July 2011. Radioactivity Pathways Assessment for the Thor Lake Project, Northwest Territories.

These reports provide updated information previously provided in the Developer's Assessment Report (submitted to MVEIRB in May 2011).

Appendix A1 contains a Final Interim Report entitled *Thor Lake Rare Earth Metals Baseline Project Environmental Baseline Report: Volume 3 – Aquatics and Fisheries.* This document should be replaced with the Final Report entitled *Thor Lake Rare Earth Metals Baseline Project Environmental Baseline Report: Volume 3 – Aquatics and Fisheries* (July 2011) provided here.

Appendix G of the Developer's Assessment Report contains Radiological Reports from SENES Consultants Ltd. A new report, entitled *Radioactivity Pathways Assessment for the Thor Lake Project, Northwest Territories*, is provided here.

AVALON
RARE METALS INC.

AVALON RARE METALS INC.

DEVELOPER'S ASSESSMENT REPORT
THOR LAKE PROJECT, NWT

APPENDICES - VOLUME I

SUBMITTED TO:
MACKENZIE VALLEY ENVIRONMENTAL IMPACT REVIEW BOARD

MAY 2011
MVEIRB FILE: EA1011-001

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A TETRA TECH COMPANY

Avalon Rare Metals Inc.

DEVELOPER'S ASSESSMENT REPORT
THOR LAKE PROJECT
NORTHWEST TERRITORIES

APPENDICES
VOLUME 1

Submitted To:
MACKENZIE VALLEY ENVIRONMENTAL IMPACT REVIEW BOARD

May 2011

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APPENDIX A

STANTEC ENVIRONMENTAL BASELINE REPORTS

Appendix A.1 Thor Lake Rare Earth Metals Baseline Project Environmental Baseline Report: Volume 3 – Aquatics and Fisheries 2011

Appendix A.2 Thor Lake Rare Earth Metals Baseline Project Environmental Baseline Report: Volume 1 – Climate and Hydrology 2010

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Appendix A.6 Thor Lake Rare Earth Metals Baseline Project Environmental Baseline Report: Volume 6 – Wildlife Resources 2010

Appendix A.1

Thor Lake Rare Earth Metals Baseline Project Environmental Baseline Report: Volume 3 – Aquatics and Fisheries 2011

THOR LAKE RARE EARTH METALS BASELINE PROJECT

Environmental Baseline Report: Volume 3 – Aquatics and Fisheries

FINAL REPORT

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EXECUTIVE SUMMARY

Avalon Rare Metals Inc. (Avalon) is currently pursuing development of the Nechalacho Rare Earth Metals Deposit, located on mineral leases it holds at its Thor Lake site in the Northwest Territories. The deposit is located approximately 100 km southeast of Yellowknife and 4 km north of the Hearne Channel of Great Slave Lake.

Stantec began environmental baseline studies at the Thor Lake project site in fall 2008 and continued with field work through 2009 and 2010. This technical data report presents results of the baseline aquatics and fisheries study, focusing on water quality, aquatic ecology and fisheries values in lakes of the study area. This includes 13 watercourses and 16 lakes that will be directly or indirectly affected by Project development, 6 other lakes in the local area to better establish local aquatic conditions, and 4 lakes considered for use as reference lakes (26 lake stations in total). One sampling station on Great Slave Lake was included, in an area being proposed for a seasonal dock.

Of the 13 watercourses studied, seven were impassable to fish, four were passable during seasonal high flows (or all year), and two are probably not passable without exceptionally high flows. Quality of the available habitat for fish in these 13 watercourses was generally low, due to very low water levels. Fish presence was observed in two of the streams: a ninespine stickleback in the outlet of Long Lake and three northern pike in the outlet of Murky Lake. The known fish species in the area primarily use lake habitats; however, northern pike, slimy sculpin and ninespine stickleback are known to use stream habitat as well. These three species spawn in still or slow-moving water and it is unlikely that any of them would fully complete their life cycle in stream habitat.

Littoral and riparian areas of each study lake were examined for predominant aquatic and terrestrial vegetation and fish habitat features (e.g., large woody debris). Substrate in the littoral areas varied from bedrock to organic muck. Several species of submerged and emergent vascular plants were present. Large woody debris and large boulders were often absent. The riparian area of most lakes was dominated by black spruce; other species observed included paper birch, tamarack, dwarf birch and Labrador tea. Wetlands and bedrock bluffs were present or predominant at several lakes.

Water and sediment data were collected at 26 lakes. Water was neutral to basic (mean pH from 7.58 to 8.35), generally with low nutrient levels and a large range of conductivity and hardness. Large ranges in many general parameters and metals were noted, due to elevated levels during winter in shallow lakes (less than 3 m deep), for example, total iron levels 3 to 61 times higher than the water quality. Sediment characteristics varied across the study area, though generally organic carbon, phosphorus, and nitrogen content was relatively high; arsenic levels were higher than guidelines in 62%, nickel in 41%, silver in 28% and copper in 21% of sample stations.

Data on the aquatic communities were collected at 22 sample stations in 2009 and eight stations in 2010. Based on chlorophyll *a* values, 12 lakes are considered ultra-oligotrophic, seven are oligotrophic and six are mesotrophic. Mean phytoplankton abundance varied in lakes sampled in both 2009 and 2010; predominant species included blue-green algae, yellow-brown algae and small flagellates. Predominant zooplankton included one cladoceran (*Bosmina longirostris*) and several species of rotifers and copepods. Several benthic invertebrate taxa were predominant across the study area and included midge larvae, crustaceans, a clam, snails, an aquatic earthworm, copepods and nematodes. For lakes sampled in both 2009 and 2010, total abundance and richness of benthic invertebrates were similar while diversity values were more variable.

Fisheries studies were conducted in 20 lakes. Of these, 12 are considered fish-bearing. The most common species found were the large bodied northern pike, lake whitefish and lake cisco and small bodied slimy sculpin and ninespine stickleback; all five species were present in Thor, Long, Elbow, A and Redemption lakes. Lake trout was captured only in Carrot and Great Slave (the deepest lakes), while lake chub was captured only in Kinnikinnick Lake. Lakes considered non-fish-bearing are isolated from other water bodies and, therefore, do not directly contribute food or nutrients to fish-bearing waters, and are not considered fish habitat under the *Fisheries Act*.

Catch per unit effort (CPUE) was calculated for the large bodied fish species captured in six-panel gang gill nets for all study years. CPUE for northern pike and lake whitefish was similar over the years (varying by 0.2 fish/hour or less); however, CPUE for lake cisco was more variable. This variability in catch rate would be expected based on the typical schooling behavior of lake cisco (northern pike and lake whitefish do not form schools).

Fish health was assessed in terms of length, weight, presence of parasites, age, organ size, and metal content. Muscle was analyzed for mercury and liver was analyzed for metals and rare earth elements. Average length was calculated for northern pike (447 mm), lake whitefish (364 mm) and lake cisco (168 mm). The length-weight relationship varied slightly between lakes. Mean relative weight was lowest for lake cisco from Great Slave Lake and highest for lake whitefish from Fred Lake; northern pike tended to have lower relative weights than lake whitefish, possibly due to differences in spawning times. Fish age ranged from 1 year (lake whitefish, lake cisco and northern pike from several lakes) to 34 years (one lake whitefish from Redemption Lake). The frequency of internal and external parasites was relatively low; among large-bodied species, frequency was highest for lake whitefish, and among lakes, frequency was highest for Elbow Lake.

Total mercury levels in northern pike and lake whitefish muscle samples exceeded the British Columbia Ministry of Environment (BCMOE) guideline for unrestricted consumption in all lakes except Murky and U for northern pike and Great Slave Lake for lake whitefish. Cadmium and arsenic levels in northern pike, lake whitefish and lake cisco liver samples from some lakes exceeded United States Environmental Protection Agency guidelines for unrestricted consumption, while selenium levels in liver samples from most of the lakes exceeded the BCMOE guideline for the protection of aquatic life. Thallium levels were elevated in whitefish and cisco liver samples from Great Slave Lake, but not from other lakes. These elevated levels reflect conditions in undisturbed lakes.

This comprehensive environmental baseline study investigated the aquatics and fisheries issues typically required by regulators for the environmental assessment process, as well as other issues specifically requested by Fisheries and Oceans Canada. Stantec designed the baseline study to prepare for long term monitoring of the Project, based on the project description available.

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ABBREVIATIONS AND ACRONYMS

%	percent
<	less than
>	greater than
µ	micro
µg/L	micrograms per litre
mg/kg	milligrams per kilogram
mL	millilitre
ANOVA	analysis of variance
ANCOVA	analysis of covariance
BCMOE	British Columbia Ministry of Environment
CCME	Canadian Council of Ministers of the Environment
CPUE	Catch Per Unit Effort
CRM	Certified Reference Materials
CV	Coefficient of Variation
DFO	Fisheries and Oceans Canada
DO.	Dissolved Oxygen
DOC	Dissolved Organic Carbon
GCDWQ	Guidelines for Canadian Drinking Water Quality
GPS	Global Positioning System
ICP-MS	Inductively Coupled Plasma Mass Spectrophotometry
ISQG	Interim Sediment Quality Guidelines
NORM	Naturally Occurring Radioactive Materials
NTS	National Topographic Scale
PAH	Polycyclic Aromatic Hydrocarbons
PEL	Probable Effects Level
QA/QC	Quality Assurance/Quality Control
REE	Rare Earth Elements
SRC	Saskatchewan Research Council
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
TSS	Total Suspended Solids
UTM	Universal Transverse Mercator

1 INTRODUCTION

Avalon Rare Metals Inc (Avalon) is currently pursuing development of the Nechalacho Rare Earth Metals Deposit, located on mineral leases it holds at its Thor Lake site in the Northwest Territories. The deposit is located approximately 100 km southeast of Yellowknife and 4 km north of the Hearne Channel of Great Slave Lake. The Thor Lake site has been subject to mineral exploration by others since the 1970s. Previous exploration focused on beryllium resources in the T-zone (approximately 1 km north of Thor Lake) and included drilling and bulk sampling. Since acquiring the property in 2006, Avalon has focused on delineating the rare earth resource within the Nechalacho Deposit, which is not part of the T-zone. Development concepts considered during the prefeasibility study included development of an underground mine, mineral concentration, tailings disposal, waste rock disposal, fuel and concentrate storage, power generation and transportation infrastructure (airstrip, upgraded site roads, seasonal dock on Great Slave Lake). Concentrate would be shipped off-site for refinement into a marketable rare earth product.

The Thor Lake site is within the Taiga Shield ecozone, characterized by Precambrian bedrock outcrops with many lakes and wetlands in glacially carved depressions.

The Thor Lake site is located within the Akaitcho Territory, an area currently under negotiation of a comprehensive land claim between the federal government and the Akaitcho First Nations, representing First Nations in LutselK'e, Fort Resolution, Ndilo and Dettah. Thor Lake lies within the Mackenzie Valley region of the NWT and is, therefore, subject to the provisions of the *Mackenzie Valley Resource Management Act* (MVRMA) in addition to other federal and territorial legislation. Federal regulations pertinent to aquatics and fisheries at Thor Lake include the *Fisheries Act* and Metal Mining Effluent Regulations.

Stantec initiated environmental baseline studies at the Thor Lake project site in fall 2008. Aquatic monitoring of drilling was also undertaken during fall 2007 and winter 2008 (data from winter 2008 were incorporated into the aquatic baseline data). This technical data report presents aquatics and fisheries baseline data collected from 2008 to 2010 in 26 lakes in the Thor Lake area. Included are physical environment, water and sediment chemistry, aquatic biota, and fisheries components. The studies included lakes that may be directly or indirectly affected by the Thor Lake project, as well as four potential reference lakes. Fisheries values in 13 watercourses in the Thor Lake area were also investigated. Information in the climate and hydrology (Volume 1) and hydrogeology (Volume 2) assessments for the Thor Lake Baseline Study also provide information relevant to the conditions in the study lakes.

2 AQUATICS AND FISHERIES OVERVIEW

This technical data report presents results of the aquatics and fisheries components of the Thor Lake baseline study. The study investigated water quality, aquatic ecology and fisheries values in 13 watercourses and 16 lakes that may be directly or indirectly affected by Project development. Ten other lakes were also studied: six in the local area to better establish local aquatic conditions and four for use as potential reference sites.

Maps are presented in Appendix A, historical data in Appendix B, photographs of the study area in Appendix C, laboratory methods in Appendix D, and data in Appendices E through L.

2.1 Baseline Study Objectives

The objectives of the aquatics baseline study are to:

- Characterize baseline water and sediment quality in the Thor Lake area
- Describe the aquatic community through collection of phytoplankton, zooplankton and benthic invertebrates
- Assess spatial and temporal variation in water quality and aquatic biota.

The objectives of the fisheries baseline study are to:

- Map and assess the physical fish habitat value of area watercourses and lakes, including bathymetry, fish passage potential, and identification of available habitat
- Determine fish species presence in study area watercourses and lakes
- Assess the health of fish by examining population characteristics, metals concentrations in tissue, external condition and parasitisation and internal parasitisation.

2.2 Baseline Study Area

The study investigated 26 lakes in the Thor Lake area (Figure 2-1 in Appendix A), including 16 lakes within or downstream of the preliminary project footprint, six other lakes in the local study area and four potential reference lakes (Table 2-1).

Aquatic sampling stations were initially selected in 2008, with Avalon’s input on preliminary Project design, potential future expansion, and the lakes’ proximity to and location within major geologic zones and watersheds in the Thor Lake area. As the Thor Lake project progressed and additional project information became available, the aquatic sampling program was expanded to reflect revised potential locations of mine infrastructure and to include a far-field reference lake, on advice from Environment Canada and Fisheries and Oceans Canada (DFO).

Fisheries study lakes were selected based on the direct project footprint and known information about surface water drainage in the Thor Lake area. All lakes that would potentially directly interact with the mine footprint (i.e., lakes above the underground excavations), tailings storage areas and ore transport routes were selected, as was the first lake downstream of the mine area. Known and suspected watercourses within the project area or that could potentially serve as migration routes between lakes were also selected for the fisheries study.

Reference lakes outside the potential influence of both air emissions and water discharges will be needed for long term monitoring programs. Reference lakes are an important component of the baseline study as they allow more informative analysis of monitoring data collected during or after mine operations and to assess the influence of factors beyond the influence of the project, such as climate change, on aquatic conditions. Two near- and two far-field reference lakes were investigated for this study. Selection of a suitable reference lake for aquatics and fisheries began in 2008 with Kinnikinnick (aquatics) and U (fisheries). Sampling at Kinnikinnick (located 5 km southeast [cross-wind] of the Thor Lake camp) began in March 2008 and was carried through the baseline program; Kinnikinnick is still being considered as a potential near-field reference lake for aquatics. U Lake (located 5 km west northwest of Thor Lake) was rejected as a potential fisheries reference lake following bathymetry and fisheries data collection in September 2008, due to its shallow depth and dissimilar fish assemblage.

Discussions with Environment Canada and DFO in 2009 identified the need for a far-field reference lake. Selection of a far-field reference lake began in September 2009. Two lakes were initially chosen based on location (upwind of project), apparent size and distance from site. However, these two lakes were rejected following a reconnaissance survey and a third lake, Carrot, was chosen for investigation. Carrot is located approximately 16 km northeast of the Thor Lake camp. Bathymetry and fisheries data collected at Carrot revealed it to be an unsuitable reference due to deep maximum depth (36 m) and a fish community dissimilar to that in the potential impact lakes (e.g., Thor Lake). A fourth lake, Redemption, was selected following a second reconnaissance survey. Bathymetry, fisheries and aquatics data were collected at Redemption Lake (18 km northeast of the Thor Lake camp) and analyses indicate it is potentially suitable as a far-field reference lake.

Following DFO's review of Avalon's Project Description Report in May 2010, DFO requested additional fisheries assessments to satisfy specific information requirements. In June 2010, Stantec completed detailed fish and fish habitat assessments at all potential road crossings of watercourses, a bathymetric study and fisheries assessment on the small waterbody between Ring and Buck lakes, and assessed the connectivity between Drizzle and Egg lakes. Data from these surveys are included in this report.

Table 2-1 presents the names, aquatic sampling station identification codes, locations and rationale for selection of the study sites, and number of sampling dates for aquatic samples and types of fisheries data collected at each location.

Table 2-1: Overview of Aquatic and Fisheries Baseline Studies (lake names, locations, rationale for selection, study components and number of sampling dates)

Name	Activity[1]	Aquatic Sample Station	Coordinates[2]		Rationale	Aquatic Components (Number of Sampling Events)[3]					Fisheries Components[4]			
			Easting	Northing		Wat	Sed	Phy	Zoo	Ben	BM	HA	FP	FH
Lakes														
A	A/F	FL-03	413762	6886729	Potential indirect affect by project	5	1	2	2	1	✓	✓	✓	✓
Ball	F	–	417796	6889038	Direct affect by project	–	–	–	–	–	✓	✓	✓	n/a
Blachford	A	BL-01	415403	6891246	Local conditions	5	1	2	2	1	✓	–	–	–
Buck	A/F	UN-12	417861	6889261	Direct affect by project	1	1	–	–	1	✓	✓	✓	n/a
Carrot	F	–	430686	6894730	Reference	–	–	–	–	–	✓	✓	✓	n/a
Cressy	A/F	FL-02	416471	6887742	Potential indirect affect by project	4	1	2	1	1	✓	✓	✓	n/a
Dinosaur	A	UN-09	418403	6889795	Local conditions	5	1	2	2	1	✓	–	–	–
Drizzle	A/F	UN-13	418851	6888823	Direct affect by project	1	1	–	–	1	✓	✓	✓	n/a
Egg	A	UN-11	420050	6888277	Local conditions	5	1	2	2	1	✓	–	–	–
Elbow	A/F	EL-01 EL-02	416388 415576	6885140 6883908	Potential indirect affect by project	5	1	2	2	1	✓	✓	✓	✓
Fred	A/F	FL-01	415751	6887108	Potential indirect affect by project	5	1	2	1	1	✓	✓	✓	✓
Great Slave	A/F	GL-01	413845	6882398	Direct affect by project	4	1	2	2	1	✓	✓	✓	✓
Kinnikinnick	A/F	UN-08	420757	6885658	Reference	5	1	2	2	1	✓	✓	✓	✓
Long	A/F	LL-02	417273	6885871	Direct affect by project	5	1	2	1	1	✓	✓	✓	✓
Megan	A/F	TL-05	418356	6886890	Potential indirect affect by project	5	1	2	1	1	✓	✓	✓	n/a

Name	Activity[1]	Aquatic Sample Station	Coordinates[2]		Rationale	Aquatic Components (Number of Sampling Events)[3]					Fisheries Components[4]			
			Easting	Northing		Wat	Sed	Phy	Zoo	Ben	BM	HA	FP	FH
Murky	A/F	UN-10	417893	6887973	Direct affect by project	5	1	2	2	1	✓	✓	✓	✓
North Tardiff	A/F	NT-01	417128	6886360	Potential indirect affect by project	5	1	2	2	1	✓	✓	✓	n/a
Pistol	A	UN-05	419676	6886500	Local conditions	5	1	2	2	1	✓	–	–	–
Porkchop	A	UN-07	418462	6885389	Local conditions	5	1	2	2	1	✓	–	–	–
Redemption	A/F	UN-14	429566	6899312	Reference	1	1	–	–	1	✓	✓	✓	✓
Ring	A/F	TL-04	417267	6888738	Direct affect by project	5	1	2	1	1	✓	✓	✓	n/a
South Tardiff	A/F	ST-01	417360	6886126	Potential indirect affect by project	5	1	2	2	1	✓	✓	✓	n/a
Thor	A/F	TL-06 TL-07	415842 416636	6886885 6887520	Direct affect by project	5	1	2	2	1	✓	✓	✓	✓
Thorn	A/F	TL-03	417700	6886655	Potential indirect affect by project	5	1	2	2	1	✓	✓	✓	n/a
U	F	–	411115	6889193	Reference	–	–	–	–	–	–	–	✓	✓
Wasp	A	UN-04	418521	6886407	Local conditions	5	1	2	2	1	✓	–	–	–
Watercourses														
Buck Out	F	–	418466	6889122	Direct affect by project	–	–	–	–	–	n/a	✓	n/a	n/a
Cressy Out	F	–	415870	6887352	Potential indirect affect by project	–	–	–	–	–	n/a	✓	n/a	n/a
Drizzle Out	F	–	418542	6888176	Direct affect by project	–	–	–	–	–	n/a	✓	✓	n/a
Egg Out	F	–			Potential indirect affect by project	–	–	–	–	–	n/a	✓	n/a	n/a
Elbow Out	F	–	414615	6883369	Potential indirect affect by project	–	–	–	–	–	n/a	✓	n/a	n/a

Name	Activity[1]	Aquatic Sample Station	Coordinates[2]		Rationale	Aquatic Components (Number of Sampling Events)[3]					Fisheries Components[4]			
			Easting	Northing		Wat	Sed	Phy	Zoo	Ben	BM	HA	FP	FH
Fred Out	F	–	415542	6887115	Direct affect by project	–	–	–	–	–	n/a	✓		n/a
Long Out	F	–	415851	6886222	Direct affect by project	–	–	–	–	–	n/a	✓		n/a
Megan Out	F	–	417976	6887031	Potential indirect affect by project	–	–	–	–	–	n/a	✓	n/a	n/a
Murky Out	F	–	417946	6887824	Direct affect by project	–	–	–	–	–	n/a	✓	✓	-
Ring Out	F	–	417603	6888871	Direct affect by project	–	–	–	–	–	n/a	✓	✓	n/a
S. Tardiff Out	F	–	417333	6885995	Potential indirect affect by project	–	–	–	–	–	n/a	✓	✓	n/a
Thor Out	F	–	415868	6887009	Direct affect by project	–	–	–	–	–	n/a	✓	✓	n/a
Thorn Out	F	–	417658	6886921	Potential indirect affect by project	–	–	–	–	–	n/a	✓	n/a	n/a

NOTES:

[1] Activity = Aquatics (A) and/or Fisheries (F)

[2] All UTM coordinates are in UTM Zone 12 and were collected in the WGS84 datum

[3] Aquatics Samples = Water Quality (Wat), Sediment Quality (Sed), Phytoplankton Taxonomy & Chlorophyll (Phy), Zooplankton Taxonomy (Zoo) and Benthic Invertebrate Taxonomy (Ben)

[4] Fisheries Study = Bathymetry (BM), Habitat Assessment (HA), Fish Presence (FP), Fish Health (FH); yes [✓], no [-], or not applicable [n/a] (e.g., fish health not assessed in lakes where no fish were caught)

2.3 Historical Data

Mineral exploration activities have occurred in the Thor Lake area since the 1970s. There were two previous baseline environmental programs (Saskatchewan Research Council [SRC] 1989, Golder Associates 1998). The 1988 and 1998 aquatics and fisheries baseline programs sampled a total of eight lakes associated with the project footprint proposed at that time, three of which were sampled in both programs. Historic data from the 1988 and/or 1998 baseline programs for seven of the current study lakes are referenced where applicable in the following sections.

Historical water quality and aquatic program details are summarized in Appendix B and include:

- In 1988, collection of aquatic data (water quality, chlorophyll a and zooplankton taxonomy) and fish habitat data for Thor, Elbow, Cressy, A and Ring lakes, with fish sampling conducted in Thor, Cressy, Ring and Elbow lakes; and habitat assessment of the watercourse Fred Out; bathymetric maps for Thor and Elbow lakes in 1989.
- In 1998, collection of aquatic data (water and sediment) at Thor, Elbow, Blachford and Great Slave lakes (seasonal dock site); habitat assessment at all except Blachford Lake; and fish sampling at Blachford Lake and the Great Slave Lake seasonal dock site.

The species most likely to inhabit lakes in the Thor Lake area were identified from the two previous studies in the area (SRC 1989; Golder 1998) and discussions with regulatory agencies, and include:

- Northern pike (*Esox lucius*)
- Lake whitefish (*Coregonus clupeaformis*)
- Lake cisco (*Coregonus artedii*)
- Lake trout (*Salvelinus namaycush*)
- Slimy sculpin (*Cottus cognatus*)
- Ninespine stickleback (*Pungitius pungitius*)
- Troutperch (*Percopsis omyscomaycus*)
- Burbot (*Lota lota*)
- Lake chub (*Couesius plumbeus*).

Historical data were used for guidance in development of the baseline study. However, differences in sample station locations, sampling depths, detection limits and methodology prevent useful comparison of historic and current aquatics and fisheries data. Although limited comparison of historic data may be possible to support certain general lake characteristics (e.g., sediment radionuclides, fish presence), much of the historic aquatics and fisheries data would be considered incomplete or inadequate when compared to current regulatory requirements. The historic aquatics and fisheries data are not included as part of the baseline data set.

3 WATERCOURSE SURVEY METHODOLOGY

In May 2009 or 2010, 13 watercourses shown on National Topographical System (NTS maps for the Thor Lake area (Figure 3-1 in Appendix A) were assessed (Table 3-1). Three of these were also assessed in September 2008. All 13 watercourses flow into or out of lakes included in the fisheries study. As these are unnamed watercourses, the names presented in this report indicate which lake the watercourse drains.

Table 3-1: Watercourse Survey Dates

Stream Name	May 2009	May 2010	Watercourse Name	May 2009	May 2010
Buck Out		✓	Megan Out	✓	
Cressy Out	✓		Murky Out[2]	✓	
Drizzle Out		✓	Ring Out		✓
Egg Out[1]		✓	South Tardiff Out[2]	✓	
Elbow Out	✓	✓	Thor Out[2]	✓	
Fred Out[1]	✓		Thorn Out	✓	
Long Out	✓				

NOTES
[1] Egg Out was surveyed in early June 2010
[2] Also surveyed in September 2008
Volume 1–Hydrology of this Technical Data Report series contains flow data for Long Out, Thor Out, Fred Out, and Murky Out.

3.1 Watercourse Occurrence and Connectivity

Habitat connectivity refers to whether a species can move between habitats. Lakes, the primary fish habitat type in the Thor Lake area, tend to be isolated from each other. Connectivity was assessed by walking the watercourses in late May or early June 2009 or 2010, during spring freshet, to investigate the potential for fish to use the watercourses to migrate between lakes during the time of highest annual flows. Potential barriers to fish passage, such as cascades or watercourse sections lacking a channel, were identified. If no channel was found, the land surrounding the suspected lake outlet was traversed several times perpendicular to the suspected channel alignment (based on topography) until a channel was identified or it was determined that no channel was present. Suspected lake outlets were identified using 1:50,000 scale NTS maps.

The early June 2010 watercourse survey included an assessment of fish habitat within or crossed by the proposed mine infrastructure footprint, including roads, buildings and the airstrip. Two biologists searched for previously unidentified watercourses by walking or driving the entire length of the proposed and existing roads in the project area. Fish habitat connectivity was assessed at all identified wet areas, both flowing and still.

3.2 Biophysical Characteristics

Fish habitat in each watercourse was assessed over the entire length of the visible channel, except for Fred Out, in which measurements were taken over a 150 m distance. Watercourse habitat was assessed in accordance with the British Columbia Reconnaissance (1:20,000) Fish and Fish Habitat Inventory Standards and Procedures (RIC 2001), which includes physical habitat and *in situ* water quality measurements, and characterization of riparian vegetation. Physical habitat measurements include channel width, wetted width, channel depth, residual pool depth (the depth of remaining pools at the lowest possible flow) and channel gradient. Each parameter was measured four to six times along the length of the surveyed channel. Channel characteristics, such as pattern and presence of pools, riffles and cascades, were identified qualitatively.

3.3 Fish Presence

Fish presence was assessed at each watercourse by electrofishing the entire length of the channel, except at Fred Out and Murky Out, in which at least 150 m of channel was electrofished. All habitat types were sampled. Most watercourse sites were not deep enough to accommodate minnow traps, so these were not used.

3.4 Habitat Quality

The value of the available habitat for feeding and rearing of juvenile and adult northern pike, slimy sculpin and ninespine stickleback was also assessed qualitatively.

4 WATERCOURSE SURVEY RESULTS

4.1 Watercourse Occurrence and Connectivity

Eight of the watercourses marked on the NTS map for the Thor Lake area had a continuous or intermittent channel, and five had no visible channel (Table 4-1).

Table 4-1: Drainage Route and Fish Passage Potential of the Thirteen Study Watercourses

Mapped Lake Outlet	Drains to	Watercourse Present	Fish Passage
Buck Out	Drizzle	No (Surface flow)	No
Cressy Out	Fred	No	No
Drizzle Out	Murky	Yes	Yes
Egg Out	Drizzle	No	No
Elbow Out	Great Slave	Yes (Intermittent)	No
Fred Out	A	Yes (Intermittent)	Unlikely
Long Out[1]	Thor	Yes	Yes

Mapped Lake Outlet	Drains to	Watercourse Present	Fish Passage
Megan Out	Thor	No	No
Murky Out	Thor	Yes	Yes
Ring Out	Buck	Yes (Intermittent)	No
South Tardiff Out	Long	Yes (Intermittent)	Unlikely
Thor Out	Fred	Yes	Yes, downstream only
Thorn Out	Thor	No	No

NOTES:
[1] See Volume 1–Hydrology for a discussion of flows in Long Out, which sometimes flows from Thor Lake to Long Lake.

Of the eight watercourses with continuous or intermittent channels, four (Thor Out, Long Out, Drizzle Out, and Murky Out) were passable to fish during normal seasonal peak flows (Thor Out is only passable in one direction); two (Fred Out and South Tardif Out) are not passable except during exceptional circumstances (i.e., very high flows); and two (Elbow Out and Ring Out) had visible surface flows but were not passable to fish (Table 4-1).

The four passable watercourses each had some impediment to fish passage during normal seasonal peak flows. In Thor Out, downstream fish passage is possible but fish cannot migrate upstream, from Fred Lake back to Thor Lake, due to a 1.2 m high bedrock cascade with no downstream pool. Long Out was blocked by a beaver dam at the time of the baseline study, but beaver dams are not permanent barriers to fish passage. Murky Out and Drizzle Out passed through wetland reaches with dense grasses and willows, developing multiple poorly defined channels; however, these channels would be deep enough to allow fish passage, particularly for small fish or northern pike.

Fred Out and South Tardiff Out had intermittent channels that would only become connected during extreme high flow events. The intermittent channel of Fred Out passed through a long wetland reach and did not retain a deep enough wetted channel to allow fish passage during normal peak flows. South Tardiff Out was blocked in multiple locations by gaps in the channel, up to 1 m long, where the water flowed through the ground.

Elbow Out and Ring Out also had intermittent channels, but would not become connected to downstream fish habitat during exceptional high flow events. Elbow Out flowed through a long wetland reach immediately downstream of Elbow Lake, then through a discontinuous channel, disappearing into the ground in several places, to Great Slave Lake at the proposed seasonal dock site. Ring Out flowed through a wetland, with dense grasses and no channel, for most of its length. Ring Out passed near but did not connect with Ball Lake before flowing to Buck Lake.

Buck, Cressy, Egg, Megan and Thorn lakes did not have channelized surface outlets. Buck Out and Cressy Out drained over the surface, but did not have channels, whereas Egg Out, Megan Out and Thorn Out appeared to drain primarily through the ground.

4.2 Biophysical Characteristics

Biophysical characteristics were assessed at the eight watercourses with visible channels. Channel and sediment dimensions are presented in Table 4-2. Thor Out has the widest channel (3.4 m) and South Tardiff Out has the narrowest channel (0.8 m) of the watercourses with defined channels. Wetted width measurements were equal to or greater than channel measurements for most of the watercourses due to freshet conditions during sampling (mostly in May). The low watercourse gradients (less than 2% for all watercourses except South Tardiff Out, with a gradient of 4.3%, and Elbow Out, with a gradient of 17% on the lower reaches) reflect the generally flat nature of the local topography. Sediment measurements also indicated generally low flow rates, as the largest particles that could be moved by water (D95) were all less than 20 cm, except for Thor Out (the largest watercourse measured, with a D95 of 35 cm). The average particle size (D) in the watercourses was generally small gravel (0-3 cm), with the exception of the lower reaches of Elbow Out, where the D was 30 cm.

Canopy cover was less than 20% for all the watercourses. The main riparian vegetation species were black spruce (*Picea mariana*), tamarack (*Larix laricina*), dwarf birch (*Betula nana*), Labrador tea (*Ledum sp.*) and other shrubs and grasses.

4.3 Fish Presence

All eight watercourses with defined channels were electrofished; Elbow Out was electrofished at its terminus at Great Slave Lake, but not at its origin at Elbow Lake, as there were too few areas near Elbow Lake with wetted areas large and deep enough to accommodate the electrofisher anode. A ninespine stickleback was observed in Long Out near Thor Lake and two 25 cm northern pike were captured in Murky Out near Thor Lake. A northern pike was also observed in Murky Out near Murky Lake. No other fish were observed or captured in any of the watercourses.

4.4 Habitat Quality

Quality of available habitat for fish was generally low due to shallow water depths. The best habitat was found in Long Out (3.1 m wide and 0.6 m deep) and Thor Out (3.4 m wide and 0.3 m deep), as their wider and deeper channels were better suited for fish use. Parts of Murky Out and Drizzle Out would also be useable habitat, but of poor quality. Known fish species in the area primarily use lake habitats, but northern pike, slimy sculpin and ninespine stickleback are also known to use streams (Scott and Crossman 1998).

Table 4-2: Physical Habitat Measurements and Channel Characteristics during Spring Freshet for Surveyed Watercourses

Parameter	Drizzle Out	Elbow Out	Fred Out	Long Out	Murky Out	Ring Out	South Tardiff Out	Thor Out
Channel Characteristics	Glide, irregular, decoupled, unconfined	Wetland from Elbow Lake to road, cascade pool from road to Great Slave Lake: straight, decoupled, occasionally confined	Riffle-pool, sinuous, decoupled, unconfined	Riffle-pool, irregular, decoupled, unconfined	Riffle-pool, irregular, decoupled, occasionally confined	Wetland with short glide at Ring Lake	Riffle-pool, straight, decoupled, unconfined	Riffle-pool, sinuous, decoupled, occasionally confined
Channel Width (m)	0.9	0.8	2.0	3.1	1.0	0.5	0.8	3.4
Wetted Width (m)	1.6	0.6	1.8	2.7	2.2	0.7	0.7	3.4
Channel Depth (m)	0.5	0.2	0.4	0.6	0.4	0.2	0.6	0.3
Residual Pool Depth (m)	0.6	0	0.03	0.1	0	0.2	0.3	0.02
Gradient (%)	0.5	17	0.8	0.3	0.7	0.5	4.3	1.5
D95 (cm)	0	30	16	1	15	0	7	35
D (cm)	0	7	3	0	8	0	1	3
Left Bank	sloping, organic soils	sloping, gravel soils	undercut, fine soils	sloping, fine soils	sloping, fine soils	sloping, organic soils	vertical, fine soils	sloping, fine soils
Right Bank	sloping, organic soils	sloping, gravel soils	sloping, fine soils	sloping, fine soils	sloping, fine soils	sloping, organic soils	vertical, fine soils	sloping, fine soils

5 LAKE SURVEY METHODOLOGY

The aquatics and fisheries field programs for lakes were conducted in: March and September-October 2008; March, June and September 2009; and April, May, June, September and October 2010. The physical environment, water and sediment chemistry, aquatic organisms and fisheries were assessed. Data were collected in 26 lakes; however, not all components were studied at all lakes. See Tables 5-1, 5-2, and 5-3 for sampling locations and dates for each parameter.

Physical parameters were studied at 24 lakes (Table 5-1). Depth was mapped through a bathymetric survey. Water column profiles were conducted at the deepest location in each lake on several dates. Vegetation, sediment types and habitat features were identified at 19 of the lakes.

Water chemistry was studied at 23 lakes up to four times per year (winter, spring, late summer, early fall) to capture seasonal variability. Sediment was sampled in late summer, as temporal variability is typically low. Some of the original March 2008 sample station locations were moved to deeper basins in October 2008 following collection of additional bathymetry data. Sampling locations changed in Blachford, Egg, Dinosaur, Long, Murky and Thor Lakes.

Aquatic organisms (phytoplankton and zooplankton) were collected in spring and late summer to assess temporal variability (Table 5-2). Benthic invertebrate samples were collected in late summer only, as temporal variability of the benthic community composition is typically low.

Fish species presence and health were assessed in late summer/early fall of 2008, 2009, and 2010 (Table 5-3). Each lake was sampled in two consecutive years. Temporal variability in fish presence is expected to be low, but multiple sampling dates are required to confirm fish species presence. A third fish sampling program was completed in March 2009 in Fred Lake, to examine winter survival in this suspected habitat sink (a lake into which fish migrate but cannot survive winter conditions).

The September 1988 and June 1998 programs (SRC 1989, Golder 1998) also studied some of the parameters included in the current baseline study; however, the water quality data are of limited use, given that they provide information about one date per program, separated by ten years, and were collected at different sampling locations and depths, with different detection limits from the current program. Sample collection types and dates for the 1988 and 1998 programs are also included in Tables 5-1, 5-2, and 5-3.

The following sections describe the rationale for study, sampling methodology, laboratory methodology, and data analysis for the parameters included in this baseline study.

Table 5-1: Study Dates and Locations for the Physical Environment Parameters of the Thor Lake Baseline Study

Lake	Profile Station	September 1988[a]			June 1998[b]	March 2008	October 2008		March 2009	June 2009	September 2009			April 2010	June 2010	September 2010			October 2010
		Bath[1]	Prof[1]	Hab[1]	Hab[1]	Prof[1]	Bath	Prof[1]	Prof[1]	Prof[1]	Bath[1]	Prof[1]	Hab[1]	Prof[1]	Prof[1]	Bath[1]	Prof[1]	Hab[1]	Prof[1]
A	FL-03		✓	✓		✓	✓	✓	✓	✓		✓	✓						
Ball	–															✓		✓	
Blachford	BL-01				✓	✓	✓	✓	✓	✓	✓	✓							
Buck	UN-12										✓	✓	✓	✓	✓		✓		✓
Carrot	–										✓		✓						
Cressy	FL-02		✓	✓		✓	✓		✓	✓		✓	✓						
Dinosaur	UN-09					✓		✓	✓	✓	✓	✓							
Drizzle	UN-13										✓	✓	✓	✓	✓		✓		✓
Egg	UN-11					✓		✓	✓	✓	✓	✓							
Elbow	EL-01 EL-02	✓	✓	✓	✓	✓ ✓	✓	✓ ✓	✓ ✓	✓ ✓	✓	✓ ✓	✓						
Fred	FL-01					✓	✓	✓	✓	✓		✓	✓						
Great Slave	GL-01					✓	✓	✓	✓	✓		✓	✓						
Kinnikinnick	UN-08					✓		✓	✓	✓	✓	✓	✓						
Long	LL-02					✓	✓	✓	✓	✓		✓	✓	✓	✓		✓		✓
Megan	TL-05					✓	✓	✓	✓	✓		✓	✓						
Murky	UN-10					✓		✓	✓	✓	✓	✓	✓	✓	✓		✓		✓
North Tardiff	NT-01					✓	✓	✓	✓	✓		✓	✓						
Pistol	UN-05					✓		✓	✓	✓	✓	✓							
Porkchop	UN-07					✓		✓	✓	✓	✓	✓							
Redemption	UN-14										✓	✓	✓	✓	✓		✓		✓
Ring	TL-04			✓		✓		✓	✓	✓	✓	✓	✓	✓	✓		✓		✓
South Tardiff	ST-01					✓	✓	✓	✓	✓		✓	✓						
Thor	TL-06 TL-07	✓	✓	✓	✓	✓ ✓	✓	✓ ✓	✓ ✓	✓ ✓		✓ ✓	✓	✓ ✓	✓ ✓		✓ ✓		✓ ✓
Thorn	TL-03					✓	✓	✓	✓	✓		✓	✓						
U	–						✓		✓										
Wasp	UN-04					✓		✓	✓	✓	✓	✓							

NOTE:
[a] Saskatchewan Research Council (SRC). 1989.
[b] Golder Associates Ltd. 1998. Profile data not collected in 1998 aquatic survey
[1] Bath = bathymetric survey; Prof = water chemistry profile; Hab = littoral and riparian survey.

Table 5-2: Sample Collection Dates and Locations for the Water and Sediment Chemistry and Aquatic Organism Components of the Thor Lake Baseline Study

Lake	Station	Dates Sampled and Sample Type																									
		September 1988			June 1998		March 2008	Oct. 2008	March 2009	June 2009			September 2009					April 2010	June 2010			September 2010					Oct. 2010
		Water	Chla[1]	Zoopl	Water	Sed	Water	Water	Water	Water	Phyto[2]	Zoopl	Water	Phyto	Zoopl	Sed	Benth	Water	Water	Phyto	Zoopl	Water	Phyto	Zoopl	Sed	Benth	Water
A	FL-03	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓										
Blachford	BL-01						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓										
Buck	UN-12												✓			✓	✓	✓	✓	✓	✓	✓	✓	✓			✓
Carrot																											
Cressy	FL-02	✓	✓	✓			✓		✓	✓	✓		✓	✓	✓	✓	✓										
Dinosaur	UN-09						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓										
Drizzle	UN-13												✓			✓	✓	✓	✓	✓	✓	✓	✓	✓			✓
Egg	UN-11						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓										
Elbow	EL-01 EL-02	✓	✓	✓	✓	✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓										
Fred	FL-01						✓	✓	✓	✓	✓		✓	✓	✓	✓	✓										
Great Slave	GL-01				✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓										
Kinnikinnick	UN-08						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓										
Long	LL-02						✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Megan	TL-05						✓	✓	✓	✓	✓		✓	✓	✓	✓	✓										
Murky	UN-10						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓
North Tardiff	NT-01						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓										
Pistol	UN-05						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓										
Porkchop	UN-07						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓										
Redemption	UN-14												✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Ring	TL-04	✓	✓	✓			✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓
South Tardiff	ST-01						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓										
Thor	TL-06 TL-07	✓	✓	✓	✓	✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓	✓ ✓
Thorn	TL-03						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓										
U																											
Wasp	UN-04						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓										

NOTE:
[1] Chl*a* = chlorophyll *a*; sampled as an indicator of phytoplankton biomass
[2] Phyto = phytoplankton taxonomy and chlorophyll *a*

Table 5-3: Study Dates and Locations for the Fisheries Parameters of the Thor Lake Baseline Study

Lake	September 1988		June 1998		September – October 2008		March 2009	September 2009		September 2010	
	FP[1]	FH[2]	FP[1]	FH[2]	FP[1]	FH[2]	FP[1]	FP[1]	FH[2]	FP[1]	FH[2]
A					✓	✓		✓	✓		
Ball										✓	
Blachford			✓	✓							
Buck								✓		✓	
Carrot								✓	✓		
Cressy	✓				✓			✓			
Drizzle								✓		✓	
Elbow	✓				✓	✓		✓	✓		
Fred					✓	✓	✓	✓	✓		
Great Slave					✓	✓		✓	✓		
Kinnikinnick								✓	✓		
Long					✓	✓		✓	✓		
Megan					✓			✓			
Murky								✓		✓	
North Tardiff					✓			✓			
Redemption								✓	✓	✓	✓
Ring	✓							✓		✓	
South Tardiff					✓			✓			
Thor	✓	✓			✓	✓		✓	✓		
Thorn					✓			✓			
U					✓	✓					

NOTE:
[1] FP = Fish Presence
[2] FH = Fish Health

5.1 Physical Environment

5.1.1 Bathymetry

Bathymetric surveys were conducted at 25 of the 26 study lakes (23 complete lakes plus bays on Blachford Lake and Great Slave Lake) during September to October of 2008, 2009, or 2010 (see Table 5-1). A bathymetric survey was not completed at U Lake, which was investigated as a potential reference lake but found to be unsuitable. Depths were measured using a depth sounder

(Humminbird PirahnaMAX 215) and location waypoints were recorded on a hand held GPS unit (either a Garmin GPSMap76 or GPSMap72). GPS waypoints and associated depth sounder readings were recorded as the boat was driven across the lake. The boat was driven as slowly as possible to minimize the effect of any lag time for GPS readings. Transects were spaced as evenly as possible, 20 to 150 m apart, depending on lake size (further apart in larger lakes). Waypoints were more tightly spaced (5 m or less– as close together as the GPS allowed) in areas where depth changed rapidly, such as near shorelines, islands and shallows, and further apart (up to 30 m) in areas with more uniform depth.

The waypoints, depth readings, and lake boundaries were loaded into ArcGIS 9.2, and the lake surface elevations were determined from the waypoints' elevations. Outliers (depths much lower than surrounding readings) were not included in the analysis. Using the waypoints, depth readings and lake shoreline, a Triangulated Irregular Network (TIN) was created to generate a three dimensional surface for the lake bottom. A Tin_Contour function in ArcGIS 9.2 was used to create the contours of the bathymetry data at 1 m or 0.5 m intervals, depending on total lake depth (0.5 m contours for very shallow lakes). The contour lines were smoothed and overlapping lines were corrected to create the bathymetric maps for each lake.

The 3D Analyst ArcMAP extension was used to calculate total surface area, littoral zone area (area less than 2 m deep), deep water area (greater than 8 m), and total lake volume.

5.1.2 Lake Water Quality Profiles

Lake water quality profiles were measured during all aquatics sampling events at each lake, at consistent sample stations. Station locations were recorded as Universal Transverse Mercator (UTM) points using a handheld Garmin Map76 GPS unit. *In situ* water quality data were collected using a YSI 600QS multi-meter; measured parameters were temperature, conductivity, pH, dissolved oxygen, salinity and oxidation-reduction potential. Measurements were recorded on pre-printed datasheets and documented every 0.5 m from the lake surface to the lake bottom. Measurements were taken at 0.25 m intervals in shallow lakes, typically those less than 2 m deep. *In situ* water quality data for aquatic sample stations are included in Appendix E.

5.1.3 Littoral and Riparian Area Survey

The littoral area—the shallow area where well mixed warm surface waters reach the lake bottom—is critical habitat for many fish species. Fish species in the Thor Lake area (northern pike, lake whitefish, lake cisco, slimy sculpin and ninespine stickleback) all make use of shallow habitats for spawning, and juveniles of some of these species also rear in the littoral area. Northern pike and ninespine stickleback prefer or are dependent on littoral habitat with aquatic vegetation for spawning, while other species spawn on bedrock or other habitats (Scott and Crossman 1998). The riparian area can affect the water quality and littoral habitat characteristics of a lake, and provides habitat for wildlife as well.

The habitat in the littoral and riparian areas of the fisheries study lakes was surveyed during the September 2009 field program (except Ball Lake, which was surveyed in September 2010). The survey included the collection of georeferenced data on littoral and riparian habitats, with the goal of mapping the different habitat types in each lake. The boat was driven near the shoreline of each lake and habitat characteristics recorded. A GPS waypoint was recorded at each location where there were changes in littoral or riparian habitat, and all habitat types were photographed. The littoral zone was estimated to be 2 m deep for the purposes of the field study.

The littoral survey identified:

- Dominant sediment class (bedrock, boulder, cobble, gravel, fines or organic)
- Locations of submerged, floating and emergent aquatic vegetation
- Locations of habitat features such as large woody debris or beaver dams.

The riparian survey identified the dominant habitat types, including:

- Black spruce forest (shrub and grass subtypes indicate vegetation on the immediate shoreline)
- Bedrock outcrop (often with lichen and sparse trees)
- Lowland wetland habitat (shrub and grass subtypes indicate the dominant wetland vegetation).

The littoral and riparian habitat types were mapped onto the habitat map for each lake using the geographic information, notes and photographs collected in the field (Appendix A).

5.2 Water and Sediment Chemistry

5.2.1 Water

Physical and chemical parameters determine the physiological performance of individual aquatic organisms and influence characteristics at the population and community levels in terms of distribution, diversity and density. Because freshwater systems are complex, adaptive and dynamic systems, the completion of an extensive water quality monitoring program is essential to distinguish natural variation over time and space from human-induced environmental changes.

The water quality assessment was designed to provide data on general water chemistry, nutrient, organic carbon content and metal levels. These parameters are relevant to toxicity and physical habitat requirements for plants, plankton, benthos, fish eggs and juvenile fish. Radionuclides potentially associated with the thorium present in the area were measured in water and sediment, and rare earth elements were measured in sediment.

The specific objectives of the water quality studies are to:

- Obtain baseline water quality data that can be used to assess changes related to construction, operation, closure and post-closure stages of the Project
- Identify parameters that may be present at elevated levels, and to use this information to propose site-specific water quality objectives, if needed
- Provide baseline data that can be used to support future biological monitoring programs.

5.2.1.1 Sample Collection

Water samples were collected at each sample station during field sampling events (Table 5-2). Water was collected at depth using a Van Dorn sampler or by hand at 0.5 m if water depth was not sufficient for Van Dorn use. During winter sampling events, an ice auger was used to access the underlying water. Sample collection depth varied and depended upon the temperature profile at the time of sampling. Water samples were collected at mid-depth if temperature was relatively constant throughout the water column and there was no evidence of thermal stratification (e.g., most stations in spring and fall, and all stations in winter). If the lake was thermally stratified (some lakes during summer), water samples were collected at mid-depth of the epilimnion, above the thermocline.

Samples requiring preservation were preserved as soon as possible after collection, usually immediately. Samples requiring filtration were typically dealt with as soon as possible after returning to camp for the day. However due to field constraints and/or physical characteristics of a specific sample (e.g., high total suspended solids), some samples for dissolved organic carbon and dissolved metals analysis could not be filtered following collection and were submitted to the analytical laboratory for filtration.

All samples and blanks were kept in coolers with ice packs until arrival at the laboratory. Chain of custody forms describing sampling times and required analyses were submitted to the laboratory.

5.2.1.2 Laboratory Methods

Water samples were analyzed at ALS Environmental, Vancouver, British Columbia, for routine parameters. These included major anions, alkalinity, total suspended solids (TSS), total dissolved solids (TDS), pH, conductivity, total metals, dissolved metals, Total Kjeldahl Nitrogen, ammonia, nitrate and nitrite, total phosphate, orthophosphate, and dissolved organic carbon (DOC). Detection limits were suitable for comparison with water quality guidelines.

Water samples for radionuclide determination were analyzed at the Saskatchewan Research Council (SRC) Analytical Laboratory in Saskatoon, SK. Radionuclides analyzed included radium-226 (^{226}Ra), radium-228 (^{228}Ra), lead-210 (^{210}Pb), thorium-230 (^{230}Th) and thorium-232 (^{232}Th).

5.2.1.3 Data Analysis

Summary statistics were generated for all parameters at each site over the entire baseline program. These statistics included number of samples, minimum and maximum values, median, mean, standard deviation, standard error, coefficient of variation, number of samples exceeding guidelines, and number of samples with values equal to or lower than the corresponding detection level. In addition, for each metal, the ratio (in percent) between dissolved and total concentrations was calculated as an indication of metal bioavailability.

For results below detection limits, a value of half the detection limit was used for calculation of summary statistics. Detection limits used in 1988 and 1998 were consistent with laboratory practice at that time but, for several parameters, were higher than used in the current program. In most cases, detection limits were well below Canadian Council of Ministers of Environment (CCME) Protection of Aquatic Life (PAL) guidelines and had no bearing on the water quality assessment.

Parameters with detection limits close to or exceeding CCME guidelines are summarized in Table 5-4. These include cadmium, mercury and selenium.

Table 5-4: Summary of CCME PAL Guidelines and Detection Limits for Water Quality Parameters with Detection Limits Approaching Guidelines

Parameter	CCME PAL (µg/L)	Detection Limit (µg/L)	
		2008 – 2009	Sept 2009 and 2010
Cadmium	Site-specific based on water hardness; ranges from 0.028 to 0.082	0.05	0.017
Mercury	0.026	0.05	0.01
Selenium	1.0	1.0	1.0

All general chemistry results were compared to available CCME guidelines (maximum levels) for protection of aquatic life (CCME 2007). The British Columbia Approved and Working Water Quality Guidelines (BCMOE 2006, 2008; Nagpal, et. al. 2006; Nordin and Pommen 2009) were used where CCME guidelines did not exist. These water quality guidelines (WQG) are listed in Table 5-5.

Table 5-5: Routine Parameters Analyzed and Canadian (CCME) and British Columbia (Approved and Working) Water Quality Guidelines for Protection of Aquatic Life

Parameter	Water Quality Guideline Maximum (µg/L unless stated)	
	CCME	BC
Temperature	–	1°C change from optimum for fish species
Dissolved oxygen	minimum 5.5 – 9.5	minimum 5 to 9, depends on life stage
pH, units	6.5 – 9	6.5 – 9
Total Alkalinity	–	site-specific
Turbidity	8 NTU (when background ≤8)	8 NTU (when background ≤8)
Dissolved organic carbon (DOC)	–	30-day median ±20%
Total suspended solids (TSS)	25 mg/L (when background TSS ≤250)	25 mg/L (when background TSS ≤250)
Fluoride	–	0.2 – 0.3 mg/L
Chloride	–	600 mg/L
Sulphate	–	100 mg/L
Ammonia-N	varies with temp., pH	varies with temp., pH
Nitrate-N	2.9 mg/L	31.3 mg/L
Nitrite-N	0.06 mg/L	0.06 to 0.60 mg/L (Cl^- range of <2 and >10 mg/L)
Aluminum, total	100 (when pH ≥6.5)	–
Aluminum, dissolved	–	100 (when pH ≥6.5)
Antimony, total	–	20

Parameter	Water Quality Guideline Maximum (µg/L unless stated)	
	CCME	BC
Arsenic, total	5 µg/L	5 µg/L
Barium, total	–	5000 µg/L
Beryllium, total	–	5.3 µg/L[1]
Boron, total	–	1200
Cadmium, total	0.02 to 0.13 µg/L[b]	0.02 to 0.13 µg/L[2]
Calcium, dissolved	–	Up to 4 mg/L–highly sensitive to acid inputs 4 to 8 mg/L–moderately sensitive >8 mg/L–low sensitivity
Chromium, total	8.9 µg/L (Cr III)	8.9 µg/L (Cr III)
Cobalt, total	–	110 µg/L
Copper, total	2 to 4 µg/L[2]	6.7 to 47.1 µg/L[2]
Iron, total	300 µg/L	1000 µg/L
Iron, dissolved	–	350 µg/L
Lead, total	1 to 7 µg/L[2]	34 to 601 µg/L[2]
Manganese, total	–	1100 to 5800 µg/L[2]
Mercury	0.026 µg/L	–
Molybdenum, total	73 µg/L	2000 µg/L
Nickel, total	25 to 150 µg/L[2]	25 to 150 µg/L[2]
Selenium, total	1 µg/L	2 µg/L[1]
Silver, total	0.1 µg/L	0.1 µg/L (for hardness ≤100 mg/L) 3 µg/L (for hardness >100 mg/L)
Titanium, total	–	2000 µg/L
Uranium, total	–[3]	300 µg/L
Vanadium, total	–	6 µg/L
Zinc, total	30 µg/L	33 to 371 µg/L[2]

NOTES:
[1] Chronic maximum guideline
[2] Varies with hardness; the range of metal values is presented for hardness of 50 – 480 mg/L
[3] Health Canada Canadian Drinking Water Guideline for uranium is 20 µg/L (Health Canada 2008)
Additional parameters analyzed include: conductivity (field and lab), total hardness, TDS, bromide, phosphate (total and ortho), Total Kjeldahl Nitrogen, bismuth, lithium, thallium, tin, magnesium, potassium, sodium, silicon and the dissolved fraction for all listed metals.

Radionuclides potentially associated with the thorium present in the area were measured in water. All radionuclide results were compared to maximum acceptable concentrations (MAC) available for the protection of drinking water, specified in the Health Canada Guidelines for Canadian Drinking Water Quality (GCDWQ; Health Canada 1995). No radionuclide criteria are available for the protection of aquatic life, and the GCDWQ are the most stringent. Canadian Guidelines for the Management of Naturally Occurring Radioactive Materials (NORM; Health Canada 2000) were also used for comparison of acceptable exposures for workers and the public to NORM. The radionuclide WQGs are listed in Table 5-6.

Table 5-6: Radionuclide Parameters Analyzed and Canadian Water Quality Guidelines

Parameter	Water Quality Guideline Maximum (Bq/L)	
	GCDWQ	NORM
Lead-210	0.1	1.0
Radium-226	0.6	5.0
Radium-228	0.5	5.0
Thorium-230	0.4	5.0
Thorium-232	0.1	1.0

Temporal trends for data collected in 2008 through 2010 were assessed for each station individually then assessed for differences among stations or lakes. Some comparisons were made with historic data (1988 and/or 1998) where available, although the constraints described in Section 2.3 (detection limits, variation in sampling station locations) allowed few comparisons to be made.

Summary statistics for water chemistry data were calculated with Microsoft Excel 2007, while graphical data were prepared with Sigmaplot 10 and Microsoft Excel 2007.

5.2.1.4 QA/QC

The Quality Assurance/Quality Control (QA/QC) program was designed to provide reliable monitoring data by minimizing sampling error, contamination and erroneous results, and by quantifying any bias in the results. Values that exceeded the mean ±2 standard deviations for a given parameter at a given station were considered as outliers when they were associated with a manipulation or analytical problem (e.g., blank contamination, high hold time). Fifteen outliers were identified throughout the data set and include:

- Total organic carbon (Ring replicate)
- Total copper (original Thor station; TL-01)
- Total zinc (Elbow South)
- Dissolved aluminum (Drizzle)
- Dissolved arsenic (Ring)
- Dissolved cadmium (Long, Long replicate, Ring, Drizzle)
- Dissolved copper (Porkchop and Long)
- Dissolved lead (Long)
- Dissolved manganese (Thor West and Thor East)
- Dissolved silver (Ring)
- Dissolved zinc (Drizzle).

Most of the outlier values were reported in the data appendix but highlighted and excluded from calculation of summary statistics. Several outliers were identified for one sampling event (September 2010) and were attributed to contamination arising during filtration in the field. Two other outliers (dissolved arsenic in Ring) occurred during late winter sampling and were highlighted but not excluded from summary statistics calculations as there are not enough data to definitively determine whether the values are outliers, or simply elevated winter results.

Another important component of the QA/QC program was to assure data quality regarding precision, bias, adequate sample hold times and detection limits. The examination of environmental data for potential artifacts due to contamination or reporting errors was thorough. Laboratory results and field notes were verified in relation to replicate and blank results, hold times and occurrence of unusual events. Levels of total and dissolved metals were compared to evaluate potential contamination during sample filtration in the field.

Field and Travel Blanks

Field blanks (bottles filled in the field with lab-supplied de-ionized water) and travel blanks (sealed de-ionized water supplied by the lab) were analyzed for each sampling event. The blanks were examined to determine whether there were detectable levels of any parameters. Most field and travel blank results were at or below detection limit; values just above the detection limit were not considered to reflect contamination. Blank results are presented in Appendix F1. Results suggesting contamination are highlighted in the appendix.

None of the travel blanks had parameters that exceeded detection limits by more than five times over the sample period. Two of the field blanks had parameters that exceeded detection limits by more than five times. Dissolved organic carbon (36.8 mg/L) from October 2008 exceeded detection limits by 73 times, and was indicative of contamination of the blank during field filtering. Radium-226 (0.13 Bq/L) from October 2008 exceeded detection limits by 6.5 times and could be related to contamination during sampling handling (field or laboratory), or from the lab-supplied de-ionized water. The elevated DOC and ^{226}Ra readings were not related to outliers among the sample results from October 2008.

In the September 2010 field blank, dissolved barium (3.51 µg/L), dissolved cadmium (2.04 µg/L), dissolved strontium (0.78 µg/L) and dissolved calcium (0.308 mg/L) exceeded their respective detection limits by 70, 120, 7.8 and 6.2 times, respectively. These results are indicative of contamination of the blank during field filtering and are related to several outliers identified at other sample stations in September 2010, implying likely contamination through the field filtering equipment (e.g., filters, filter apparatus, de-ionized rinse water, etc).

Replicates

Field replicates (10% of samples) were collected for each sampling event. Results for field replicates were examined to determine if precision thresholds were exceeded. Field duplicates should have a difference of no more than 25% of their mean for parameters equal to or greater than five times the detection limit. Results for duplicate samples are presented in Appendix F1. Results for which the precision thresholds were exceeded are highlighted in the appendix.

Among the approximately 824 analyses performed in duplicate, 1% (10 analyses) showed results differing by more than 25% of the mean, when the replicate values were more than five times the detection limit. These included TSS, turbidity, TOC and total aluminum at Ring Lake (March 2008), total phosphate at Cressy Lake (September 2009), dissolved manganese at Redemption Lake (September 2009), total iron at Drizzle Lake (April 2010) and dissolved manganese, chlorophyll *a* and phaeopigments at Murky Lake (September 2010).

Dissolved versus Total Concentrations

Levels of total and dissolved metals were compared to evaluate potential contamination during sample filtration. Dissolved concentrations that exceeded the total concentrations by more than 25%, when concentrations were at least five times the detection limit, were flagged as an indication of contamination. Where the metal concentration in the dissolved phase exceeded the total concentration by less than 10%, the higher values of the dissolved phase were attributed to random variations.

Dissolved metal concentrations exceeded total concentrations ten times: aluminum (five times greater than total in Drizzle Lake in September 2010); arsenic (up to 1.4 times greater than total in Dinosaur, Megan and Thor West lakes in June 2009, and up to 1.3 times greater than total in Long, Ring and Thor West in October 2010); barium (up to 1.6 times greater than total in Drizzle in September 2010); copper (1.4 times greater than total in Egg Lake in October 2008); and manganese (1.3 times greater than total in Great Slave Lake in March 2009). This low number of incidents of dissolved greater than total metals indicates that field filtration techniques were well managed.

Hold Time

All efforts were made to submit samples within applicable hold times, although with the remote location of the property and periodically limited flights, the 72 hour hold time for alkalinity, nitrate, nitrite, total phosphate and ortho-phosphate was typically exceeded by four to five days. The seven day hold time for TSS and TDS was occasionally exceeded by one to two days. Additional wait time may also have occurred at the analytical laboratory after sample receipt and prior to sample analysis.

To assess the effect of hold time exceedances on analytical results, three individual samples were collected from Thor West immediately prior to leaving the camp on March 20, 2009. Samples were shipped to ALS Laboratories and received three days later (March 23, 2009). General chemistry parameters were analyzed in each sample at pre-determined time intervals after collection to assess changes in water chemistry:

- The first sample was analyzed as soon as possible after arrival at the laboratory (one to three days), equivalent to four to six days after sample collection.
- The second sample was analyzed 12 to 14 days after sample collection.
- The third sample was analyzed 25–27 days after sample collection.

The three samples were received at the laboratory at the end of the 72 hour hold time and within the seven-day hold time for TSS and TDS. However the hold time was exceeded for the first TSS and TDS sample as analyses were conducted eight and nine days after arrival at the laboratory (corresponding to 11 and 12 days after sample collection). TSS and TDS analysis in the second and third samples also took place much later than other general chemistry parameters.

Though the 72 hour hold time was exceeded for all samples when analyzed, most general chemistry results among the three individual samples did not dramatically change as time between sampling and analysis increased (standard deviation ranged from 0 to 0.58). Increased time (exceeded hold times) appeared to affect TDS and alkalinity, as these two parameters varied the most between the three samples (standard deviation was 7.09 and 9.29, respectively). Alkalinity levels decreased with time, but there was no clear trend for TDS (levels decreased then increased); results and summary statistics for these three samples are located in Appendix F1.

5.2.2 Sediment

Sediment metal analysis is widely used as an indicator of environmental quality in baseline monitoring and environmental assessments. Lake sediments serve as a repository for metals in both the particulate and dissolved fractions, often containing higher metal concentrations than are found in water. When sediment is disturbed, metals can be resuspended into the water column. Metals that enter aquatic systems may cause acute or chronic toxicity in benthic and planktonic organisms (e.g., biochemical and physiological changes; Hook and Fisher 2001; Grosell, *et al.* 2006; Wilding and Maltby 2006; Shaw *et al.* 2006), which can lead to altered community structure and to effects on other organisms in the aquatic food web.

Metals accumulate in sediments when metal particles are washed into water and settle onto the substrate or when soluble metals become sorbed by sediment particles. The fate of these metals depends on local physical and chemical conditions in the sediment. Sediments act as either a source or a sink for metals, depending on redox potential, cation exchange capacity, particle size of sediments and organic carbon content (Salomons, *et al.* 1987).

With the exception of iron and manganese, which preferentially bind to larger particles (>300 µm), most metals tend to be associated with fine particles (clays, <63 µm) as a result of the following characteristics:

- Diverse shapes and sizes
- Tendency to aggregate and precipitate into the sediment as floc networks, which provides an open structure that binds metal ions in water
- Electrical charge, so metals are attracted and bound more easily than to coarse, non-charged particles
- Formation of aggregates of clay particles from colloidal suspension, resulting in faster settling than for particles in colloids.

Water depth, pH, hardness, nutrient concentration, temperature, dissolved oxygen and water circulation also affect the behaviour of metals (Mudroch and MacKnight 1991). Metal-sediment interactions strongly influence the toxicity of metals in freshwater systems. Although there is some debate surrounding the sources and mechanisms of metal toxicity for benthic organisms (i.e., water vs. sediment) or absorption of dissolved metals vs. ingestion of particulate metals, the bioavailability and toxicity of metals can largely be determined by metal ion activity in sediment pore water (Carbonaro, *et al.* 2005). Thus, chemical interactions that produce insoluble metal species reduce the potential for metal toxicity. For example, the natural presence of iron monosulphide (FeS) lowers dissolved concentrations of Cu^{2+}, Cd^{2+}, Ni^{2+}, Pb^{2+}, Zn^{2+}, and Ag^{+} through formation of insoluble metal sulphides (Carbonaro, *et al.* 2005). The potential for metal toxicity also depends on oxygen levels, which oxidize metal sulphides, releasing metal ions back to the sediment pore water (Carbonaro, *et al.* 2005). Binding of metal ions to organic carbon also affects metal concentrations in pore water (Ankley, *et al.* 1996).

In the present assessment, samples from each lake were analyzed for total metals, particle size, total carbon, organic and inorganic carbon, Total Kjeldahl Nitrogen, and total phosphorus in the fine fraction. Radionuclides and rare earth elements were analyzed in September 2009, along with polycyclic aromatic hydrocarbons (PAHs) in samples from four lakes (potential exposure and reference area lakes), to provide baseline data for future mine activities that could result in air emissions containing PAHs.

Metal and PAH concentrations were compared to CCME Interim Sediment Quality Guidelines (ISQG) (CCME 2002) and BC working sediment quality guidelines (SQGs) (Nagpal, *et al.* 2006), which are the same for most parameters. CCME SQGs are provided as two values: ISQG, representing concentrations below which adverse biological effects are not expected, and probable effects levels (PELs), above which adverse biological effects are usually or always observed. Both levels are derived from available literature; however, at present metal and PAH SQG are considered interim due to a lack of data. It is also noted that the ISQG are not defined for a particular sediment particle size range; since the fine fraction (< 63 µm) was analyzed for this project, this introduces a bias by preferentially analyzing the fraction likely to have the highest metal content.

5.2.2.1 Sample Collection

Sediment samples were collected during September 2009 and 2010 using a 2.4 L (152 x 152 mm) petite ponar sediment grab. Three individual sites at least 20 m apart were established in the deepest basin of each lake and sediment grabs were collected at each site. The top 3 cm of sediment from each grab was removed with a stainless steel spoon and placed in clean sample jars for analyses of general sediment chemistry and total metals. Due to field issues in 2009, only one set of sediment samples (composite of three grabs) was collected at several lakes; sediment samples were collected in triplicate from all other lakes.

In 2009, one composite sample containing well-mixed sediment from each of the three sample sites was also collected from each sample lake. A portion of the top 3 cm of sediment from each of the three sites was removed, composited in a clean, stainless steel bowl, and transferred to clean sample jars for analysis of radionuclides and rare earth elements (REE). An additional composited sediment sample was collected from four lakes for PAH analysis.

In 2010, sediment samples were collected in triplicate from four stations (Thor East, Thor West, Long and Redemption), to provide additional data for lakes in the identified project footprint and the reference lake.

After collection, samples were kept in coolers with ice packs until arrival at the laboratory. Chain of custody forms describing sampling times and required analyses were submitted to the laboratory.

5.2.2.2 Laboratory Methods

Sediment samples were analyzed at ALS Laboratories in Edmonton, AB, for general chemistry and PAHs. General chemistry parameters included total carbon, organic and inorganic carbon, Total Kjeldahl Nitrogen, total phosphorus, total metals and particle size. Detection limits were generally suitable for comparison with sediment quality guidelines.

Radionuclides and REEs were analyzed at the SRC Analytical Laboratory in Saskatoon, SK. Radionuclides analyzed included radium-226, radium-228, lead-210, thorium-230 and thorium-232. REEs analyzed include the Lanthanide series (lanthanum to lutetium, except promethium), niobium, tantalum, yttrium, zirconium and hafnium.

5.2.2.3 Data Analysis

Summary statistics were generated for all parameters at each site where samples were collected in triplicate. These statistics included mean, standard deviation, and coefficient of variation (CV). For results below detection limits, a value of half of the detection limit was used in the calculations. Detection limits used in 1998 appear to be generally comparable to current detection limits, though not all detection limits were reported in 1998. In most cases, current detection limits were well below CCME ISQG and PEL for protection of aquatic life and did not influence the interpretation of results. Table 5-7 lists parameters with detection limits approaching or exceeding ISQG or PELs; most PAH parameters had detection limits exceeding the CCME ISQG and/or PELs and detection limits varied by lake. Mercury and PAH measurements that were within the detection limits were considered to be within guidelines.

Table 5-7: Summary of CCME ISQ Guidelines and Detection Limits for Sediment Parameters with Detection Limits Approaching Guidelines

Parameter	CCME (mg/kg)		Detection Limit (mg/kg)
	ISQG	PEL	
Mercury	0.17	0.486	0.05
Silver	0.5[a]	–	1.0
Cadmium	0.6	3.5	0.5
PAHs[1]	0.00587 – 0.111	0.0889 – 2.355	0.3 – 1.0

NOTE:
[a] Silver sediment guideline from BC Working Sediment Quality Guidelines
[1] PAHs includes 17 parent PAHs; individual guideline values are described in Table 5-8

Metal and PAH data were compared to available CCME SQG for protection of aquatic life (CCME 2002) and, where there are no CCME guidelines, to the British Columbia Working Sediment Quality Guidelines (Nagpal, *et al.* 2006), as shown in Table 5-8. To Stantec's knowledge, there are no guidelines for radionuclides or REE in sediment.

Table 5-8: Parameters Analyzed and Canadian (CCME) and British Columbia Working Sediment Quality Guidelines for Protection of Aquatic Life

Parameters	Sediment Quality Guidelines (mg/kg)			
	CCME ISQG[1]	CCME PEL[1]	BC LEL[2,3]	BC SEL[2,3]
Arsenic, total	5.9	17.0	–	–
Cadmium, total	0.6	3.5	–	–
Chromium, total	37.3	90.0	–	–
Copper, total,	35.7	197.0	–	–
Lead, total	35.0	91.3	–	–
Mercury, total	0.17	0.486	–	–
Nickel, total	–	–	16	75
Selenium, total	–	–	5	–
Silver, total	–	–	0.5	–
Zinc, total	123	315	–	–
Polycyclic Aromatic Hydrocarbons				
Acenaphthene	0.00671	0.0889	–	–
Acenaphthylene	0.00587	0.128	–	–
Anthracene	0.0469	0.245	–	–
Benz(a)anthracene	0.0317	0.385	–	–
Benzo(a)pyrene	0.0319	0.782	–	–
Benzo(g,h,i)perylene	–	–	0.17	3.2
Benzo(k)fluoranthene	–	–	0.24	13.4
Chrysene	0.0571	0.862	–	–
Dibenz(a,h)anthracene	0.00622	0.135	–	–
Fluoranthene	0.111	2.355	–	–
Fluorene	0.0212	0.144	–	–
Indeno(1,2,3-c,d)pyrene	–	–	0.2	3.2
2-Methylnaphthalene	0.0202	0.201	–	–
Naphthalene	0.0346	0.391	–	–
Phenanthrene	0.0419	0.515	–	–
Pyrene	0.053	0.875	–	–

NOTE:
[1] ISQG = Interim Sediment Quality Guideline; PEL = Probable Effects Level
[2] BC LEL and SEL guideline equal to CCME ISQG and PEL guideline, respectively, unless otherwise shown
[3] LEL = Lowest Effects Level; SEL = Severe Effects Level
Additional parameters analyzed include: inorganic carbon, TOC, total carbon, $CaCO_3$ equivalent, Total Kjeldahl Nitrogen, total phosphorus, benzo(b&j)fluoranthene, and total, barium, beryllium, cobalt, molybdenum, antimony, tin, thallium, uranium and vanadium.

5.2.2.4 QA/QC

QA/QC protocols consisted of standard procedures in the field to avoid sample contamination, examination of certified reference materials (CRM) and laboratory duplicates, and assessment of the precision of field replicates.

Field Procedures

Quality assurance in the field included cleaning the equipment (stainless steel bowl, stainless steel spoons), rinsing thoroughly with ambient water between replicates and stations, and wearing nitrile gloves (clean gloves at each site). The glass sampling jars were acid-washed and supplied uncontaminated from the laboratory. Upon collection, samples were immediately placed in a clean cooler, with ice packs. Care was taken to not contaminate the inside of the jar or the cap. Samples were kept in coolers until they were sent to the laboratory for analysis.

Laboratory Procedures

Certified Reference Materials

ALS Laboratories provided results for analysis of CRM, reporting the analyses, certified values and percent of target value. The laboratory analyses generally met the criteria of less than 20% difference in the value of metals found in the CRM samples compared to the target value as determined by the National Research Council (NRC).

Analytical Duplicates

Laboratory replicates were within 20% difference when parameter levels exceeded five times the detection limits.

Field Replicates

Replicate samples provide information about heterogeneity of the sediment within a station. Field replicates were collected for composited samples (10% of samples) in 2009. Due to field difficulties in 2009, the collection of three replicate samples for general chemistry took place at some, but not all, lakes. Three replicate samples were collected at each sample station in 2010, with an additional replicate set collected at one sample station (e.g., nine additional samples). The three replicate samples were assessed for precision and variability by calculating the CV of each parameter at a site, using the formula CV = [standard deviation/mean]*100. Standard deviation and CV should be no more than 20% of the mean when the replicate values are all at least five times the detection limit. Results for which the precision thresholds were exceeded are highlighted in Appendix G1.

Of the 203 analyses completed in triplicate (29 parameters at seven stations) in 2009, 15 results (7%) had CV greater than 20% (one to five parameters per station); arsenic exceeded 20% CV at four stations, while organic carbon, Total Kjeldahl Nitrogen, total phosphorus, barium, copper and molybdenum exceeded once at separate stations. Replicates for composited samples of radionuclides and REE had only three results (7%) of 46 analyses with CV greater than 20% (lead-210, radium-228 and zirconium one time each).

In 2010, eight results (7%) of the 116 analyses completed (29 parameters at four stations) had CV greater than 20% (two to four parameters per station): chromium at three of four stations, arsenic and nickel at two stations, and barium at one station (Long Lake). Additionally, the replicate sample set (nine additional samples) collected at Long Lake had three results (arsenic, barium, and chromium) of 29 parameters (10%) which exceeded 20% CV.

These precision analyses indicate some heterogeneity of lake sediments in some lakes in the study area. Additional sampling would provide a better characterization of lake benthic habitat to improve detection of differences in sediment quality among sites or over time.

5.3 Aquatic Organisms

5.3.1 Phytoplankton

Phytoplankton are algae that grow suspended in the water column, and provide the primary source of energy in lakes (Wetzel 2001). They convert inorganic carbon, nitrogen and phosphorus into organic matter, making it available for secondary consumers such as zooplankton and benthic invertebrates. Phytoplankton are sensitive to changes in water chemistry, and have been used as indicators of water quality since the early 1900s because of known sensitivity to changes in nutrient, TSS and metal levels, which makes them useful sentinels of changes related to mine operations. They also provide valuable links between water chemistry and the fish community. Nutrient additions (eutrophication), through direct discharge of effluent or through diversion of water from one system to another, can lead to increased and excessive phytoplankton growth, which deplete oxygen as they decompose and can alter composition of the zooplankton community.

5.3.1.1 Sample Collection

Phytoplankton were collected at lake sampling stations during the ice-free season in 2009 and 2010 (June and September; see Table 5-2). The Van Dorn sampler was deployed to 1 m depth to collect phytoplankton. Collected water was divided into samples for chlorophyll *a* (chl *a*) analyses (a measure of phytoplankton biomass), and taxonomic determination.

The chl *a* sample was collected in a 1 L amber glass jar and kept in a dark cooler with ice packs until filtering at the end of the day. Samples were filtered through a 0.45 µm filter and magnesium carbonate ($MgCO_3$) was added to the last portion of filtering sample water to stabilize the phytoplankton cells and chlorophyll pigments. The filter was then folded and wrapped with aluminum foil, labeled with the location, date and time of sample collection and volume filtered, and frozen until arrival at the analytical laboratory.

Taxonomic samples were collected in 250 mL labeled plastic bottles and preserved with Lugol's solution (1/100 mL). Samples were kept in coolers until arrival at the laboratory. Chain of custody forms describing sampling times and analytical requirements were submitted with each phytoplankton sample shipment.

5.3.1.2 Laboratory Methods

Chlorophyll and Phaeopigment

Chlorophyll *a* samples were analyzed at ALS Laboratories in Vancouver, BC for chlorophyll *a* and phaeopigment (an indicator of natural degradation of chlorophyll). ALS analyzed samples using fluorometry based on procedures adapted from the USEPA Method 445. Chlorophyll *a* and phaeopigment results were reported as µg/L.

In mid 2010, following a revalidation of their methods, ALS found that the efficiency of the chlorophyll *a* and phaeopigment extraction decreased with the number of filters per extraction vessel; the maximum number of filters ALS can put into an extraction tube is two. In September 2010, Stantec submitted between two and nine filters per 1 L sample. ALS was able to easily analyze for chlorophyll *a* since it is possible to sum the results from multiple extraction tubes. This process is more difficult for phaeopigments, however, and it was decided to only analyze one extraction tube (two filters) per sample. ALS reported phaeopigment results as µg/L once results were standardized to 1 L, depending on the total volume filtered and number of filters used.

Taxonomy

Taxonomy samples were examined at Fraser Environmental Services in Surrey, BC, following procedures outlined in the Fraser Environmental Methods Manual and described in Appendix D. Samples were settled in 25 mL settling chambers for approximately 24 hours and examined in an inverted microscope. The entire chamber was scanned at increasing powers of magnification to determine the species or genera present. At least ten random fields were counted, to a total count of at least 100 for the predominant species, and data were converted to cells/mL.

5.3.1.3 Data Analysis

Chlorophyll *a* data are included in Section 6.3.1.1. Summary statistics (minimum, maximum, mean, median, standard deviation and standard error) were generated for each sample station for each year. Chlorophyll *a* data were collected from 25 sample stations, with five stations (Long, Murky, Thor East, Thor West and Ring) sampled in both 2009 and 2010.

Raw taxonomic data (cells/mL) from the 2009 and 2010 sampling events are presented in Appendix H. Data are reported by taxonomic group and for the most abundant taxa at each site. The six groups are diatoms (*Bacillariophyceae*), green algae (*Chlorophyta*), yellow-brown algae (*Chrysophyta*), cryptophyte algae (*Cryptophyta*), blue-green algae (*Cyanophyta*) and dinoflagellates (*Pyrrophyta*).

Phytoplankton diversity at each station was calculated using Simpson’s Diversity Index (Environment Canada 2002):

$$D = 1 - \sum_{i=1}^{S} (p_i)^2$$

where:

> p_i is the proportion of the total cell density (cells/mL) for each taxon *i*, and *S* is the total number of taxa.

Abundance data for many taxa were reported as a less than value, indicating the taxa were observed during the initial visual scan, but not found during the regular counting protocol. The Simpson's Diversity Index was calculated for three scenarios: treating less than values as zero, treating less than values as half the reported value, and treating less than values as their reported non-less than value (e.g., <1.4 becomes 1.4). Due to the high number of phytoplankton taxa reported, the diversity index did not vary greatly between the three scenarios. As a result, the convention followed was the same as for chemistry data (using one-half the reported less than value) for calculation of Simpson's Diversity Index. This ensured that taxa reported as less than values were not excluded from diversity calculations and did not inflate diversity calculations, making rare taxa seem more common.

Percent abundance of diatoms, green, blue-green, yellow-brown and cryptophyte algae species was estimated and abundance was summarized as predominant (>25% abundance), common (5 to 25% abundance) or present.

5.3.1.4 QA/QC

Quality control procedures involved precautions for ensuring samples were protected from contamination and deterioration (consistency of sampling, correct use of equipment, detailed field notes, use of clean bottles, adequate preservation). Bottles for taxonomy samples were labeled with indelible ink (sample station, collection date and preservative). Care was taken to ensure bottles were kept in a cool, clean environment, either cooler or refrigerator, with minimal exposure to light.

Replicate samples were collected for chlorophyll *a* and taxonomy (10% of samples); however, due to the inherent high degree of variability within biological samples, a data quality objective was not set for replicate samples. Variability between replicates was initially observed and noted. Field blanks were collected for chl *a* to assess the potential for cross-contamination from one sample filtration to the next. For blank samples, results were required to be below detection for all parameters.

Standard protocols for chlorophyll *a* samples were followed to maintain sample quality prior to analysis. Fraser Environmental Services followed internal procedures for taxonomy: microscope calibration, counting procedures, Batch Quality Control procedures for precision and accuracy in taxonomic identifications, verification with an in-house reference collection and external review.

5.3.2 Zooplankton

Zooplankton are an important lake component because of their role as secondary producers and relationship with phytoplankton and fish production (Mazumder 1994; Vadstein, *et al.* 1995). The smallest zooplankton can be characterized as recyclers of water-column nutrients and often are closely tied to measures of nutrient enrichment. Larger zooplankton are important food for forage fish and the larval stages of all fish. The zooplankton community is composed of primary consumers, which eat phytoplankton, and secondary consumers, which feed on other zooplankton. There are three main taxonomic groups: rotifers and two subclasses of the Crustacea (*Cladocera* and *Copepoda*). Protozoans, a few coelenterates, larval trematode flatworms, gastrotrichs, mites and the larval stages of some insects are also considered zooplankton, even if some of them only live in the water column occasionally or for a portion of their life cycles (Wetzel 2001).

5.3.2.1 Sample Collection

Zooplankton samples were collected at lake sampling stations in June and September 2009 and 2010 (see Table 5-2). A 12 cm diameter zooplankton net (64 µm mesh size) was used in 2009 while a 20 cm diameter zooplankton net (64 µm mesh size) was used in 2010. Where lake depth was sufficient, two 3-m vertical net tows were deployed to collect zooplankton. In shallow lakes (e.g., less than 3 m deep), two 3-m horizontal net tows were used. The zooplankton net was rinsed with filtered ambient water at each sampling station to ensure all captured organisms were collected in the sample bottle.

Zooplankton samples were collected in 500 mL labeled plastic bottles and preserved with 10% buffered formalin (25/250 mL sample). Zooplankton samples were kept in clean coolers until arrival at the analytical laboratory. Chain of custody forms describing sampling times and required analyses were submitted with the zooplankton samples.

5.3.2.2 Laboratory Methods

Samples for zooplankton taxonomy were examined at Fraser Environmental Services in Surrey, British Columbia, following procedures outlined in the Fraser Environmental Methods Manual and described in Appendix D. The volume of each sample was measured and a 50 mL subsample removed and examined in a petri dish. The entire dish was examined at increasing magnification and taxa identified. A series of 1 mL aliquots of sample were then settled in a Sedgewick-Rafter chamber for 15 minutes, and counted using a strip counting method. At least three aliquots were counted, to yield a minimum of 200 organisms. Results were averaged and counts converted to organisms per litre (i.e., per sample).

5.3.2.3 Data Analysis

Raw taxonomic data from 2009 and 2010 sampling events are presented in Appendix I as organisms per litre. Data were reported by taxonomic group and abundance of taxa at each site.

Diversity of zooplankton at each station was calculated using Simpson’s Diversity Index (Environment Canada 2002):

$$D = 1 - \sum_{i=1}^{S} (p_i)^2$$

where:

> p_i is the proportion of the total average cell density (cells/mL) for each taxon *i*, and *S* is the total number of taxa.

Percent abundance of zooplankton at each sample station was estimated and abundance was characterized as predominant (>25% abundance), common (5 to 25% abundance) or present, providing a semi-quantitative summary.

5.3.2.4 QA/QC

Quality control procedures involved precautions for ensuring samples were protected from contamination and deterioration (consistency of sampling, correct use of equipment, detailed field notes, use of clean bottles). Bottles for taxonomy samples were labeled with indelible ink (sample station, collection date, and preservative). Care was taken to ensure sample bottles were kept in a cool, clean environment, either cooler or refrigerator, with minimal exposure to light.

Replicate samples were collected for taxonomy (10% of samples), however due to the inherent high degree of variability within biological samples, a data quality objective was not set for replicate zooplankton samples. Variability between replicates was initially observed and noted.

Standard protocols for zooplankton samples were followed to maintain sample quality prior to analysis. Fraser Environmental Services followed internal procedures for taxonomy: microscope calibration, counting procedures, Batch Quality Control procedures for precision and accuracy in taxonomic identifications, verification with an in-house reference collection and external review.

5.3.3 Benthic Invertebrates

Benthos (benthic invertebrates) are commonly used for biomonitoring purposes. Their ubiquity and basically sedentary nature allow effective spatial analysis of the effects of contaminants and disturbance on a long-term basis through measurement of changes in density, community composition or ecosystem functioning. Benthic invertebrates are an important component of both flowing and standing water habitats, as they consume smaller animals and plants, aid in decomposition of organic material and are an important source of food for fish and other animals.

The main advantages of using benthic invertebrates for biomonitoring are: 1) they are ubiquitous, so can be affected by perturbations in many aquatic habitats; 2) the many species involved offer a wide range of responses to environmental stresses; 3) they are relatively sedentary, which allows for the determination of the spatial changes caused by perturbations; and 4) they have long life cycles, so effects of perturbations over time can be observed (Rosenberg and Resh 1993; Barbour, *et al.* 1999).

5.3.3.1 Sample Collection

Benthos samples were collected during September 2009 and 2010 using a 2.4 L (152 x 152 mm) petite ponar sediment grab. Three individual sites at least 20 m apart were established in the deepest basin of each lake and sediment grabs were collected at each site. Due to field difficulties in 2009, two different methods were used for collection of benthos samples: in some lakes, nine grabs were composited to make one sample while, in other lakes, the nine grabs were composited into three samples (three grabs per sample). At the four stations sampled (Thor East, Thor West, Long and Redemption) in 2010, additional grabs were taken and composited to compensate for the low densities observed for several lakes in 2009 (six grabs per sample).

Benthos grabs were composited in buckets and transported to shore where the samples were sieved through a box with 500 µm mesh. Sediment and invertebrates that did not pass through the sieve were collected in labeled 500 mL plastic jars. Benthos samples were preserved with 10% buffered formalin to a final concentration of 50% preservative. Samples were placed in clean coolers or totes until arrival at the analytical laboratory. Chain of custody forms describing sampling times and required analyses were submitted with the benthos samples.

5.3.3.2 Laboratory Methods

Benthos samples were examined by Cordillera Consulting through Fraser Environmental Services in Surrey, British Columbia, following procedures outlined in the Fraser Environmental Methods Manual and Cordillera Consulting Methods described in Appendix D. The samples were rinsed through 0.5 and 1 mm sieves to remove smaller debris and organisms. The sieved samples were sorted in a dissecting microscope to determine total numbers and identify any need for subsampling. Invertebrates were identified to the lowest practical level (genus for most insects including chironomids, family or order for other organisms, species or phylum in some cases).

5.3.3.3 Data Analysis

To facilitate data analysis and presentation, the various life stages of individual taxa were combined (i.e., adult, larval, and pupal stages). For comparison and discussion purposes, lower taxonomic levels were often combined into higher levels (usually family). Further, where three samples (of three [2009] or six [2010] grabs each) were collected from a station, data were composited into one sample set.

Density (number of individuals per unit area), an indicator of habitat availability and fish food abundance, and summary statistics including minimum, maximum, median, standard deviation and standard error for each taxon were calculated for each site. Abundance data were reported as organisms/m^2, with appropriate conversions of the data. Percent composition of dominant/indicator taxa (abundance of dominant/indicator taxa relative to the total number of organisms) was also calculated for each site. Dominant/indicator taxon groups were defined as those groups representing greater than 5% of total organism abundance, characterized as predominant (>25% abundance), common (5 to 25% abundance) or present, providing a semi-quantitative summary.

Community diversity, *D*, of benthic invertebrates at each site was calculated using Simpson's Diversity Index (Environment Canada 2002). This index is a measure of community structure defined by the relationship between the number of distinct taxa and their relative abundances:

$$D = 1 - \sum_{i=1}^{S} (p_i)^2$$

where:

p_i is the proportion of the i^{th} taxon at the station and S is the total number of taxa at the station.

Simpson's Evenness Index, E, was calculated as:

$$E = D/(1 - S^{-1})$$

The evenness index takes into account relative abundance and number of taxa at each site to provide an indication of community structure. The index ranges from 0 to 1. A higher value generally indicates a community with relatively uniform distribution of taxa (more homogenous) while a low value generally reflects a community with a greater distribution of taxon abundance (more heterogeneous).

5.3.3.4 QA/QC

In 2009 and 2010, field and analytical QA/QC measures were based on the British Columbia Freshwater Biological Sampling Manual (MWLAP 2003) and internal QA/QC procedures of Fraser Environmental Services and Cordillera Consulting. The procedures ensured that all personnel were adequately trained, sampling methods were consistent, samples were correctly collected, labeled and preserved, and equipment was properly cleaned. Detailed field notes were kept, chain of custody forms were used, and safe shipping and storage methods were used.

Analytical QA/QC was based on the internal QA/QC procedures of Fraser Environmental Services and Cordillera Consulting. Sorting efficiency was assessed, with 90% efficiency considered acceptable. Samples were split when the number of individuals per sample was high. Splitting efficiency was calculated. A minimum of 300 organisms was counted.

5.4 Fish Studies

5.4.1 Species Presence

5.4.1.1 Fish Sampling

Fish species presence was investigated in 12 lakes in September-October 2008, 18 lakes in September 2009 (second year of sampling in 11 of the lakes), and six lakes in September 2010 (second year of sampling in five of the lakes) (see Table 5-3). Multiple sampling methods were used to target as many of the different species that potentially inhabit the lakes as possible. Gill netting and minnow trapping were used in 2008. These methods as well as beach seining and dip netting were used in 2009. Gill netting, beach seining and dip netting were used in 2010. The fishing effort at each lake is summarized in Table 5-9.

Fred Lake was suspected to be a 'sink' habitat, in which many fish die over the winter, because of its shallow depth and low winter oxygen concentrations. Therefore, Fred Lake was also sampled in March 2009, using gill nets and minnow traps, to investigate winter fish presence.

Two years of fishing effort are recommended by DFO for baseline investigations of fish presence. All of the lakes within and downstream of the project footprint were sampled twice except for Ball Lake, which was only sampled in 2010. The proposed reference lake, Redemption Lake, was also sampled in two years (2009 and 2010).

Gill Nets

Gang gill nets were employed to target as many of the fish species present in each lake as possible. One or two gang gill nets with six panels of varying mesh sizes were set overnight in each lake to ensure that they were in place during the dawn and dusk periods, which are the most active times of day for many fish species.

The nets were manufactured according to the British Columbia Fish Collection Methods and Standards (RIC 1997) specifications. Each of the six panels in the gang net was 15.2 m long and 2.4 m deep, resulting in a combined total net length of 91.2 m. The mesh size of the panels varied in the following order (from one end to the other): 25, 76, 51, 89, 38 and 64 mm. Although these mesh sizes will most effectively sample fish with fork lengths ranging from 114 to 380 mm, larger fish can also be captured.

Two gang gill nets, one floating and one sinking, were set in each large lake, and one gang gill net (either floating or sinking) was set in each small lake. Floating nets were generally set perpendicular to shore, with one end near the shore, to capture fish traveling through the littoral area or parallel to the shoreline. Sinking nets were generally set parallel to shore, between the littoral area and deeper waters, to capture fish traveling between shallow and deep waters (RIC 1997). In the smaller shallow lakes, the nets often spanned the entire water column; therefore a single gang net, either floating or sinking, was placed perpendicular to shore in these lakes.

Table 5-9: Fishing Effort During the 2008, 2009 and 2010 Fisheries Field Programs Using Overnight Gill Net Sets (GN), Overnight Minnow Trap Sets (MT), Beach Seines (BS) and Dip Netting (DN)

Lake	Sept – Oct 2008		Mar 2009		Sept 2009				Sept 2010		
	GN[1]	MT	GN	MT	GN	MT	BS	DN[2]	GN	BS	DN
A	S	5	–	–	F, N	8	1	65	–	–	–
Ball	–	–	–	–	–	–	–	–	F, N	–	–
Buck	–	–	–	–	F, N	8	–	–	F	1	32
Carrot	–	–	–	–	S, F, N	8	2	10, 60	–	–	–
Cressy	S, F	8	–	–	S, N	8	1	–	–	–	–
Drizzle	–	–	–	–	F, N	8	–	–	F, N	1	32
Elbow	S, F	10	–	–	S, F, N	8	1	–	–	–	–
Fred	S	8	S[3]	7	F, N	8	1	–	–	–	–
Great Slave	S, F	8	–	–	S, F, N	8	1	–	–	–	–
Kinnikinnick	–	–	–	–	S, F, N	8	1	30	–	–	–
Long	S(2), F(2)	11	–	–	S, F, N	8	2	150, 150	–	–	–
Megan	F	6	–	–	F, N	8	–	30	–	–	–
Murky	–	–	–	–	F, N	8	–	45, 20	F	1	37
North Tardiff	–	6	–	–	N	8	–	80	–	–	–
Redemption	–	–	–	–	S, F, N	8	1	–	S, F, N	2	–
Ring	–	–	–	–	F, N	8	–	–	F, N	1	43
South Tardiff	F	8	–	–	F	8	–	35	–	–	–
Thor	S, F	12	–	–	S, F, N	8	3	–	–	2	–
Thorn	S	6	–	–	F, N	8	–	20	–	–	–
U	S, F	8	–	–	–	–	–	–	–	–	–

NOTES
[1] Gill net types: sinking (S), floating (F), and fine (N).
[2] Dip net effort is recorded as metres of shoreline dip netted; if more than one area was dip netted then the lengths are separated by commas
[3] Fred Lake March 2009 gill net sets: 25 mm and 76 mm mesh panels, 30 m total net length.

A single panel gill net (15 m long by ~2.5 m deep with 25 mm mesh) was set in addition to the gang gill net(s) in each lake in 2009 and 2010 to target small bodied fish. The net was set in shallow littoral habitat, near aquatic vegetation or other features that would provide cover for small fish.

Fred Lake was also sampled using gill nets in March 2009. Two panels of a gang gill net (one large mesh [76 mm] panel and one small mesh [25 mm] panel), were set under the ice for two 8-hour periods. An ice auger was used to drill holes in the ice, and an ice jigger was used to set the nets under the ice (see Murphy and Willis 1996). The nets spanned the water column under the ice. One set was perpendicular to shore, the other parallel. The nets had to be set in the middle of the lake rather than near the shore because the space between the ice and the lake bottom was too small near the shore to use the ice jigger.

Minnow Traps

Between 5 and 12 minnow traps (usually 8) baited with cat food, fish muscle tissue or no bait were set overnight in littoral areas of each lake. The traps were usually set in pairs, in a variety of representative habitat types in each lake. Depending on habitat availability, trapping locations included areas with boulders, emergent or submerged aquatic vegetation, large woody debris, bare cobbles, or bedrock areas.

Minnow traps were set overnight to ensure that the dawn and dusk periods were sampled. Minnow trapping is a non-lethal fishing method, so there was no concern that long set times could be detrimental to fish populations.

Beach Seine

One or two beach seine passes were conducted in each lake that contained suitable habitat. The beach seine net was about 20 m long and 1.5 m deep, with 5 mm mesh. Lakes with organic sediments in the littoral area could not be seined effectively, as the seine filled with muck and was very difficult to pull to shore. Any fish caught in these sets would have been very difficult to locate. Some lakes were not beach seined due to logistical difficulties in the field, such as soft treacherous footing along the shoreline or long (>200 m) portages when the lakes were accessed overland.

Habitats with bedrock, small cobble and fine sediments were seined on foot or by boat, depending on the slope and strength of the substrate. If field staff could walk through the water without sinking into the substrate then the beach seine was deployed by walking, otherwise the net was set by boat.

The net was dragged perpendicularly away from shore until it was about two thirds deployed, then parallel to shore until fully deployed, then straight toward shore. Both ends of the net were then pulled together and out of the lake until any fish within the seined area were caught in the net mesh.

Dip Net

In several lakes, littoral habitats providing cover were dip netted using two handheld nets. Each net had a 1 m long handle, 0.5 m opening, and approximately 25 mm mesh. Field staff moved the net quickly through cover habitat, such as areas with aquatic vegetation, by walking along the lake edge, or by driving the boat through the littoral area. Each dip-netted area was visually scanned before sampling to search for fish; if a fish was seen then the fish was targeted with the dip net. If no fish were seen, the net was used to sweep the habitat to capture any fish present. One or two patches of suitable habitat were sampled in each lake; patches of emergent vegetation were sampled most frequently.

5.4.1.2 Catch Rate Calculations

The catch per unit effort (CPUE) for the gang gill net sampling was calculated for each species in each lake. The CPUE was calculated as the number of fish caught per hour that the net was set. Each sampling date was considered separately; data from both nets were combined when more than one net was set. The CPUE data cannot be used to estimate absolute fish density but can be used qualitatively to describe relative fish density in the different years. They can also be used in the future for comparison before and after mine development.

5.4.1.3 Species Identification

Captured fish were removed from the fishing gear carefully to minimize injury, and placed in a large container of water. All fish were identified to species in the field. Any unfamiliar species were brought to the laboratory for identification using Scott and Crossman (1998). Voucher specimens were collected for species with uncertain identification, if possible; otherwise, photographs of the fish were taken for later confirmation of identification using McPhail and Lindsey (1970) and Scott and Crossman (1998).

QA/QC

All staff were trained in use of sampling equipment, and equipment was deployed consistent with the British Columbia Fish Collection Methods and Standards (RIC 1997). Data forms were filled out as equipment was deployed, checked each evening, and checked again during data entry. Any fish that could not be readily identified to species in the field was photographed and/or collected as a voucher specimen for identification using Scott and Crossman (1998) or McPhail and Lindsey (1970).

5.4.2 Fish Habitat

Each lake was classified as fish-bearing or non-fish-bearing based on the results of the physical habitat (including watercourse investigations), water quality, and fish presence assessments discussed above. Lakes were identified as non-fish-bearing if three criteria were met:

- No fish were captured in two years of study
- The lake is isolated from known fish-bearing habitat (no surface flow, or surface flow was impassable to fish)
- The winter water quality data indicated that the dissolved oxygen (DO) concentration is below the acute minimum value for the protection of aquatic life (5 mg/L; CCME 1999).

The DO, which is required by aquatic organisms for survival, varies in concentration throughout the year. The primary sources of DO are the atmosphere and photosynthesis of aquatic plants and algae. Oxygen is consumed by respiring aquatic organisms and oxidative decomposition of organic material. The sources of DO in northern lakes are cut off by ice in the winter, but respiration and decomposition continue, resulting in decreasing concentrations as the winter progresses. The DO levels can become so low that aquatic organisms die or lead to developmental deformities in developing fish eggs.

The CCME guideline for the minimum concentration of DO to prevent acute effects on aquatic life is 5 mg/L. The guideline for the minimum level sustained for seven days is 6.5 mg/L. Fish are known to survive below these levels, but levels below these guidelines can lead to mortality.

Sensitivity to low DO levels varies among species. Northern pike are very tolerant and have been found alive at 0.04 mg/L (Casselman 1978). However, a threshold of 5 mg/L for lethal and sub-lethal effects is representative for a broad range of species.

The plankton community was also considered in the determination of fish-bearing status as there is generally an inverse relationship between maximum zooplankton body size and the degree of fish predation (Vanni 1988). If the plankton community was indicative of a fishless lake (i.e., if large zooplankton species were present, particularly the predators *Chaoborus* and *Heterocope*), it was considered supporting evidence for identifying the lake as non-fish-bearing.

If no fish were captured but other parameters did not definitively exclude fish presence then the lake was suspected to be non-fish-bearing.

5.4.3 Fish Biometrics and Health

5.4.3.1 Field Methodology

Fish Processing

Length and weight were measured in the field while fish were as fresh as possible, to avoid changes that can occur due to rigor mortis. Fish that were alive and in good condition were measured and released alive. Fish that were alive but injured, such that they were unlikely to survive if released, were euthanized. Fork length of all captured fish was measured in the field using a measuring board with millimeter markings. Wet weight of each fish was measured; in 2008 fish were weighed with a spring scale with 10 g precision (Accu-weigh tubular spring scale, 2 kg, 20 g) due to difficulties with the electronic scale; in 2009 and 2010 fish were weighed with an electronic scale with 0.1 g precision (Ohaus Scout Pro SP4001). Each fish was examined for external parasites. See Section 5.4.2.2 for further discussion of fish parasites.

QA/QC: Fish Processing

Field staff were trained in measurement methods. Weigh scales were protected from the wind as much as possible; if the wind made measurements inaccurate, and then the fish were weighed in the lab. Data were recorded on forms in the field, checked during data entry, and checked again during statistical analysis of length-weight relationships.

Tissue Sampling and Fish Dissection

Subsets of the large-bodied species (northern pike, lake whitefish and lake cisco) captured in each lake were brought back to the camp laboratory for dissection and collection of aging structures and tissue. Up to 12 fish of each species were sampled from each lake; if more than 12 fish were caught then they were selected to sample as wide a range of lengths as possible.

The camp laboratory was located in one of the core processing tents in 2008 and 2009 and in a modified trailer in 2010. The fish processing laboratory was set up anew each day, and all tools were stored in a closed container between uses to minimize contamination. Benches were covered in plastic and fish were kept in plastic trays during dissection. Plastic trays were wiped with clean paper towel and de-ionized water regularly to prevent contamination between fish. All tools used to collect tissues were washed with de-ionized water between fish, and new scalpel blades were used for each species. Staff wore nitrile gloves when handling fish and samples, and changed gloves between species. Care was taken not to pierce organs with any tools.

Age structures were removed from each dissected fish. In 2008, scales were removed from lake whitefish and northern pike. In 2009 and 2010 otoliths were removed from lake whitefish and lake cisco, and cleithra were removed from northern pike. All age structures were cleaned and stored in paper coin envelopes until they were sent to the ageing lab. Scales and otoliths were sent to Hamaguchi Fish Aging Services for aging in 2008 and 2009. Otoliths collected in 2010 and cleithra collected in 2009 and 2010 were sent to North/South Consultants Inc.

A block of muscle tissue, without skin or bones, was removed from each northern pike and lake whitefish. The block was removed from the left dorsal surface (above the lateral line), from the posterior margin of the dorsal fin to the posterior end of the fish. In small fish, the block was removed from the anterior margin of the dorsal fin to the posterior end of the fish. The samples were weighed to 0.01 g (Ohaus Pro Scale PS202). At least 10 g of tissue is required for laboratory analysis; if the tissue block was too small then a second block of tissue was collected from the same location on the right side of the fish. Care was taken not to cut into the tissue blocks. The muscle blocks were frozen promptly and sent to ALS Laboratory Group for mercury analysis. See Section 5.4.3.4 for further discussion of tissue metals analyses.

The body cavity of each fish was opened and the internal organs examined for visible parasites. See Section 5.4.3.3 for further discussion of fish parasites.

The gender of each fish was determined by examining the gonads. If the fish was too small for its gender to be reliably identified, it was considered immature. In 2009 the gonads were removed whole and weighed to 0.01 g. A gonad sample of approximately 1 g was removed from each female, weighed, and stored in 10% formalin. These samples were used to assess maturity of the eggs.

The liver was removed, without the gall bladder or bile duct, and weighed to 0.01 g. The livers were frozen promptly and sent to a laboratory for metals analysis. In 2008 samples were sent to SRC and in 2009 and 2010 samples were sent to ALS. In all years, composites of the liver samples were prepared and analyzed by SRC for the rare earth elements lanthanum (La), gadolinium (Gd) and yttrium (Y). See Section 5.4.3.4 for further discussion of tissue metals analyses.

QA/QC: Tissue Sampling and Fish Dissection

The field QA/QC procedures involved precautions to ensure that samples were protected from contamination and deterioration. Sampling equipment was regularly rinsed with de-ionized water, scalpel blades and gloves were changed between species or more frequently, the dissection area was protected with plastic, and care was taken to ensure that samples were not punctured. Samples were frozen as quickly as possible following dissection, and maintained frozen until delivery to the laboratory. Sample containers were labeled with indelible ink at the time of sample collection, and a second label (pencil on waterproof paper) was added as soon as possible. Replicate samples were collected from three fish (replicate samples could only be collected from large bodied fish). Laboratory QA/QC methods are discussed in Section 5.4.3.4.

5.4.3.2 Length-Weight, Age and Condition Parameters

Length and Weight Measurements

The length-weight relationship indicates whether the fish grow isometrically (maintain the same shape as they grow) or allometrically (change shape as they grow), and is used in the calculation of fish condition. Length-weight relationships are best described using a power function:

$$W = aL^b$$

where:

W is wet weight, *L* is fork length, and *a* and *b* are model parameters. Growth is isometric when *b* equals 3, and is allometric for other values of *b*.

Length-weight relationships are calculated based on log transformed data, which results in a linear rather than a power relationship.

$$log_{10}W = log_{10}a + b(log_{10}L)$$

Length-weight relationships were examined for each of the three large bodied species (northern pike, lake whitefish, and lake cisco) using R version 2.11.1. For each species, all of the data were combined and analyzed using linear regression of log transformed weight versus log transformed length, with lake as an additional factor (analysis of covariance). If there were no significant lake effects, the lake factor was removed from the model. Model diagnostic plots (e.g., model residuals vs. fitted values, standardized residuals vs. theoretical quantiles, Cook’s distance) were used to identify outlying data points. Outliers were retained in the analyses unless it was clear that the point was an error (e.g., weight more than 50% too high or too low for a fish of the measured length). Very few points were found to be errors (four lake whitefish and two lake cisco).

A second linear model tested to determine whether the length-weight relationships in Thor Lake and Redemption Lake differed significantly. The model was run on the subset of data from these two lakes. If Thor and Redemption differed significantly (p-value <0.05) then model coefficients (intercepts and slopes) were calculated for each lake individually.

Condition-Relative Weight

Relative weight describes the condition, or "plumpness", of the fish. It can be used to compare fish of different lengths and different populations when growth is allometric (i.e., when *b* in the length-weight relationship above is not equal to three). The relative weight is calculated using a species-specific standard-weight equation prepared for that species using data from a minimum of 50 populations.

The relative weight is calculated using the formula:

$$W_r = (W/W_s) \text{ x } 100$$

where:

> W_r is the relative weight, W is the weight of the individual fish, W_s is the standard weight calculated for that fish based on its length using the standard weight equation, and 100 is a constant.

Standard weight equations are available for northern pike, lake whitefish and lake cisco, based on total length, not fork length. Measured fork lengths of fish in this study were converted to total lengths using published formulae. Standard weight and conversion equations are presented in Table 5-10.

Table 5-10: Fork Length to Total Length Conversions and Standard Weight Equations for Northern Pike, Lake Whitefish and Lake Cisco

Species	Fork Length to Total Length Conversion[1]	Standard Weight[2]
Northern pike	$TL = 0.442 + 1.048(FL)$	$log_{10}W_s = -5.437 + 3.096(log_{10}TL)$
Lake whitefish	$TL = 6.885 + 1.095(FL)$	$log_{10}W_s = -5.560 + 3.218(log_{10}TL)$
Lake cisco	$TL = 1.102(FL)$	$log_{10}W_s = -5.517 + 3.224(log_{10}TL)$

NOTES

[1] Fork length to total length conversions from: Casselman (1996) for northern pike; Fisher and Fielder (1998) for lake whitefish; and Carlander (1969) for lake cisco

[2] Standard weight equations from: D.W. Willis, South Dakota State University (unpublished) for northern pike; Rennie and Verdon (2008) for lake whitefish; Fisher and Fielder (1998) for lake cisco.

Age

Scales and otoliths were aged by Hamaguchi Fish Aging Services in 2008 and 2009. Scales were aged by viewing through a microscope and counting the light and dark rings, which indicate periods of faster (summer) and slower (winter) growth. Clean otoliths were aged by cutting them in half, as close to the oldest part of the otolith as possible. The cut surface was then burned slowly in an alcohol flame until it became an orange colour. The cut surface was brushed with canola oil and examined under a microscope. The light and dark rings were counted, as in scales. Photographs of the cut surfaces were taken when the whole surface could be brought into focus. A photograph of an aged otolith is presented in Appendix D.

Northern pike cleithra were aged by North/South Consultants Inc. Cleithra do not require preparation prior to aging, except for cleaning. Cleithra were read a minimum of two times and, if results were inconsistent, a third reading was taken. All readings were conducted 'blind' (i.e., independent from each other). Quality control checks were made by independent technicians on 10% of the samples, also on a “blind” basis. In 2010 otoliths were also aged by North/South Consultants, using a clearing medium (oil of wintergreen). A laboratory methodology document is presented in Appendix D.

Organosomatic Indices

The average gonadosomatic index (GSI) and hepatosomatic index (HSI) were calculated for northern pike, lake whitefish and lake cisco collected in 2009 in each lake. The GSI is the ratio of ovary weight to body weight, and is an indication of stage of ovary development. The GSI indicates whether different populations are at approximately the same maturity stage. The HSI is the ratio of liver weight to body weight; it may decrease in starved fish, or increase in fish exposed to toxins.

5.4.3.3 External and Internal Parasite Assessment

Visible external parasites and other signs of injury or poor health were recorded for each captured fish as it was measured and weighed. The body surface, lips and jaws, mouth, eyes and gills of each fish were examined. The type of parasite was also recorded if the field staff could readily identify it.

During dissection, visible internal parasites and cysts were recorded. The body cavity, liver surface and surface of the gastro-intestinal tract were examined. While other tissues and the gut were not specifically examined, the presence of obvious parasites on such tissues was noted.

Field staff were not specifically trained in fish parasitology and did not use magnifying devices to search for parasites; these data are an indication of the presence of large, visible parasites only. Photographs were taken of the more common types of parasites, but specimens were not collected for identification.

5.4.3.4 Tissue Metals Analysis

Muscle and liver tissue samples from large bodied species (northern pike and lake whitefish) were analyzed for total mercury and a metals scan. If northern pike or lake whitefish were not present, then another large bodied species was sampled, if possible. In 2009 lake cisco were also sampled in lakes that were expected at that time to be directly affected by mining activities (A and Great Slave), and in two candidate reference lakes (Redemption and Carrot), as lake cisco is a candidate species for long term monitoring. Subsequently, lake cisco tissue samples from Carrot Lake were not analyzed, as Carrot Lake was found to be unsuitable as a control lake. Arctic grayling from the Great Slave seasonal dock site were analyzed for metals in 2008 because only three northern pike were caught at that site.

Mercury

Muscle samples from northern pike and lake whitefish were sent to ALS Laboratory to be analyzed for total mercury content using cold vapour atomic spectrophotometry. The detection limit for mercury was 0.001 mg/kg wet weight, which is suitable for comparison with the BC guideline for unrestricted human consumption of fish of 0.01 mg/kg wet weight (BCMOE 2006). The BC guidelines suggest human consumption of fish tissue should be limited to a maximum weekly amount of 1050 g when total mercury concentration in fish tissue reaches 0.1 mg/kg wet weight; recommended quantities for safe weekly consumption decrease as mercury concentrations increase.

Data were analyzed using mercury levels that were normalized to 80% wet weight. The relationship between mercury level and fish weight was analyzed using linear regression with lake as an additional factor (ANCOVA). The mercury-weight relationship was examined because mercury is known to bioaccumulate (increasing mercury content with increasing size of fish), and it is not relevant to discuss of compare average mercury levels.

Metals Scan

Livers from northern pike, lake whitefish and lake cisco were sent to SRC in 2008 and ALS in 2009 and 2010. Samples were analyzed for metal concentrations using inductively coupled plasma mass spectrometry (ICP-MS). The two labs analyze slightly different metals and have slightly different detection limits (Table 5-11). Detection limits also varied somewhat for each metal due to factors such as sample size. However, all detection limits are below the available guidelines for tissue metals concentrations (Table 5-12). Guidelines for tissue metals concentrations are only available for methyl and total mercury (discussed above), lead and selenium (BCMOE 2006), and arsenic and cadmium (US EPA 2000).

Table 5-11: Metals Included in the Metals Scans at SRC and ALS Laboratories, and the Detection Limits (mg/kg wet weight) at Each Facility

Metal	SRC Detection Limit (mg/kg wet wt)	ALS Detection Limit (mg/kg wet wt)	Range of detection limits (mg/kg wet wt)
Aluminum (Al)	0.02	2	0.02 – 10
Antimony (Sb)	0.05	0.01	0.01 – 0.05
Arsenic (As)	0.02	0.01	0.01 – 0.5
Barium (Ba)	0.02	0.01	0.01 – 0.05
Beryllium (Be)	0.005	0.1	0.005 – 0.5
Bismuth (Bi)	–	0.03	0.03 – 0.15
Boron (B)	0.5	–	0.5
Cadmium (Cd)	0.005	0.005	0.005 – 0.025
Calcium (Ca)	–	2.0	2 – 10
Chromium (Cr)	0.2	0.1	0.1 – 0.5
Cobalt (Co)	0.005	0.02	0.005 – 0.1
Copper (Cu)	0.02	0.01	0.01 – 0.05
Iron (Fe)	0.05	–	0.05 – 2.6
Lead (Pb)	0.005	0.02	0.005 – 0.2
Lithium (Li)	–	0.1	0.1 – 0.5
Magnesium (Mg)	–	1.0	1 – 5
Manganese (Mn)	0.05	0.01	0.01 – 0.05
Molybdenum (Mo)	0.05	0.01	0.01 – 0.05
Nickel (Ni)	0.02	0.1	0.02 – 0.5

Metal	SRC Detection Limit (mg/kg wet wt)	ALS Detection Limit (mg/kg wet wt)	Range of detection limits (mg/kg wet wt)
Phosphorus (P)	–	5	5 – 65
Potassium (K)	–	20	20 – 260
Selenium (Se)	0.02	0.2	0.02 – 1
Silver (Ag)	0.005	–	0.005 – 0.01
Sodium (Na)	–	20	20 – 260
Strontium (Sr)	0.05	0.01	0.01 – 0.05
Thallium (Tl)	0.02	0.01	0.01 – 0.05
Tin (Sn)	0.02	0.05	0.02 – 0.6
Titanium (Ti)	0.02	–	0.02 – 1.3
Uranium (U)	0.002	0.002	0.002 – 0.01
Vanadium (V)	0.05	0.1	0.05 – 0.5
Zinc (Zn)	0.2	0.1	0.1 – 0.5

Table 5-12: Guidelines for Tissue Metals Levels

Metal	Criterion	Guideline Maximum (mg/kg)
Lead (Pb)[1]	Human consumption	0.8
Selenium (Se)[1]	Aquatic life	1.0
Arsenic (As)[2]	Unrestricted human consumption	0.088
Cadmium (Cd)[2]	Unrestricted human consumption	0.088

NOTES:
[1] BCMOE (2006)
[2] US EPA (2000)

Metal levels below detection limits were recorded as half the detection limit. Metals were examined further if their levels were above detection limits in at least one sample. The metals data were visually examined using bar charts for each metal for each species. High values, differences between lakes, and levels relative to guidelines were identified.

Rare Earth Elements

The concentrations of three rare earth elements–lanthanum, gadolinium and yttrium–were analyzed in composite liver samples for each species in each lake. Very little information is available on the potential toxic effects of any rare earth elements, although available literature suggests low to moderate acute toxicity (e.g., Tu, *et al.* 1994). Rare earth elements are the target minerals of the Thor Lake Project and were, therefore, selected for analysis.

Composite liver samples were analyzed by SRC using ICP-MS for La, Gd and Y at a detection limit of 0.01 mg/kg wet weight. In 2008 the rare earth elements cerium, dysprosium, erbium, europium, holmium, neodymium, promethium, samarium, terbium, and ytterbium were also included in the scan, at a detection limit of 0.01 mg/kg wet weight. No guidelines exist for tissue concentrations of any rare earth elements.

QA/QC

Three field duplicates were collected from large fish in 2009; the data quality objective for duplicate samples was no more than 30% of the mean for parameters at least ten times the detection limit. Duplicate sample results are presented in Appendix L.

Laboratory QA/QC included the analysis of certified reference materials, method blanks, and replicates. Raw data on laboratory QA/QC are included in Appendix L.

6 LAKE SURVEY RESULTS OVERVIEW

The following section outlines the findings of the aquatics and fisheries baseline programs. An overview of the results is presented first, followed by details on key findings at individual lakes, organized into lake groupings. Study lakes were grouped geographically based on known or anticipated drainages, as shown in Table 6-1.

Table 6-1: Groupings of Lakes by Known or Presumed Drainage System

Drainage System	Lakes	Aquatic Station Name
Thor	Thor West and Thor East	Thor West (TL-06) and Thor East (TL-07), plus original stations (TL-01 and TL-02)
	Long	LL-02, plus original station (LL-01)
Cressy	Cressy	FL-02
	Fred	FL-01
	A	FL-03
Ring	Ring	TL-04
	Ball	no station
	Buck	UN-12
	Drizzle	UN-13
	Murky	UN-10
	Egg	UN-11
Reference[1]	Kinnikinnick	UN-08
	Redemption	UN-14
	U	no station
	Carrot	no station
Tardiff	North Tardiff	NT-01
	South Tardiff	ST-01
Tributary[2]	Thorn	TL-03
	Megan	TL-05
	Wasp	UN-04
	Pistol	UN-05
	Porkchop	UN-07

Drainage System	Lakes	Aquatic Station Name
Blachford[3]	Blachford (bay) Dinosaur	BL-01 UN-09
Elbow	Elbow North Elbow South	EL-01 EL-02
Great Slave	Great Slave (seasonal dock site)	GL-01

NOTES:
[1] These lakes are not in the same drainage but are grouped because of their distance from the Project and potential suitability as reference lakes
[2] The Tributary lakes drain into Thor Lake (Thorn and Megan) or Long Lake (Wasp, Pistol, and Porkchop)
[3] Dinosaur appears to drain indirectly into Blachford through a series of lakes

The 2008-2010 water quality dataset is presented in Appendix F3 while summary statistics are presented in Appendix F2. Data for sediment, phytoplankton, zooplankton, benthic invertebrates and fish are included in Appendices G, H, I, J, K and L, respectively.

6.1 Physical Environment

6.1.1 Bathymetry

Bathymetric maps were prepared for 25 lakes (see Figures 6-1 through 6-26 in Appendix A). Morphometric measurements were made for 23 lakes (Table 6-2), but not for Great Slave Lake or Blachford Lake, as these sites are open bays with no defined edge. At the Great Slave Lake site, the deepest location surveyed was 24 m. The west side of the bay is steeper than the east side. The bay slopes steadily from its northern point, where a small watercourse flows into the lake, toward the southwest at a 12% grade. At the Blachford Lake site the deepest location surveyed was 5.3 m.

Table 6-2: Estimates of Morphometric Characteristics of Study Lakes

Lake	Surface Area (m^2)	Littoral Area (m^2)	Deep Area[1] (m^2)	Maximum Depth (m)	Total Volume (m^3)
A	133,000	25,500	71,100	18	1,100,000
Ball	23,800	23,800	0	1.9	25,900
Buck	123,000	123,000	0	2.0	137,000
Carrot	736,000	165,000	357,000	36	8,290,000
Cressy	64,400	25,700	0	7.5	212,000
Dinosaur	158,000	137,000	0	5.1	215,000
Drizzle	456,000	440,000	0	2.5	623,000
Egg	454,000	288,000	14,800	10	1,020,000
Elbow	1,103,000	293,000	300,000	17	5,090,000
Fred	49,500	49,500	0	1.9	39,900

Lake	Surface Area (m^2)	Littoral Area (m^2)	Deep Area[1] (m^2)	Maximum Depth (m)	Total Volume (m^3)
Kinnikinnick	396,000	84,300	100,000	19	2,250,000
Long	304,000	60,800	75,600	16	1,750,000
Megan	96,900	56,300	0	6.6	241,000
Murky	193,000	193,000	0	2.3	225,000
North Tardiff	14,000	14,000	0	1.7	14,300
Pistol	171,000	171,000	0	1.8	129,000
Porkchop	177,000	40,500	50,400	17	1,110,000
Redemption	559,000	7,020	116,000	15	2,800,000
Ring	167,000	167,000	0	1.8	164,000
South Tardiff	37,000	37,000	0	1.9	39,300
Thor	1,450,000	437,000	99,400	16	5,050,000
Thorn	59,200	20,000	0	5.9	185,000
Wasp	64,400	25,700	0	2.5	212,000

NOTES:
[1] Area of lake greater than 8 m deep

The deepest lake surveyed was Carrot (36 m). Seven of the lakes were 2 m deep or less, and nine were more than 8 m deep. Total depth ranged from 1.7 m (North Tardiff) to 36 m (Carrot), surface area from 14,000 m^2 (North Tardiff) to 1,450,000 m^2 (Thor), and volume from 14,300 m^3 (North Tardiff) to 5,050,000 m^3 (Thor).

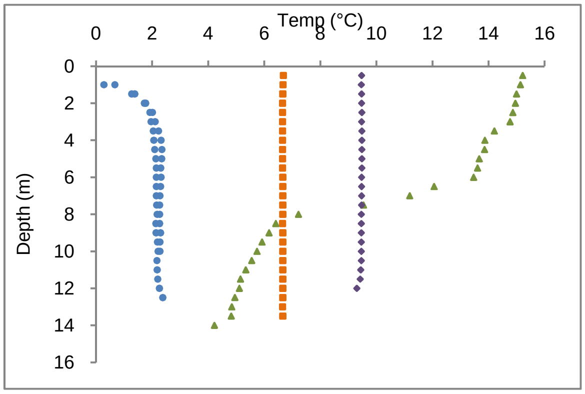
6.1.2 Lake Water Quality Profiles

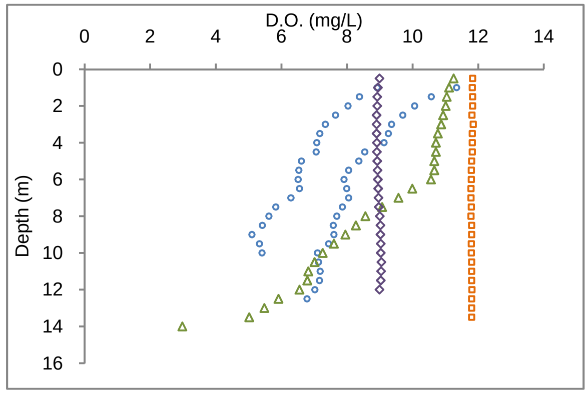
Water quality profiles indicate a mean water temperature across the study area of 9.7°C in the open water season (June to October) and 2.2°C during winter (late March/early April). Mean pH generally was lower in winter (7.50) than during the open water season (8.07). Dissolved oxygen levels fluctuated seasonally and the shallow lakes generally had anoxic conditions in the winter (<5% DO). Winter ice thickness was similar through 2008 to 2010, ranging from 0.54 to 1 m (mean of 0.69 m) in 2008, from 0.56 to 1.14 m (mean of 0.70 m) in 2009, and from 0.63 to 0.84 m (mean of 0.70 m) in 2010. Water quality profile data for each sample station are included in Appendix E and are organized chronologically by season.

Thermal stratification occurred in all lakes greater than 3 m deep across the study area in both summer and winter. Figure 6-26 shows temperature and DO profiles of select lakes that stratified, typically those greater than 3 m deep.

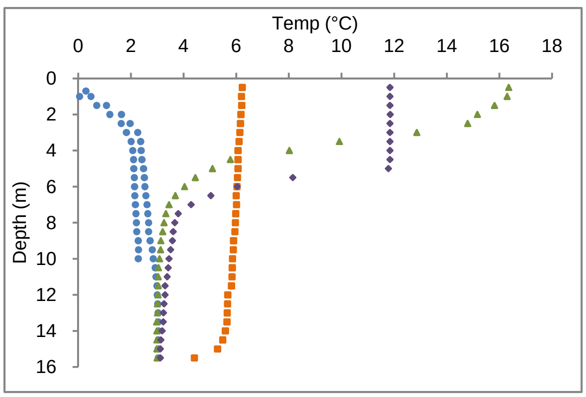
Figure 6-26: Temperature (left) and Dissolved Oxygen (right) Profiles of Select Lakes
(Blue circles=winter; green triangles=spring; purple diamonds=late summer/early fall; orange squares=fall)

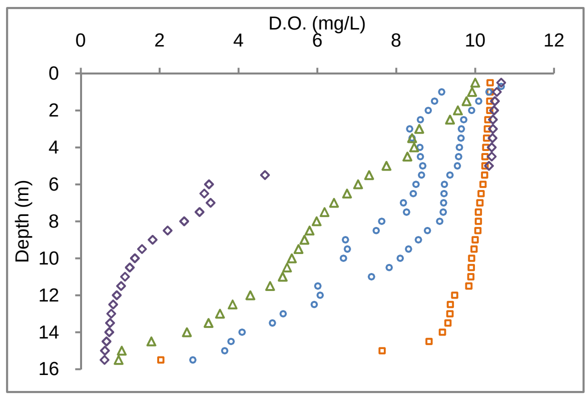
Elbow Lake North



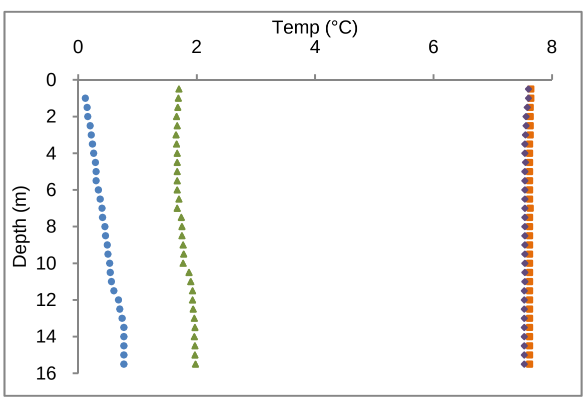


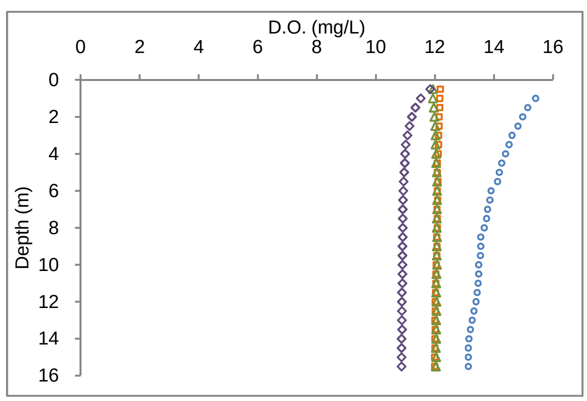
A Lake



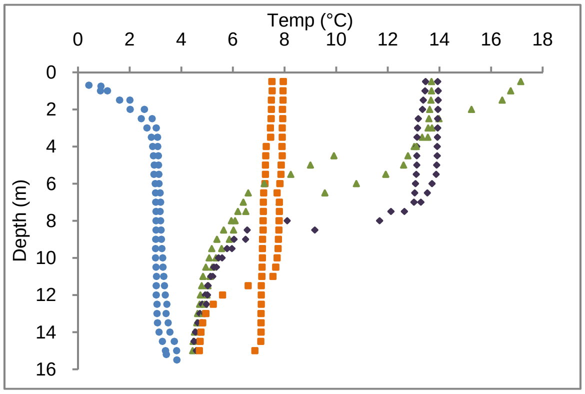


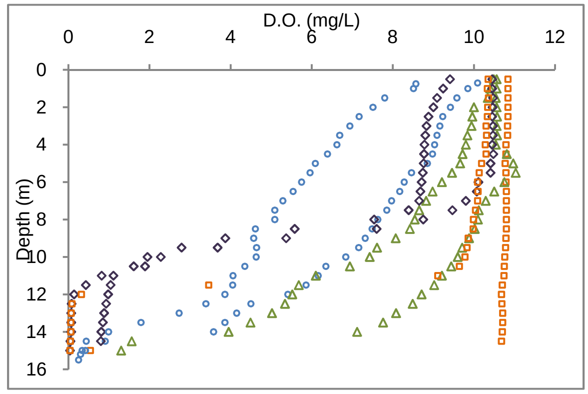
Great Slave Lake



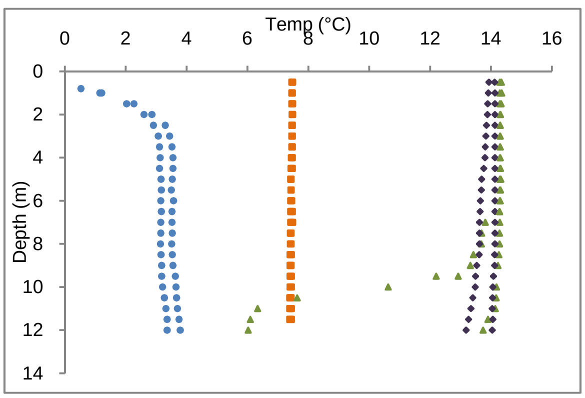


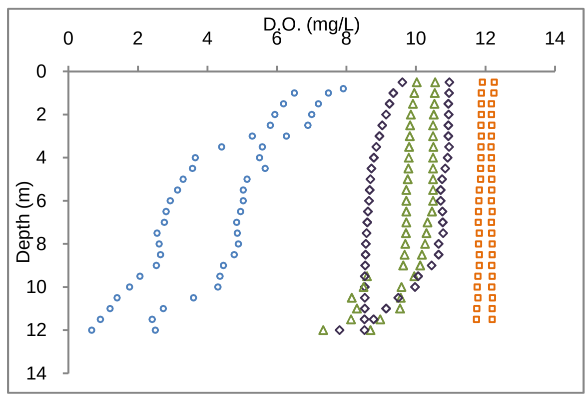
Long Lake



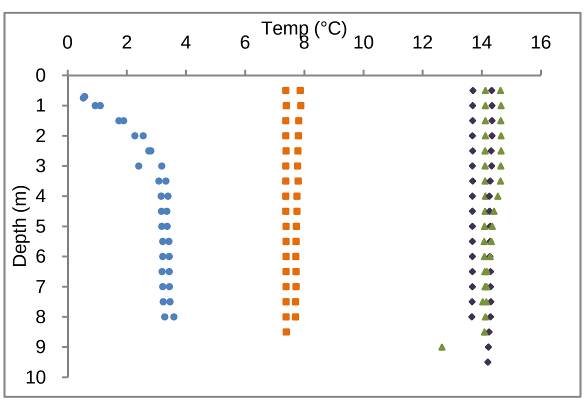


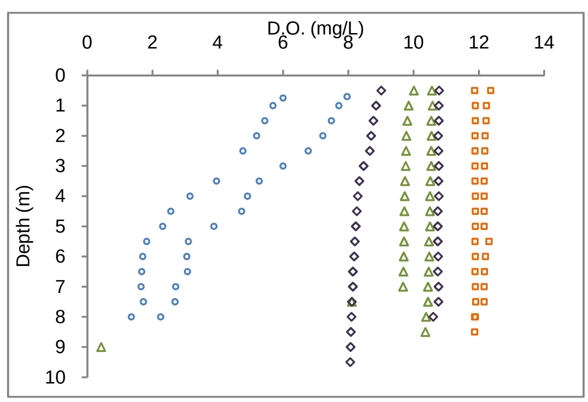
Thor Lake West



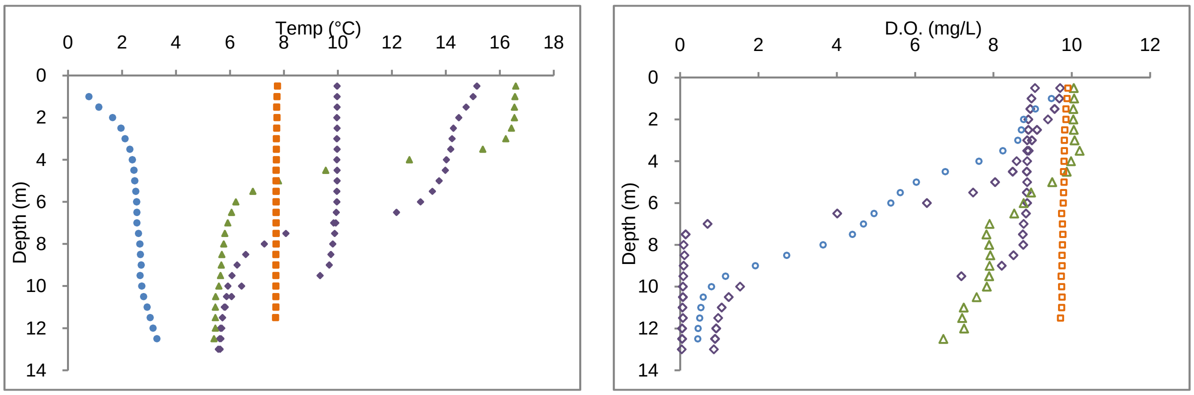


Thor Lake East





Redemption



In winter, deeper lakes were inversely stratified under ice (minimum temperature at the surface, increasing to 4 °C by 3 m depth, then uniform to the bottom). The lakes were again stratified between June and late September or early October, depending on lake depth. The Great Slave station and Thor Lake provided exceptions to the trend for summer stratification, with relatively uniform temperature through the water column. The proposed seasonal dock site in Great Slave Lake is located in a shallow bay, compared to the main part of the lake, and a lack of stratification during summer might be expected. Thor Lake has a maximum depth of 16 m but is generally shallow (the area greater than 8 m accounts for only 7% of the total surface area, Table 6-2), and the lack of stratification during summer may be a result of the overall shallow depth and morphometry, and exposure to wind (orientation to prevailing wind, lack of protective bedrock bluffs).

The DO profiles typically followed a similar pattern to temperature in spring through fall. In spring and summer, DO levels and temperature generally decreased with depth, with some stratification present. In late summer/early fall, DO levels were relatively uniform with depth as thermal stratification broke down. However in winter, DO decreased relatively linearly under ice, while water temperatures increased or remained constant.

6.1.3 Littoral Area

Substrate in the littoral areas varied from bedrock to organic muck (Table 6-3). All rocky substrates were coated in algae and a film of organic matter. A layer of algae was often visible on shallow fine and organic sediments.

Several species of submerged and emergent vascular plants were present. The plants are discussed here based on whether their stems and leaves were submerged, floating, or emergent (Table 6-3). Floating and emergent species were most abundant in the littoral areas. Floating plants included one or more pondweed species (*Potamogeton,* possibly *P. natans*) and a lily species (*Nuphar,* possibly *N. variegatum*). Emergent plants included grasses, sedges and rushes, and a horsetail (*Equisetum fluviatile*). Submerged species were not identified. Volume 5–Vegetation of the Thor Lake Rare Earth

Metals Baseline Project Interim Report presents results of the 2009 vegetation studies, which included some shoreline vegetation.

Table 6-3: Littoral Substrates and Aquatic Vegetation Present in Fisheries Study Lakes

Lake	Littoral Substrate	Littoral Aquatic Vegetation
A	Cobbles, some boulder/bedrock patches	Patches of emergent plants Small area of floating plants
Ball	Organic muck, some boulders and a patch of bedrock	None
Buck	Organic muck	Abundant floating plants
Carrot	Bays: fines and organic muck Most of lake: steep bedrock, boulders	Floating plants present in bays only
Cressy	Bays: organic muck Most of lake: steep bedrock and cobbles	Floating plants along south shoreline and east and west bays
Drizzle	Organic muck with some large boulders	Low density of emergent and floating plants over most of lake
Elbow	South bay and west arm: organic muck Most of lake: gravel and cobble	Emergent plants common throughout
Fred	Organic muck	Floating plants common throughout
Great Slave	Boulders and cobbles	None
Kinnikinnick	Boulders, cobbles, steep bedrock	Emergent plants in shallow bays only
Long	Cobbles, boulders, steep bedrock	Emergent plants common throughout Floating plants abundant at west end
Megan	Cobbles, small bedrock patches	Emergent and floating plants present, not abundant
Murky	Organic muck	Floating plants abundant
North Tardiff	Organic muck	Floating plants very abundant
Redemption	Bedrock, boulders	Floating and submerged plants in bays only
Ring	Organic muck with some boulders Small bedrock areas	Floating and emergent plants abundant throughout
South Tardiff	Organic muck	Floating plants abundant
Thor	Cobbles, gravels, boulders, bedrock, fines,	Emergent plants present throughout Floating and submerged plants in sheltered areas
Thorn	Boulders and cobbles	Emergent plants present throughout Floating plants present in small patches

Large woody debris and large boulders, which provide habitat structure and cover for small fish, were often absent or not abundant.

Littoral substrates, aquatic vegetation and habitat features (beaver lodges and woody debris) of the lakes included in the fisheries study were recorded in the field using a GPS and were mapped onto the bathymetric maps (Appendix A).

6.1.4 Riparian Area

The riparian area in over 80% of the lakes was dominated or co-dominated by black spruce (*Picea mariana*) (Table 6-4). Species associated with black spruce included paper birch (*Betula* sp), tamarack (*Larix laricina*), dwarf birch (*Betula* sp) and Labrador tea (*Ledum* sp.). Where black spruce forests grew to the lake boundaries, either grasses or shrubs (e.g., willow, *Salix* sp.), grew along the shoreline. This vegetation group is a potential source of large woody debris to the lakes.

Table 6-4: Riparian Plant Groups Dominant (D), Present (✓) and Absent (-) at Study Lakes

Lake	Black Spruce Forest	Wetland	Bedrock Bluff
A	D	✓	✓
Ball	D	D	✓
Buck	✓	D	✓
Carrot	D	–	D
Cressy	D	✓	D
Drizzle	D	✓	✓
Elbow	D	✓	✓
Fred	D	✓	✓
Great Slave	D	–	✓
Kinnikinnick	D	–	D
Long	D	–	D
Megan	D	–	✓
Murky	D	✓	✓
North Tardiff	✓	D	–
Redemption	D	–	✓
Ring	D	✓	✓
South Tardiff	✓	D	–
Thor	D	–	✓
Thorn	D	–	✓

Two other types of ecosystems (wetland and bedrock bluff) were present or predominant at several lakes. Wetlands were present at over 50% of the lakes and dominated the riparian area at Buck, North Tardiff and South Tardiff lakes. They occurred either as mats of floating vegetation or as grass and willow vegetation along the lakeshore. At least one small area of bedrock bluff was present at almost every lake, and bedrock bluffs formed a substantial amount (about 50%) of the riparian area at Carrot, Cressy, Kinnikinnick and Long lakes.

The types of riparian communities present at the fisheries study lakes are listed in Table 6-4. The locations of different types of riparian groups were recorded in the field using a GPS and mapped onto the bathymetric maps (Appendix A).

6.2 Water and Sediment Chemistry

6.2.1 Water Chemistry

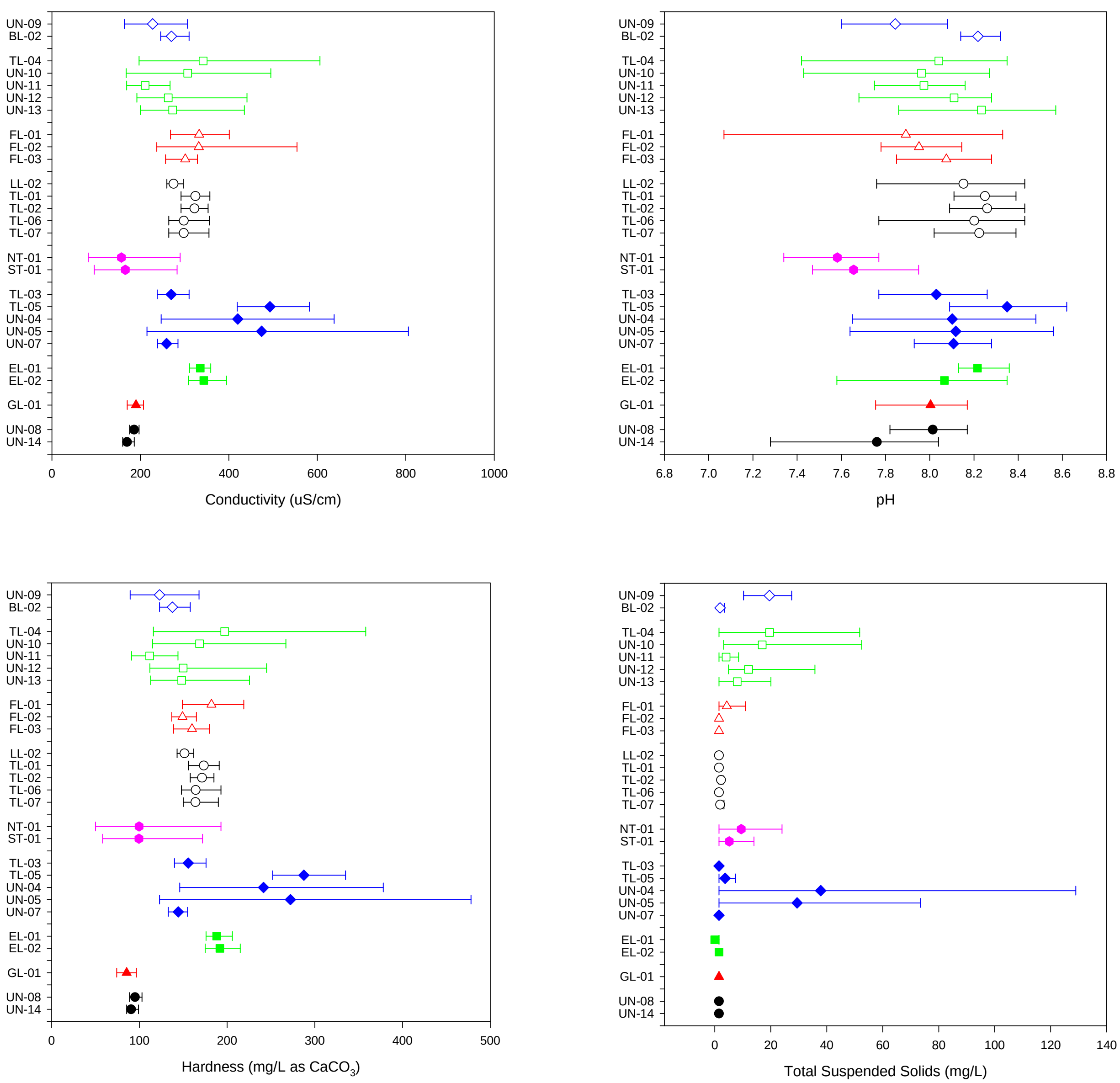
Neutral to basic conditions were documented at all sample stations from 2008 to 2010, with mean pH ranging from 7.58 to 8.35. Mean conductivity ranged from 157 to 493 µS/cm and hardness ranged from 86 to 288 mg/L. Mean nitrate, ammonia and total phosphate values were low or below detection at many samples stations, though levels were higher and more variable in Fred, Cressy, North Tardiff, South Tardiff, Megan, Wasp and Pistol lakes (shown in Figure 6-27).

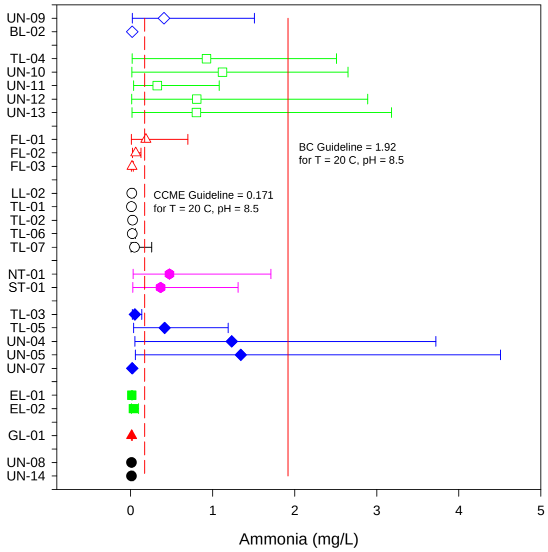
Within a sampling station, there were large fluctuations seasonally in many general chemistry and metal parameters, as indicated by minimum and maximum values (Figure 6-27). The winter samples from shallow lakes (less than 3 m deep, including Dinosaur, Wasp, Ring, Buck, Drizzle, Murky, Fred, Pistol, North Tardiff and South Tardiff) typically had highly reducing, anoxic conditions under ice, with decreased pH and increased solubility of many metals and other compounds. Larger and/or deeper lakes (e.g., A, Long, Thor, Elbow, Kinnikinnick, Porkchop, Thorn, Redemption and Great Slave) sometimes showed small increases in some metals, conductivity, hardness and total phosphate in winter, though the range of variation was inconsistent and much less than in the shallow lakes.

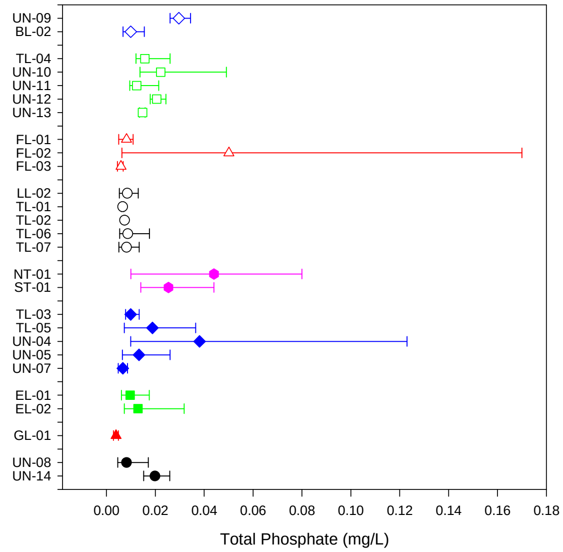
Winter water quality had a large effect on summary statistics for the shallow lakes, as the high values inflated the mean. This is depicted in Figure 6-28 where mean values, with and without winter data, have been plotted for specific parameters. Mean values for larger, deeper lakes are less affected by omission of winter data, showing less seasonal variation in general chemistry. Megan Lake is one exception to this, though it would not be considered a shallow lake (maximum depth of about 6.6 m), and tends to have greater mean values for conductivity, pH, hardness, ammonia and total arsenic, with and without winter data, compared to other non-shallow lakes.

Conductivity, hardness, ammonia, total phosphate and total aluminum, arsenic, iron, manganese, molybdenum, strontium, and uranium values were generally greatest during winter in shallow lakes; the CCME guideline for total iron was exceeded in winter by 3.4 to 61 times. Winter anoxia and increased metal solubility likely caused the large increases in total and dissolved iron and other metals in samples from shallow lakes. Increased TSS levels in these winter samples may also contribute to the large increases in total metals observed and likely reflects difficulties encountered when sampling shallow lakes under ice (e.g., by suspension of bottom sediments).

Figure 6-27: Minimum, Average and Maximum Levels of Several Water Quality Parameters from 2008 to 2010
(Blue open diamonds=Blachford Group; green open squares=Ring Group; red open triangles=Cressy Group; black open circles=Thor Group; pink circles=Tardiff Group; blue diamonds=Tributary Group; green squares=Elbow; red triangle=Great Slave; black circles=Reference Group; Red vertical lines=CCME and/or BC Guidelines)




UN-09
BL-02
TL-04
UN-10
UN-11
UN-12
UN-13
FL-01
FL-02
FL-03
LL-02
TL-01
TL-02
TL-06
TL-07
NT-01
ST-01
TL-03
TL-05
UN-04
UN-05
UN-07
EL-01
EL-02
GL-01
UN-08
UN-14
BC Guideline = 1.92
for T = 20 C, pH = 8.5
CCME Guideline = 0.171
for T = 20 C, pH = 8.5
0
1
2
3
4
5
Ammonia (mg/L)


UN-09
BL-02
TL-04
UN-10
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UN-13
FL-01
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FL-03
LL-02
TL-01
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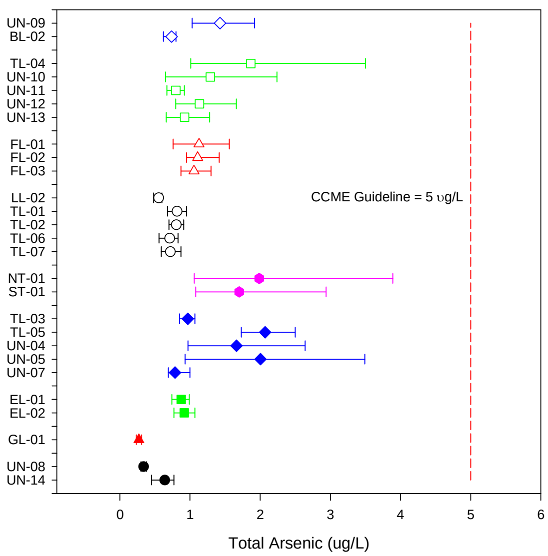
TL-07
NT-01
ST-01
TL-03
TL-05
UN-04
UN-05
UN-07
EL-01
EL-02
GL-01
UN-08
UN-14
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
Total Phosphate (mg/L)


UN-09
BL-02
TL-04
UN-10
UN-11
UN-12
UN-13
FL-01
FL-02
FL-03
LL-02
TL-01
TL-02
TL-06
TL-07
NT-01
ST-01
TL-03
TL-05
UN-04
UN-05
UN-07
EL-01
EL-02
GL-01
UN-08
UN-14
CCME Guideline = 5 υg/L
0
1
2
3
4
5
6
Total Arsenic (ug/L)

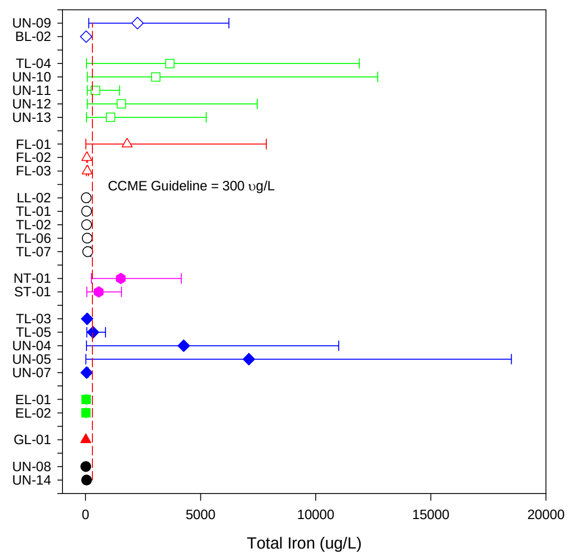
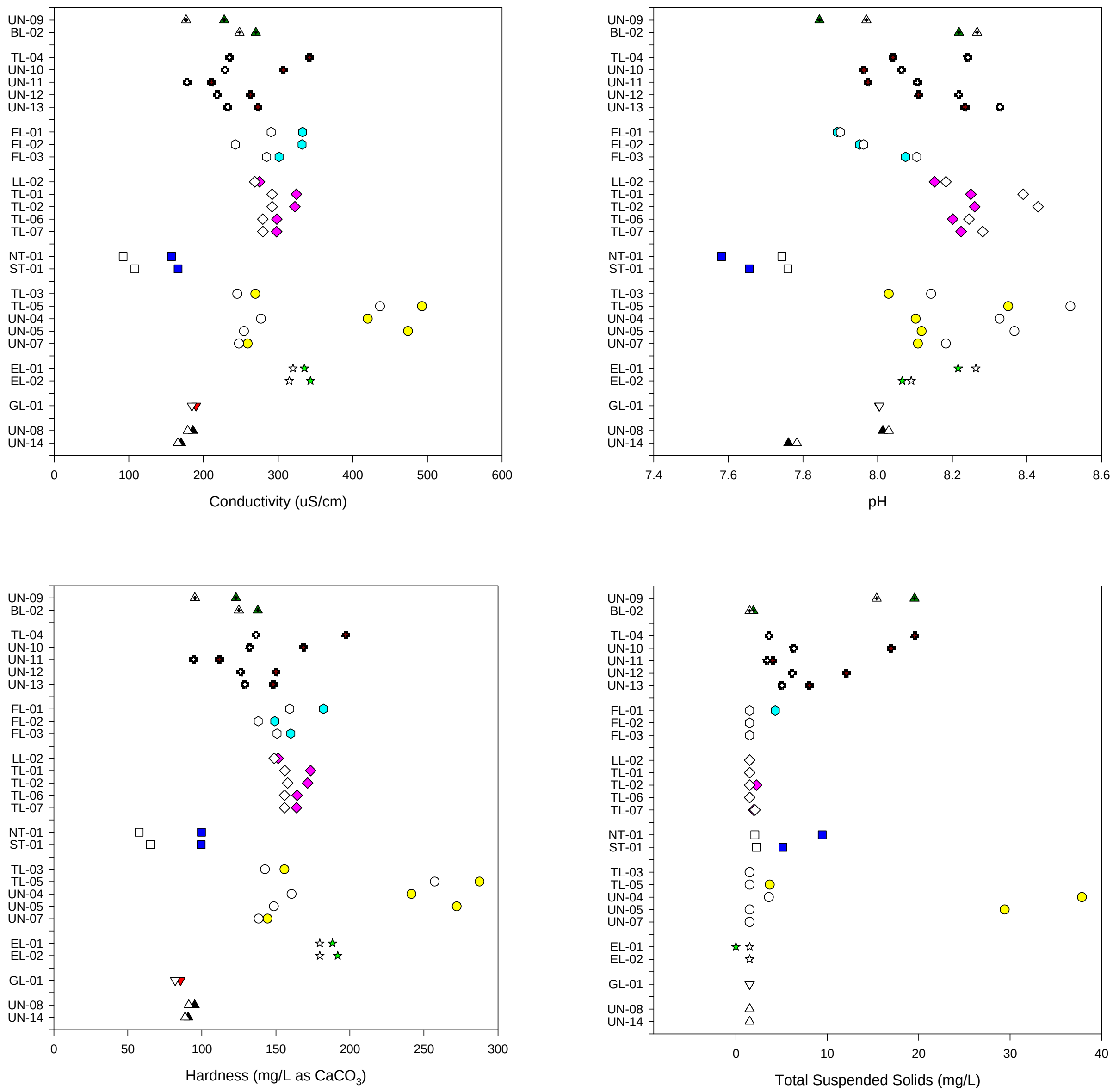
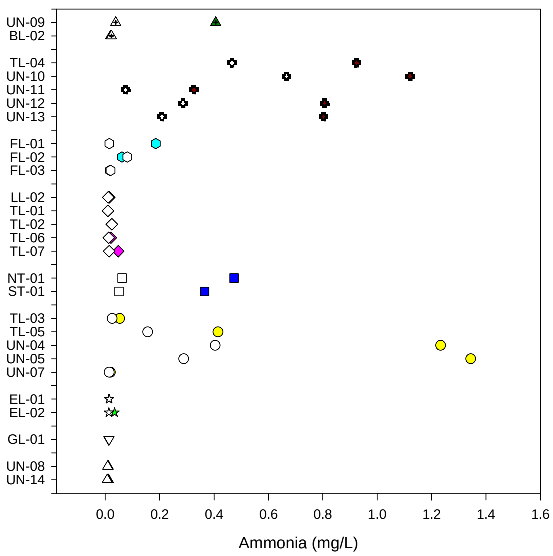
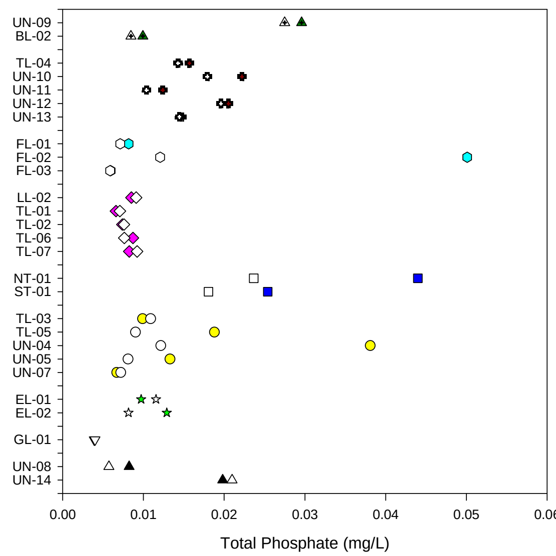
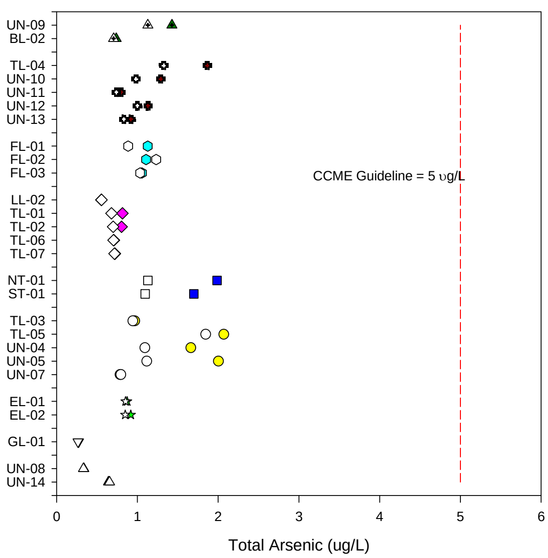

UN-09
BL-02
TL-04
UN-10
UN-11
UN-12
UN-13
FL-01
FL-02
FL-03
LL-02
TL-01
TL-02
TL-06
TL-07
NT-01
ST-01
TL-03
TL-05
UN-04
UN-05
UN-07
EL-01
EL-02
GL-01
UN-08
UN-14
CCME Guideline = 300 υg/L
0
5000
10000
15000
20000
Total Iron (ug/L)

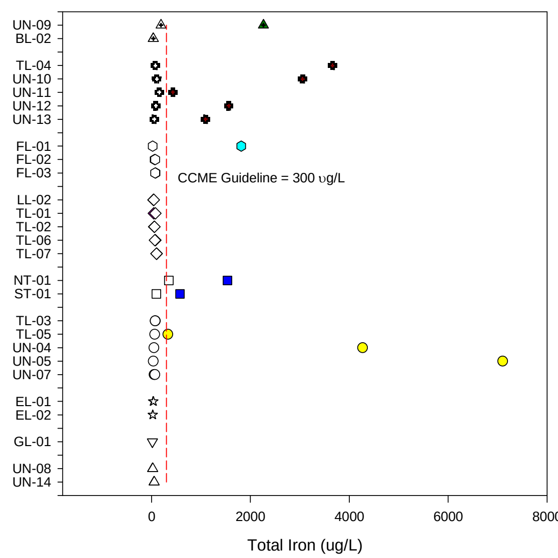
Figure 6-28: Average Levels of Several Water Quality Parameters from 2008 to 2010, including (solid symbols) and excluding (open symbols) Winter Data
(Triangles with plus sign=Blachford Group; plus signs=Ring Group; hexagons=Cressy Group; diamonds=Thor Group; squares=Tardiff Group; circles=Tributary Group; stars=Elbow; upside-down triangle=Great Slave; triangles= Reference Group)











Radionuclide results at all sample stations were typically below detection or less than five times the detection limit. No guideline exceedances were observed for any of the measured radionuclide parameters (lead-210, radium-226, radium-228, thorium-230 and thorium-232).

Differences in general chemistry between the lake groups were noted for the Tardiffs, Reference and Great Slave lakes, which had lower mean conductivity and hardness than the other lakes; mean pH was also lower in the Tardiffs. The Tardiff, Tributary and Ring lake groups tended to have higher mean ammonia, phosphate, iron and arsenic levels than the other groups, likely related to the shallow depth in the majority of these lakes.

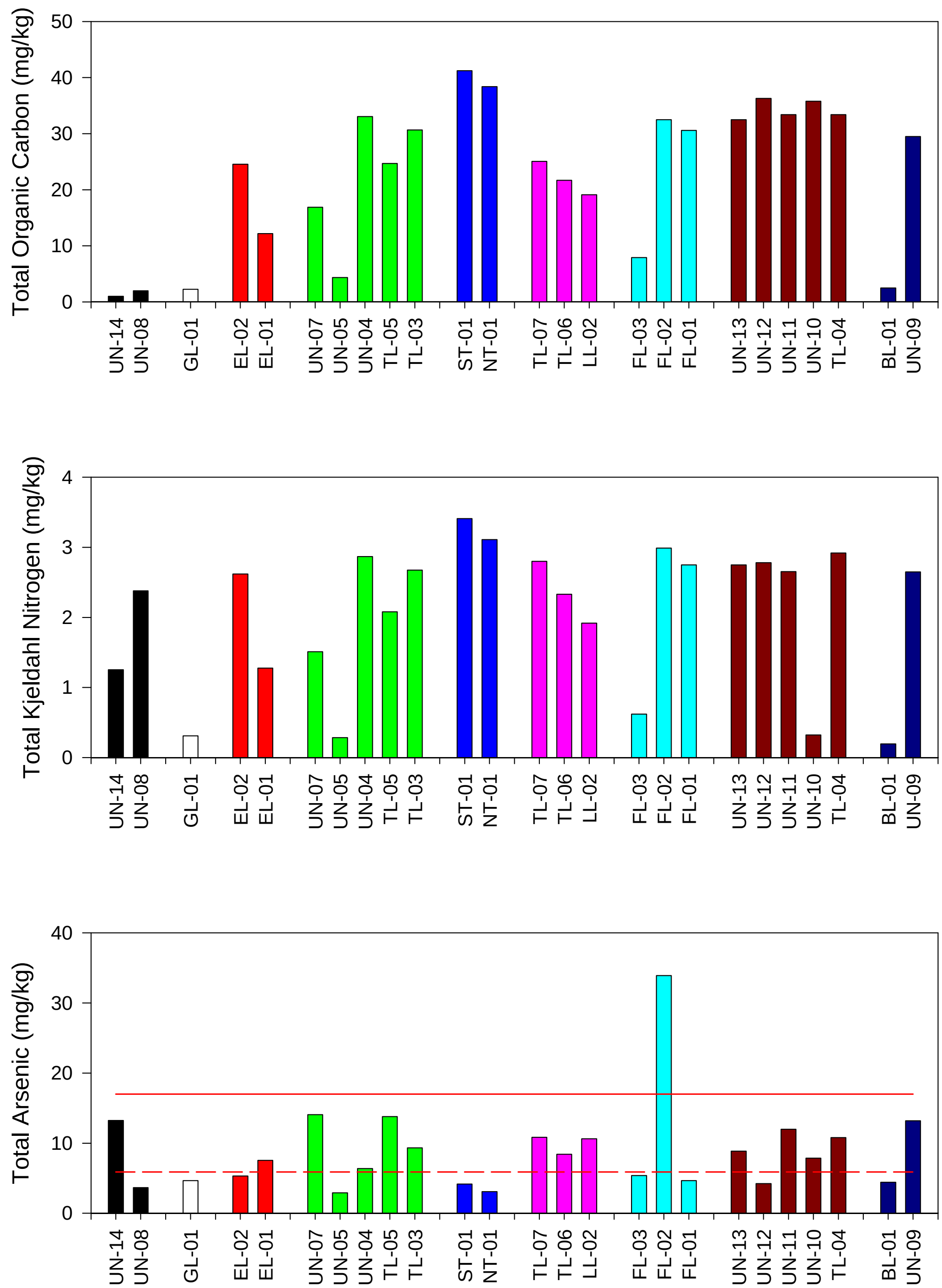
6.2.2 Sediment Chemistry

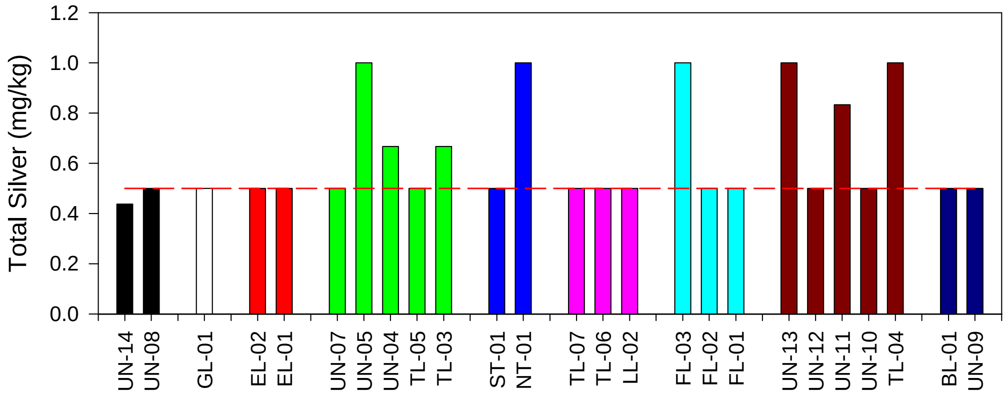
Sediment characteristics varied across the study area, though the lakes can be generally described as having relatively high phosphorus content (306 to 1,890 mg/kg), with organic carbon comprising the greatest portion of total carbon; TOC ranged from 2.24 to 41.2 mg/kg whereas inorganic carbon ranged from less than detection to 4.03 mg/kg. Both TOC and Total Kjeldahl Nitrogen were relatively high across the study area, though values were highest in the Tardiff group (see Figure 6-29). TOC was lowest in the Reference group, while Blachford Lake showed the lowest Total Kjeldahl Nitrogen.

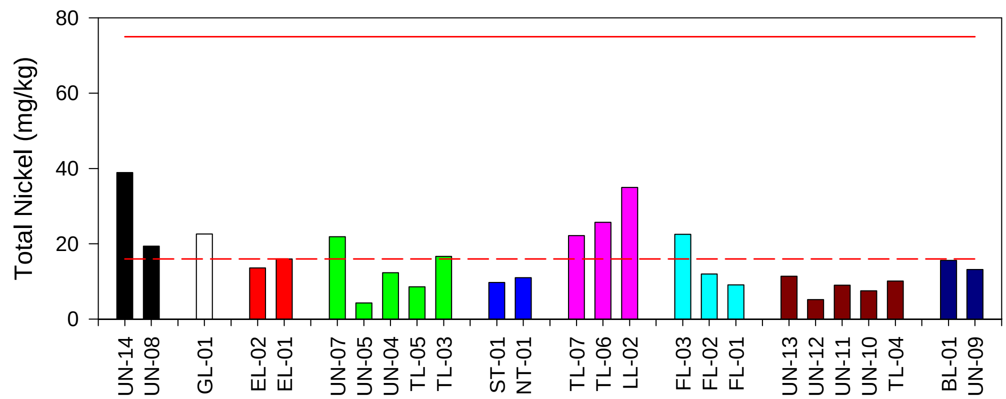
Metal concentrations varied, ranging from less than detection to higher than guidelines. Arsenic exceeded its CCME ISQG at 62% of sample stations, followed by nickel (41%), silver (28%) and copper (21%). Arsenic and zinc also exceeded their CCME PELs at one sample station (Cressy Lake in 2009). No trends were identified in metal concentrations among lake groups.

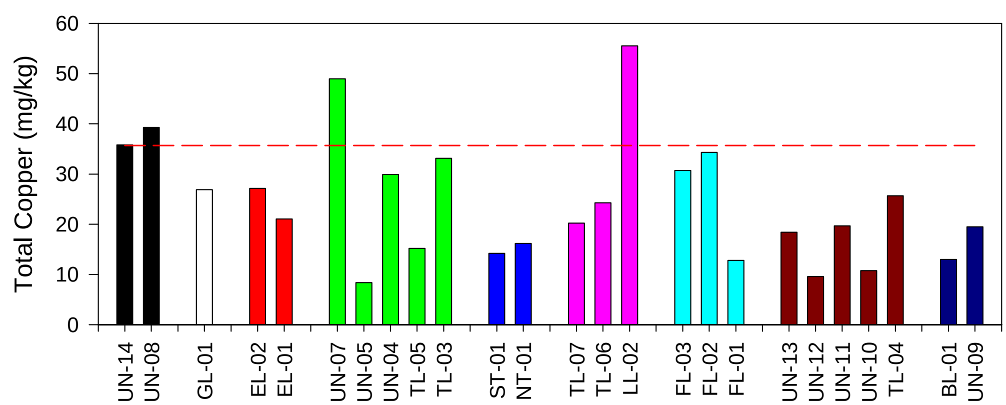
To Stantec's knowledge, there are no guidelines for radionuclides or REE in sediment. In 2009, radionuclide values were generally low and ranged from <0.01 to 0.07 Bq/g for radium-226, <0.03 to 0.4 Bq/g for radium-228, <0.02 to 0.055 Bq/g for thorium-230 and <0.02 to 0.08 for thorium-232. Lead-210 was higher than other radionuclides and ranged from <0.04 to 1.4 Bq/g. A large range of values were reported for REEs across the study area in 2009. Tantalum and hafnium were always low, being reported at less than detection at all (24) and 19 sample stations, respectively.

Figure 6-29: Mean Levels of Several Sediment Parameters in September 2009 and 2010
(Red dashed line indicates the CCME ISQG, solid red line indicates CCME PEL)




Total Silver (mg/kg)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
UN-14 UN-08 GL-01 EL-02 EL-01 UN-07 UN-05 UN-04 TL-05 TL-03 ST-01 NT-01 TL-07 TL-06 LL-02 FL-03 FL-02 FL-01 UN-13 UN-12 UN-11 UN-10 TL-04 BL-01 UN-09


Total Nickel (mg/kg)
80
60
40
20
0
UN-14 UN-08 GL-01 EL-02 EL-01 UN-07 UN-05 UN-04 TL-05 TL-03 ST-01 NT-01 TL-07 TL-06 LL-02 FL-03 FL-02 FL-01 UN-13 UN-12 UN-11 UN-10 TL-04 BL-01 UN-09


Total Copper (mg/kg)
60
50
40
30
20
10
0
UN-14 UN-08 GL-01 EL-02 EL-01 UN-07 UN-05 UN-04 TL-05 TL-03 ST-01 NT-01 TL-07 TL-06 LL-02 FL-03 FL-02 FL-01 UN-13 UN-12 UN-11 UN-10 TL-04 BL-01 UN-09

6.3 Aquatic Organisms

6.3.1 Phytoplankton

6.3.1.1 Chlorophyll *a*

In 2009, chlorophyll *a* values ranged from 0.294 to 5.73 µg/L in June (n=21) and from 1.08 to 14.6 µg/L in September (n=22) (Table 6-5 and Figure 6-30). In 2010, chlorophyll *a* values ranged from 0.732 to 2.86 µg/L in June (n=8) and from 0.273 to 24.5 µg/L in September (n=8).

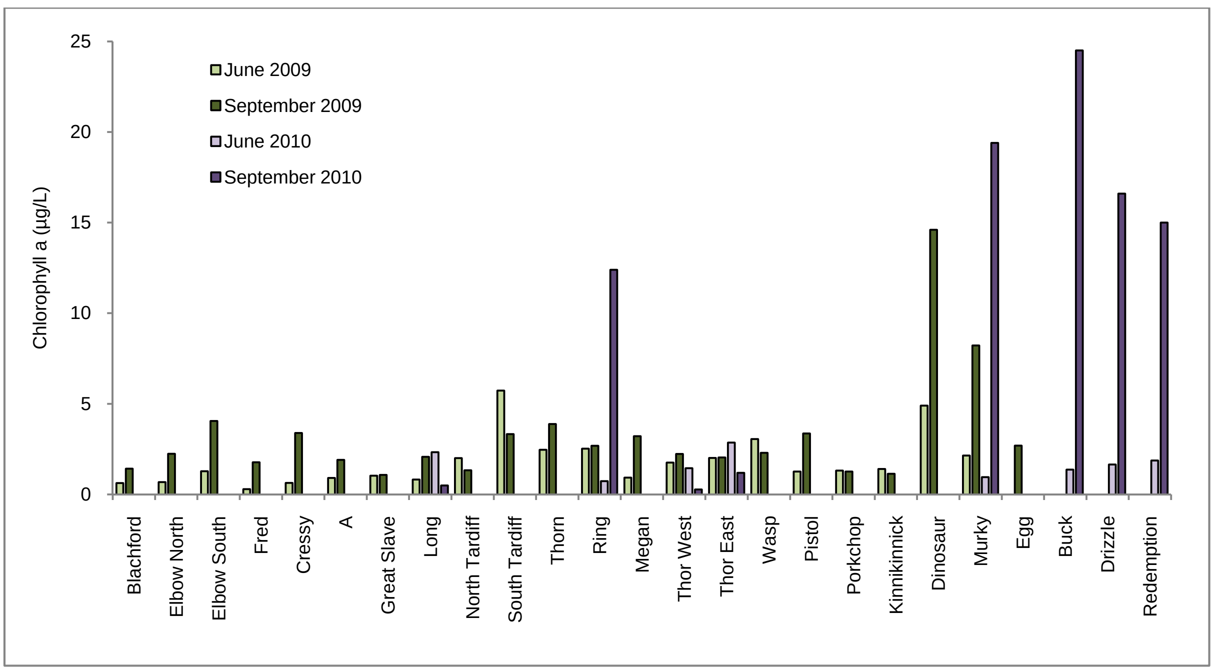
Table 6-5: Chlorophyll Concentrations in Study Area Lakes in 2009 and 2010

Station	Chlorophyll *a* (µg/L)						
	June 2009	September 2009		June 2010		September 2010	
	Chl a[1,2]	Chl a[1]	Phaeo[3]	Chl a[1]	Phaeo[3]	Chl a[1]	Phaeo[3]
A	0.908	1.91	0.498	–	–	–	–
Blachford	0.626	1.42	0.379	–	–	–	–
Buck	–	–	–	1.37[a]	0.224[a]	24.5	2.37
Cressy	0.637	3.39[a]	1.20[a]	–	–	–	–
Dinosaur	4.90	14.6	7.74	–	–	–	–
Drizzle	–	–	–	1.65	0.487	16.6	3.63
Elbow North	0.675	2.24	0.662	–	–	–	–
Elbow South	1.28	4.05	0.480	–	–	–	–
Egg	–	2.69	0.400	–	–	–	–
Fred	0.294	1.77	1.39	–	–	–	–
Great Slave	1.03[a]	1.08	0.230	–	–	–	–
Kinnikinnick	1.40	1.14	0.191	–	–	–	–
Long	0.816	2.07	1.07	2.33	0.570	0.497[a]	0.120[a]
Megan	0.930	3.21	0.450	–	–	–	–
Murky	2.14	8.22	4.11	0.949	0.211	19.4	6.90
North Tardiff	2.00	1.33	2.72	–	–	–	–
Pistol	1.26	3.36	0.721	–	–	–	–
Porkchop	1.31	1.26	0.381	–	–	–	–
Redemption	–	–	–	1.87	0.438	15.0	2.79
Ring	2.52	2.68	0.65	0.732	0.207	12.4	4.20
South Tardiff	5.73	3.33	1.71	–	–	–	–

Station	Chlorophyll *a* (µg/L)						
	June 2009	September 2009		June 2010		September 2010	
	Chl a[1,2]	Chl a[1]	Phaeo[3]	Chl a[1]	Phaeo[3]	Chl a[1]	Phaeo[3]
Thor West	1.76	2.23	1.43	1.45	0.256	0.273	0.027
Thor East	2.01	2.04	0.712	2.86	0.420	1.19	0.317
Thorn	2.46	3.88	1.67	–	–	–	–
Wasp	3.05	2.29	0.851	–	–	–	–

NOTE:
[1] Chl *a* = Chlorophyll *a*
[2] Phaeopigment was not measured in June 2009
[3] Phaeo = Phaeopigment
[a] Reported value is the mean between replicates

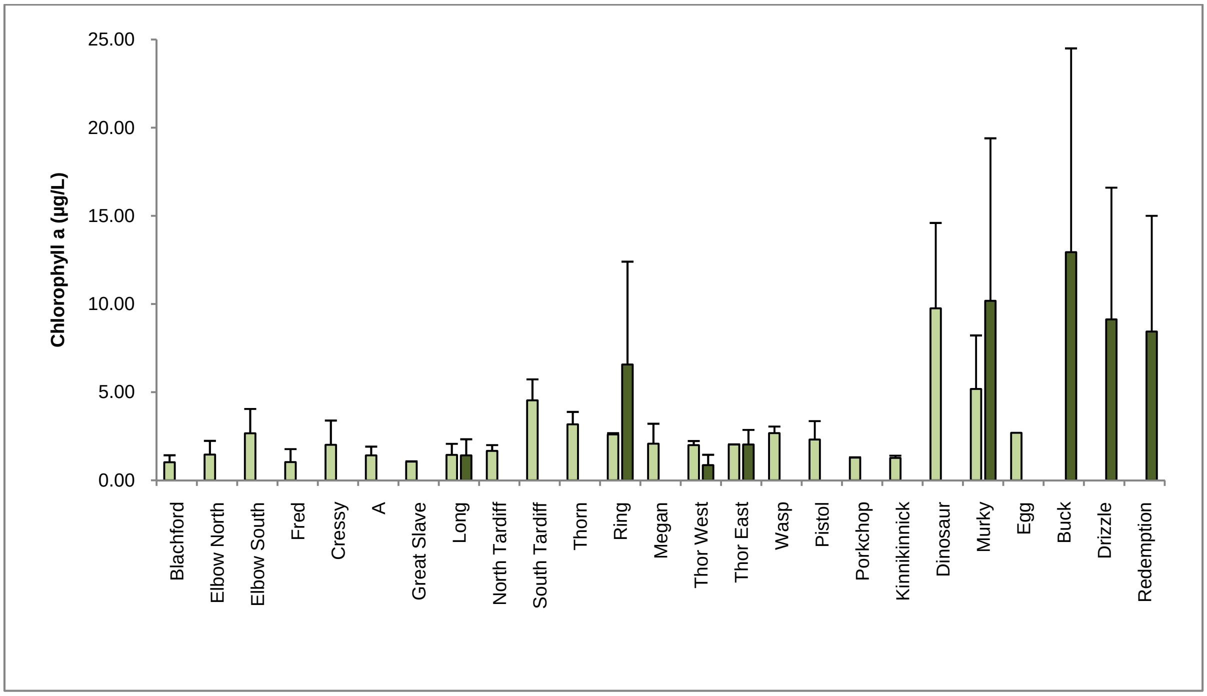
Figure 6-30: Levels of Chlorophyll *a* in June and September of 2009 and 2010



Within a lake, variation in chlorophyll *a* levels from one year to the next reflects a range of natural variation, likely related to timing of sampling in relation to melting of ice cover and fall overturn (and nutrient regeneration patterns). For example, spring came later in 2009 than in 2010. Also, the fall field program extended over 26 days in 2009 (22 stations) and 6 days in 2010 (9 stations), resulting in a wider range of weather conditions in 2009 than in 2010. Some of the trends apparent in the chlorophyll *a* data (Table 6-5, Figures 6-30 and 6-31) include:

- Some lakes had notably higher chlorophyll *a* levels in September than in June in both years; these include Buck, Dinosaur, Drizzle, Murky, Redemption and Ring lakes (Ring in 2010 but not 2009), which also had the highest chlorophyll *a* levels of the lakes studied. All except Redemption are shallow lakes (5 m or less in depth).
- Among the five lakes sampled in both years, mean chlorophyll *a* levels were higher in 2010 for the smaller, shallow lakes (Buck, Murky and Ring lakes); levels were similar in the two years for the larger, deeper lakes (Long, Thor West and Thor East).

Figure 6-31: Mean and Maximum Levels of Chlorophyll a in 2009 (light bars) and 2010 (dark bars)



A system of classifying lake trophic status by chlorophyll *a* concentrations, total phosphorus concentrations and transparency (Secchi depth) was developed by OECD (1982), and has been adopted in Canada (Environment Canada 2004). Although there are limitations in using this approach for these study area lakes, as they were sampled only one to four times, it is likely the majority of lakes would be considered ultra-oligotrophic to oligotrophic based on mean and maximum chlorophyll *a* levels (Figure 6-31). However, additional sampling would be required to confirm lake trophic state. Trends are as follows, using the trophic status system of OECD (1982):

- Ultra-oligotrophic (<2.5 µg/L): A, Blachford, Fred, Great Slave, Kinnikinnick, Long, North Tardiff, Porkchop, Thor, and Wasp lakes
- Oligotrophic (<8 µg/L): Cressy, Elbow, Egg, Megan, Pistol, South Tardiff, and Thorn Lakes

- Mesotrophic (<25 µg/L): Buck, Dinosaur, Drizzle, Murky, Redemption and Ring lakes
- Eutrophic (25 to 75 µg/L): none, however at a maximum of 24.5 µg/L, Buck Lake is at the border between mesotrophic and eutrophic.

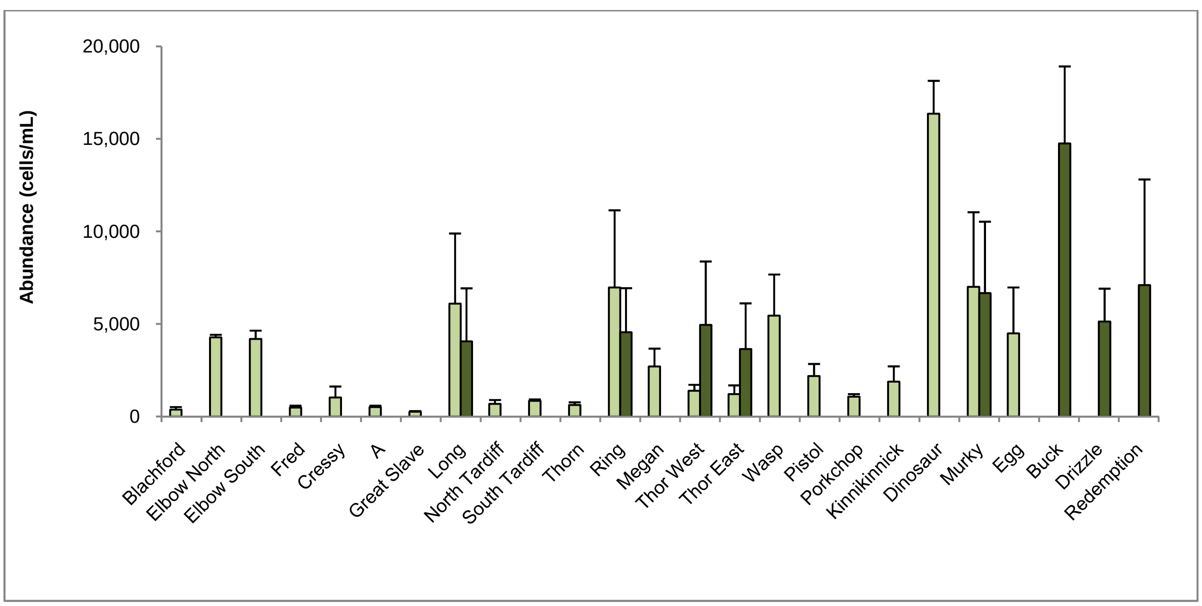
An abundance of phaeopigment suggests a phytoplankton community is senescing (past its period of peak growth). Phaeopigment concentrations were analyzed in September 2009 and June and September 2010, but not in June 2009. Levels ranged from 0.027 to 7.74 µg/L, compared to a chlorophyll *a*, which ranged from 0.273 to 24.5 µg/L. Temporal trends for phaeopigment and chlorophyll *a* were similar, tending to be lower in June and higher in September. Phaeopigment levels were higher than chlorophyll *a* levels in one sample (North Tardiff Lake, September 2009), indicating the end of the phytoplankton bloom (USGS 2010). The proportion of phaeopigment was also high for Drizzle Lake (June 2010) and Murky Lake (September 2010), though results still indicated active growth. The lowest relative proportion of phaeopigment (active growth) was noted for Elbow South (September 2009), Thor East (June 2010) and in Buck (September 2010).

6.3.1.2 Phytoplankton Community Composition

Abundance

Mean phytoplankton abundance in 2009 ranged from 258 cells/mL (Great Slave Lake) to 16,400 cells/mL (Dinosaur Lake) in both June and September for the 22 lake stations sampled (Figure 6-32). The high abundance in Dinosaur Lake corresponded to the highest mean and maximum chlorophyll *a* in 2009. For the eight lake stations sampled in 2010, mean phytoplankton abundance ranged from 3,640 cells/mL (Thor East) to 14,800 cells/mL (Drizzle in June and Redemption in September).

Figure 6-32: Mean and Maximum Abundance of Phytoplankton across the Study Area in 2009 (light bars) and 2010 (dark bars)

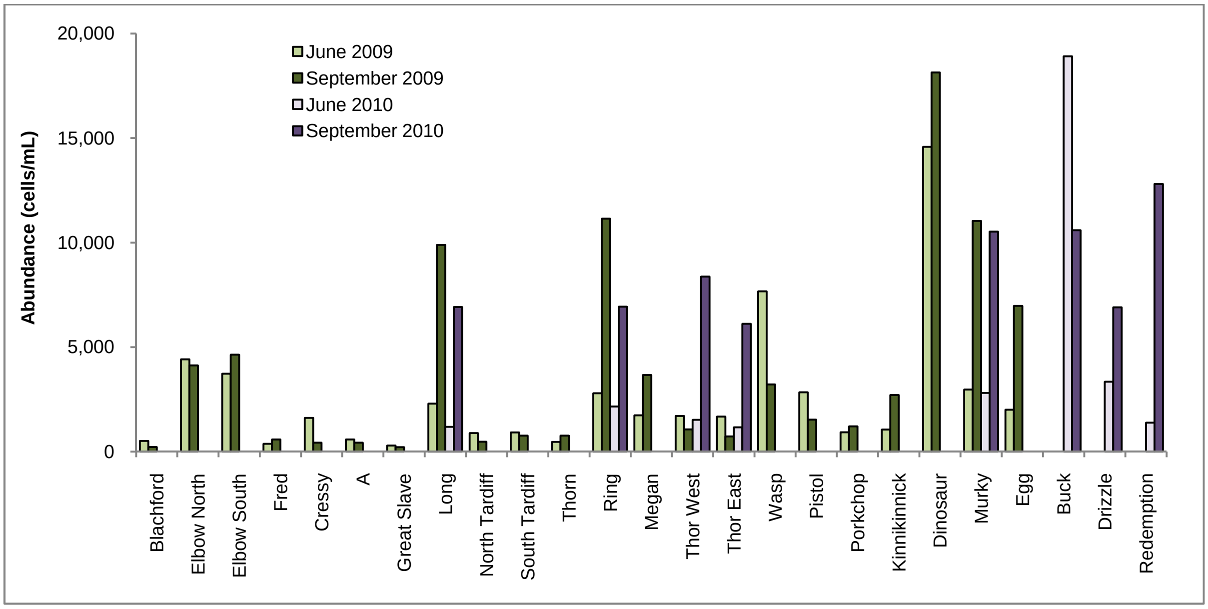


Within lake groups, mean phytoplankton abundances ranged from:

- 1,200 to 6,090 cells/mL in the Thor Group in 2009 and 3,640 to 4,950 cells/mL in 2010
- 482 to 1,020 in the Cressy Group in 2009
- 6,970 to 7,000 cells/mL in the Ring Group (excludes Buck and Drizzle) in 2009 and 4,550 to 14,753 cells/mL in 2010
- 1,880 cells/mL in Kinnikinnick of the Reference Group in 2009 and 7,100 cells/mL in Redemption of the Reference Group in 2010
- 684 to 844 cells/mL in the Tardiff Group in 2009
- 616 to 4,490 cells/mL in the Tributary Group in 2009
- 369 to 16,400 cells/mL in the Blachford Group in 2009
- 4,190 to 4,270 cells/mL in Elbow in 2009
- 258 cells/mL in Great Slave in 2009.

Phytoplankton abundance varied between June and September 2009, increasing in half the sample stations and decreasing or staying the same in the others (Figure 6-33), similar to the trend for chlorophyll *a* (Figure 6-31). In 2010, phytoplankton abundance was higher in September than in June for all lakes except Buck Lake. Most of the stations sampled in both years had lower phytoplankton abundance in 2010; exceptions were Thor East and Thor West which had notably higher abundance in September 2010.

Figure 6-33: Abundance of Phytoplankton across the Study Area in June and September of 2009 and 2010



Richness

Richness, the number of taxa per sampling station, ranged from an average of 34 (Great Slave Lake) to 81 (Fred Lake) in 2009 (Figure 6-34), with a total of 186 phytoplankton taxa identified across the study area. Richness in 2010 ranged from 65 (Long Lake) to 97 (Thor West), with a total of 180 taxa identified across the study area. Stations sampled in both 2009 and 2010 typically had higher numbers of taxa in 2010, which may be attributed to differences in weather, time of sampling or both, between years.

Similar to abundance, richness within a lake differed for June and September 2009 (higher in some lakes, lower in others) as shown in Figure 6-35. In six of the eight stations sampled in 2010, richness was higher in September than June, and the reverse was noted for Drizzle and Redemption lakes. For stations sampled in both 2009 and 2010, there was no obvious trend for June samples, but richness was highest in samples collected in September 2010.

Figure 6-34: Mean and Maximum Richness of Phytoplankton across the Study Area in 2009 (light bars) and 2010 (dark bars)

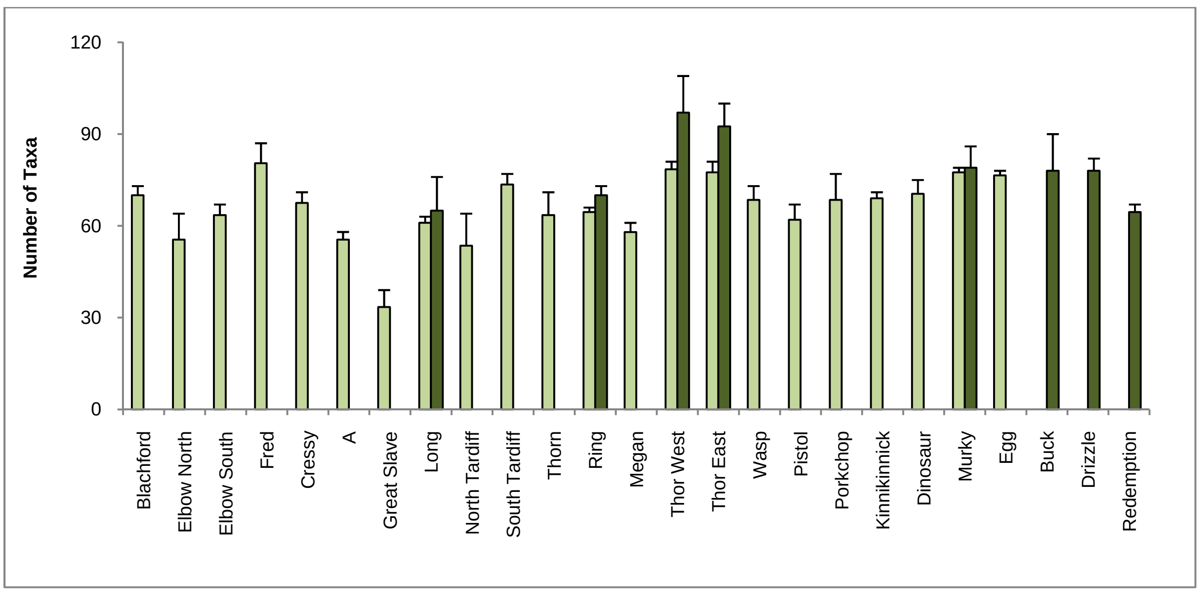
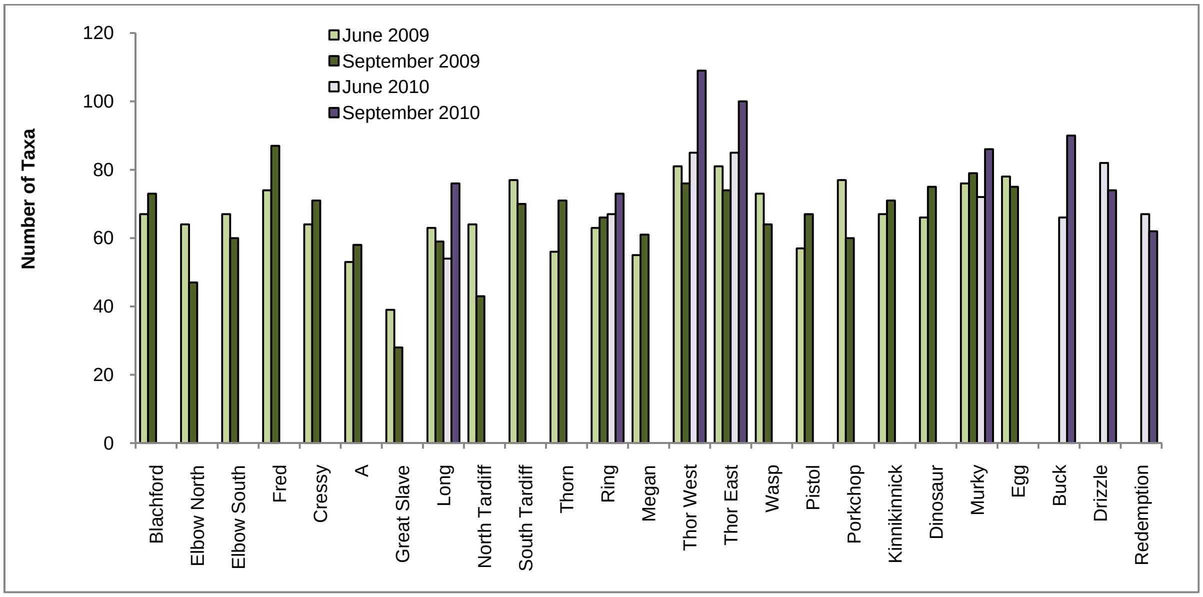


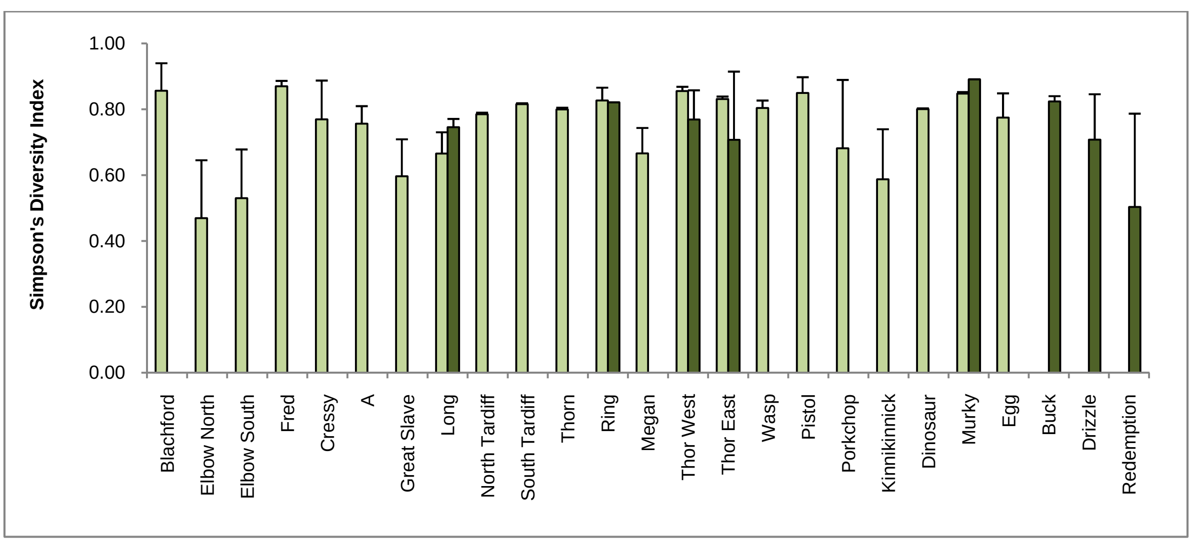
Figure 6-35: Richness of Phytoplankton across the Study Area in June and September of 2009 and 2010



Diversity

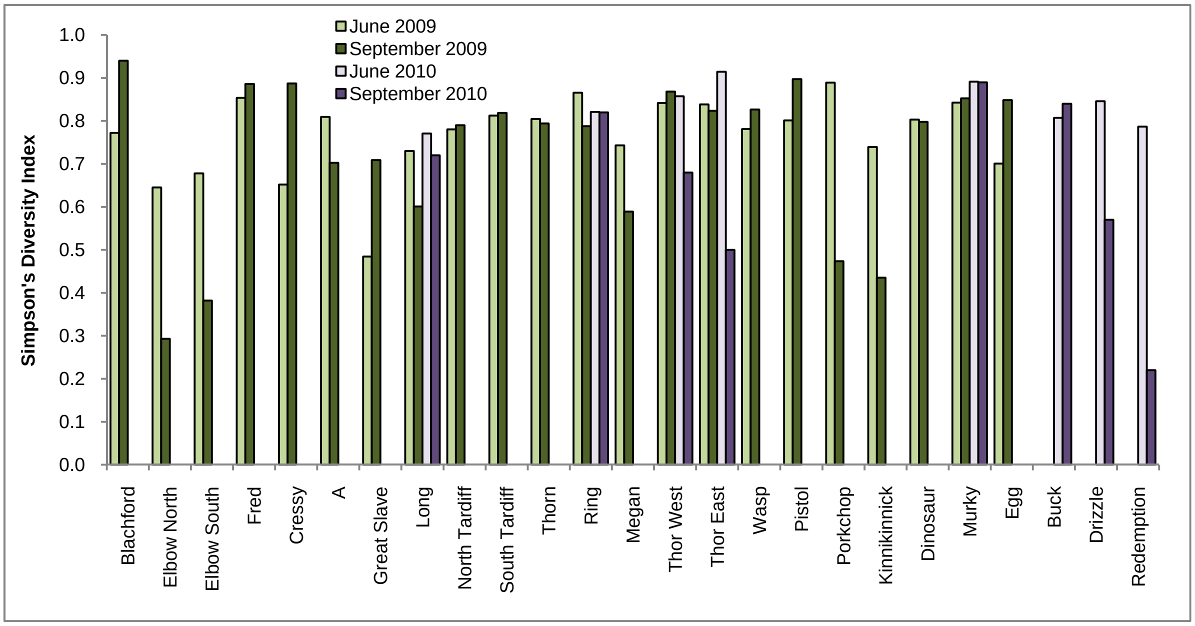
Mean diversity ranged from 0.47 (Elbow North) to 0.87 (Fred) in 2009 and from 0.50 (Redemption) to 0.89 (Murky) in 2010 (Figure 6-36). There was variability among years for Long and Murky lakes (increase) and Thor East and West (decrease) but not Ring Lake, which had similar diversity in the two years.

Figure 6-36: Mean and Maximum Diversity of Phytoplankton across the Study Area in 2009 (light bars) and 2010 (dark bars)



Within lakes, diversity was generally similar in June and September, or higher in June, in both years; exceptions included Blachford, Cressy, A, Great Slave, Wasp, Pistol and Egg lakes in 2009 and Buck Lake in 2010 (Figure 6-37). Of stations sampled in both years, diversity was higher in samples collected in June 2010 than June 2009 from at Long, Thor East, Thor West and Murky; the same trend was noted for September (higher in 2010) at Long, Ring and Murky lakes.

Figure 6-37: Diversity of Phytoplankton across the Study Area in June and September of 2009 and 2010



Taxonomic Composition

Taxonomic composition across the study area in 2009 and 2010 is described in Appendix H. Predominant and common species present in the study area in 2009 and 2010 are summarized in Table 6-6. More detailed discussion for individual lakes and groups of lakes is provided in Section 7.

The diatom *Fragilaria crotonensis* and the yellow-brown alga *Dinobryon* sp. were the only taxa present within all 22 study lake stations in 2009. Due to the smaller number of lake stations sampled in 2010 (eight stations), there was a higher number of taxa present among all sampled lakes; this included five diatoms (*Cymbella* sp., *Fragilaria crotonensis, Fragilaria* sp., *Navicula* sp, and unidentified Pennales), two green alga (*Ankistrodesmus falcatus* and *Botryococcus braunii*), two yellow-brown alga (*Dinobryon* sp. and *Kephyrion/Pseudokephyrion*) and one blue-green alga (*Lyngbya limnetica*). No phytoplankton taxa were present among all study lakes and also comprised enough of the community to be considered common (greater than 5%); ubiquitous distribution did not imply higher abundance. Predominant species included filamentous blue-green algae (several species of *Lyngbya*), coccoid blue-green algae (several species of *Anacystis*), colonial yellow-brown algae (several species of *Dinobryon*) and small cryptoflagellates (*Chroomonas acuta*).

Table 6-6: Predominant (P) and Common (C) Phytoplankton Taxa in the Study Area in 2009 and 2010 (one or more times per station)

Taxon	Sample Station[1,2]																								
Genus and Species	**BL-02**	**EL-01**	**EL-02**	**FL-01**	**FL-02**	**FL-03**	**GL-01**	**LL-02**	**NT-01**	**ST-01**	**TL-03**	**TL-04**	**TL-05**	**TL-06**	**TL-07**	**UN-04**	**UN-05**	**UN-07**	**UN-08**	**UN-09**	**UN-10**	**UN-11**	**UN-12**	**UN-13**	**UN-14**
Bacillariophycae (Diatoms)																									
Cyclotella glomerata												C					C					C	C	C	
Cyclotella sp.													C												
Fragilaria crotonensis						C				C			C	C	C			C		C					
Tabellaria fenestrata							C																		
Chlorophyta (Green algae)																									
Ankistrodesmus falcatus						C												C							
Botryococcus braunii									P	P	C			C											
Crucigenia quadrata				C																					
Gloeocystis ampla					C	C			C		P					C									
Scenedesmus cf. *denticulatus*				C													C								
Sphaerocystis schroeteri					C				C		C														
Tetraedron minimum	C																		C						
Chrysophyta (Yellow-brown algae)																									
Dinobryon cf. *bavaricum*	C			C		C						C									C			C	
Dinobryon divergens					P	C					C														
Dinobryon elegantissimum												C													
Dinobryon sp.	C	C	C	C	C	P	C	C		C		C	P	P	P	C	C			C	C	P	C		C
Kephyrion / Pseudokephyrion								C						C	C										
Synura sp.					C	C																			
Cryptophyta																									
Chroomonas acuta	C			P	C	P	P		C	C	P			C	C			C							C
Cryptomonas ovata/erosa					C	C	C		C	C				C	C										

Taxon	Sample Station[1,2]																								
Genus and Species	BL-02	EL-01	EL-02	FL-01	FL-02	FL-03	GL-01	LL-02	NT-01	ST-01	TL-03	TL-04	TL-05	TL-06	TL-07	UN-04	UN-05	UN-07	UN-08	UN-09	UN-10	UN-11	UN-12	UN-13	UN-14
Cryptomonas sp.							C																		
Cyanophyta (Blue-green algae)																									
Agmenellum tenuissima				C							C	C				P	P				C	C	C	C	
Agmenellum sp.																	C								
Anabaena flos-aquae										P					C										
Anacystis cf. *aeruginosa*									P																
Anacystis cf. *elachista*				P	C			C				P	P	P	P	P	C			C	P	P	P	P	
Anacystis cf. *limneticus*											C	C	C	C	C	C					C	C	C	C	
Anacystis sp.																					C		C		
Aphanizomenon flos-aquae	C	C	P																						
Aphanizomenon cf.		C	C					C																	
Lyngbya Birgei					C																				
Lyngbya contorta																				P					
Lyngbya cf. *contorta*												P		P						P	C	C	C		
Lyngbya limnetica	P	P	P	C			C	P			C	P		P	P	C	C	P	P	P	C	P	C	C	P
Lyngbya cf. *limnetica*		P	P											C	C				P	C	C				
Lyngbya sp.			C											C											
Oscillatoria tenuis								P						C	C										
Pseudanabaena cf. *catenata*																									P
Pseudanabaena cf.								C											P						

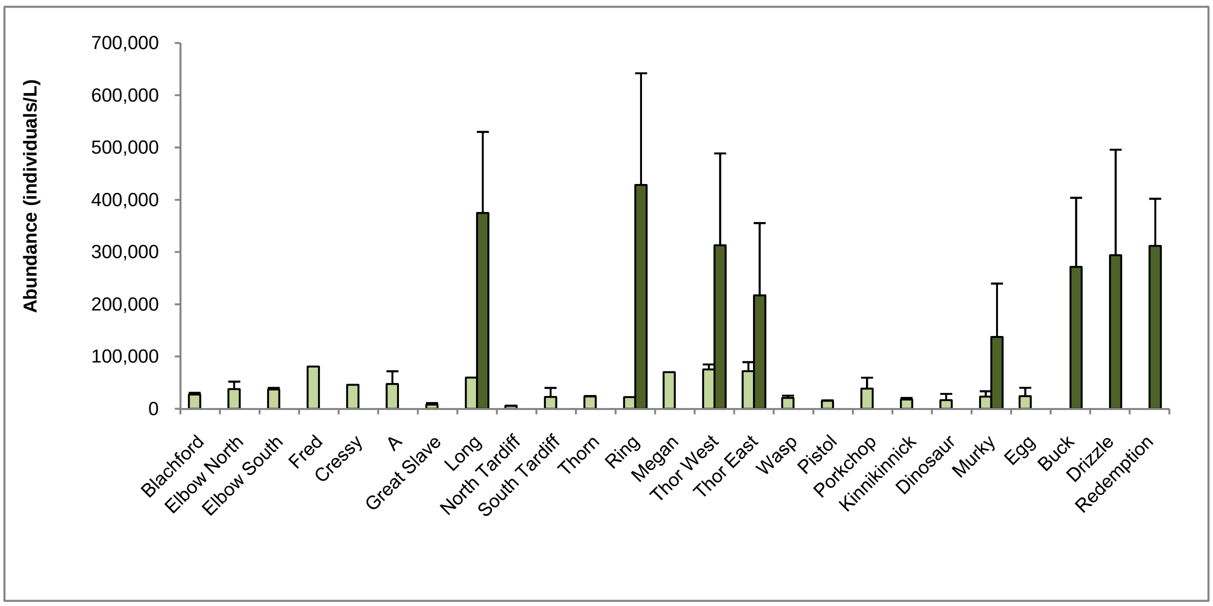
NOTE:
[1] See Table 6-1 for sample station locations
[2] P = Predominant (>25% abundance); C = Common (5 to 25% abundance)

6.3.2 Zooplankton Community Composition

6.3.2.1 Abundance

Mean zooplankton abundance in 2009 ranged from 5,670 organisms/L (North Tardiff) to 80,700 organisms/L (Fred Lake) as shown in Figure 6-38. The stations sampled in both 2009 and 2010 indicated higher numbers for all lakes in 2010, with mean abundance ranging from 137,000 organisms/L (Murky Lake) to 428,000 organisms/L (Ring Lake). Higher abundance in 2010 was related to the larger diameter zooplankton net used in 2010 (20 cm vs. 12 cm in 2009) as well as minor differences in timing of sampling.

Figure 6-38: Mean and Maximum Abundance of Zooplankton across the Study Area in 2009 (light bars) and 2010 (dark bars) (different diameter nets used in 2009 and 2010)



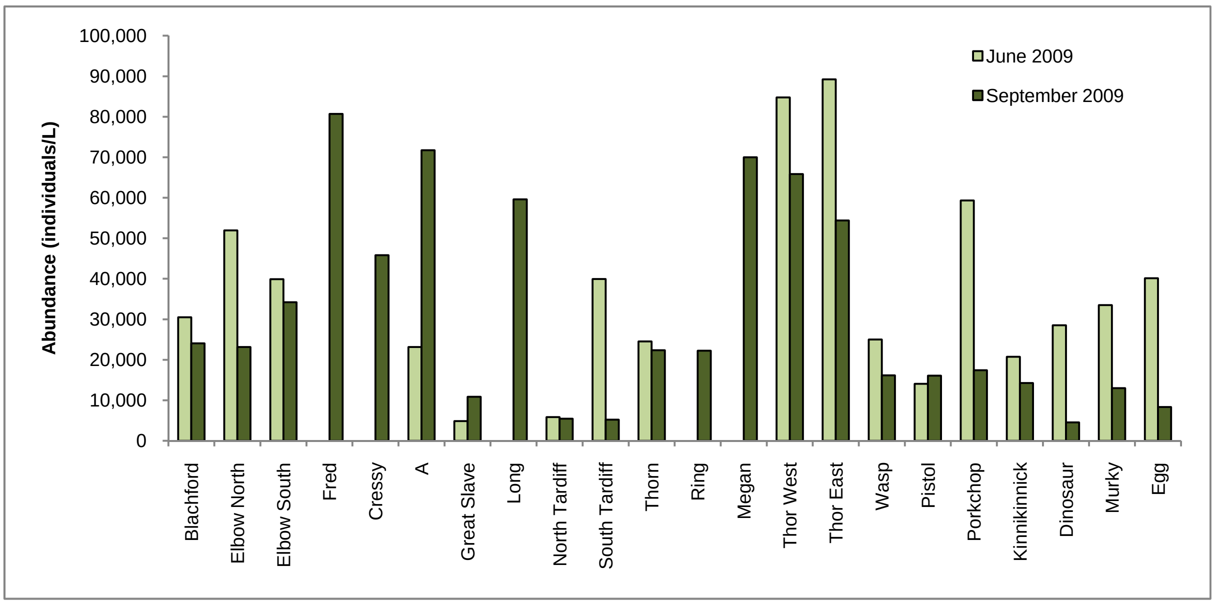
Within lake groups, mean zooplankton abundances ranged from:

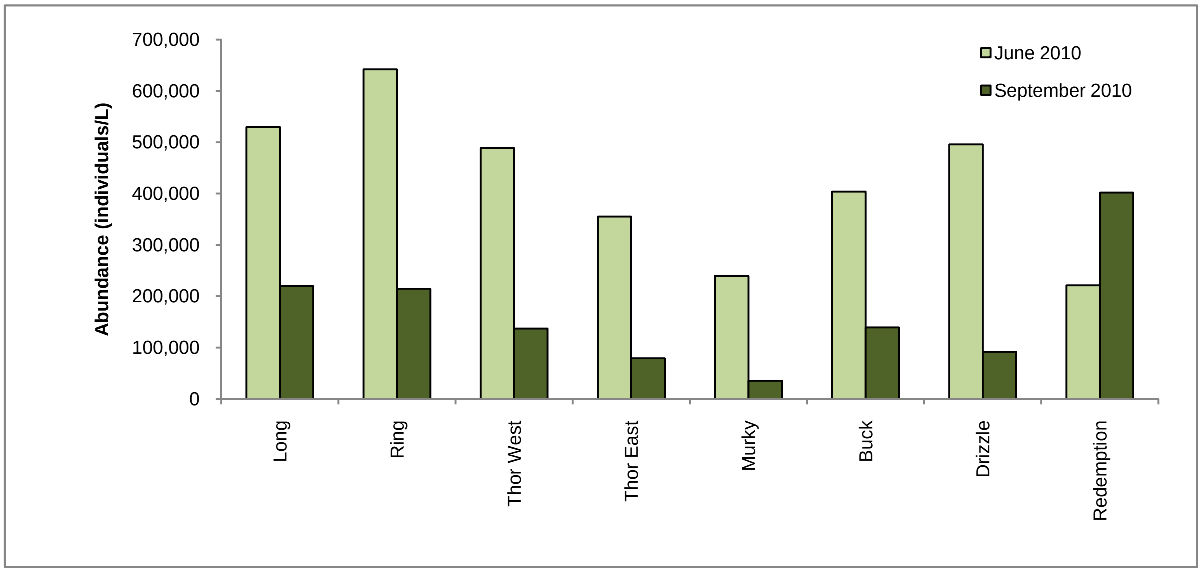
- 59,600 to 75,300 organisms/L in the Thor Group in 2009 and 217,000 to 374, 000 organisms/L in 2010
- 45,800 to 80,700 organisms/L in the Cressy Group in 2009
- 22,300 to 23,200 organisms/L in the Ring Group in 2009 (excludes Buck and Drizzle) and 137,000 to 428,000 organisms/L in 2010
- 17,500 organisms/L in Kinnikinnick of the Reference Group in 2009 and 311,000 organisms/L in Redemption of the Reference Group in 2010
- 5,670 to 22,600 organisms/L in the Tardiff Group in 2009

- 15,100 to 70,000 organisms/L in the Tributary Group in 2009
- 16,500 to 27,300 organisms/L in the Blachford Group in 2009
- 37,000 to 37,500 organisms/L in Elbow in 2009
- 7,900 organisms/L in Great Slave in 2009.

Within lakes, zooplankton abundance was higher in June than September in both years, with exceptions noted at A, Great Slave and Pistol lake in 2009 and Redemption Lake in 2010 (Figure 6-39). This trend was the opposite of that generally noted for phytoplankton abundance (higher in September than June at Elbow South, A, Great Slave, Thorn, Pistol, Porkchop, Kinnikinnick, Dinosaur, Murky and Egg lakes in 2009 and all sampled lakes in 2010, except Buck Lake). As noted above, abundances were higher in 2010 due to the larger diameter zooplankton net used.

Figure 6-39: Abundance of Zooplankton across the Study Area in June and September of 2009 and 2010

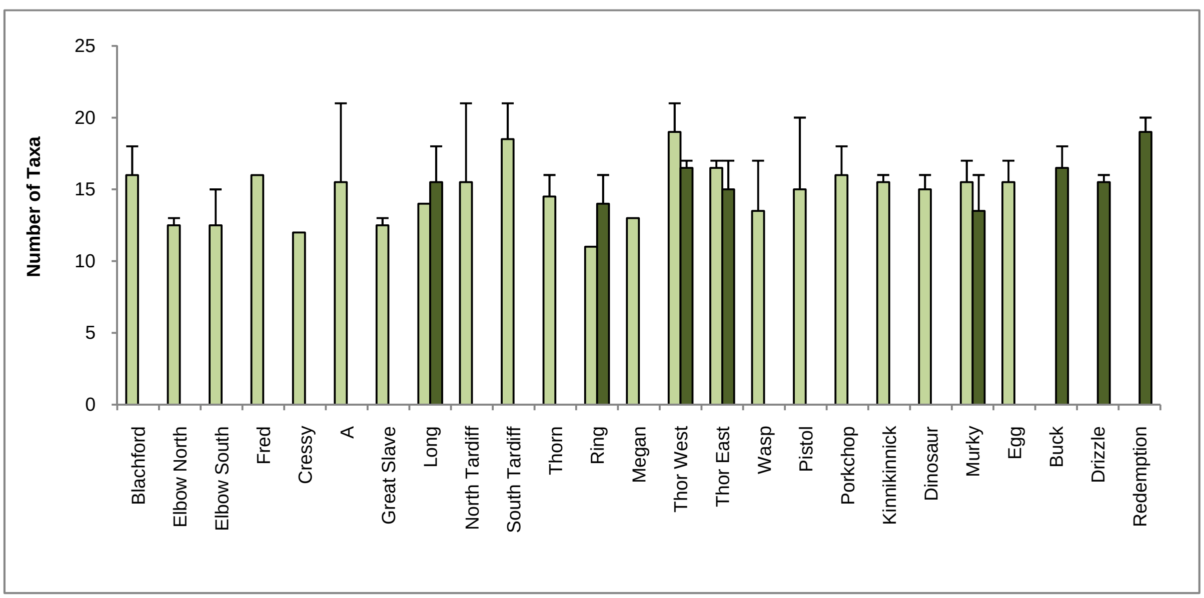




6.3.2.2 Richness

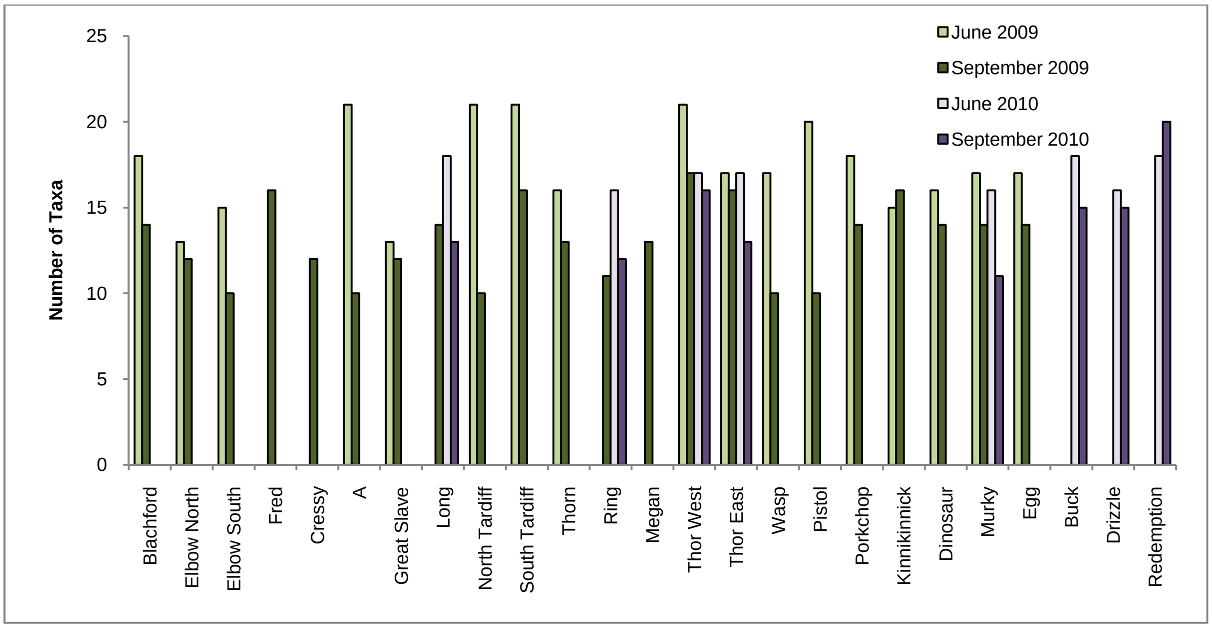
Mean taxon richness ranged from 11 (Ring Lake) to 19 (South Tardiff and Thor West) in 2009 (Figure 6-40), with 44 taxa identified across the study area. In 2010, richness ranged from 14 (Ring and Murky lakes) to 19 (Redemption Lake), with 38 taxa identified across the study area. Stations sampled in both 2009 and 2010 showed variability, with an increase for Long and Ring lakes and a decrease in Thor East and West and Murky for 2010.

Figure 6-40: Mean and Maximum Richness of Zooplankton across the Study Area in 2009 (light bars) and 2010 (dark bars)



Within lakes, zooplankton richness was higher in June than September in 2009 and 2010 (Figure 6-41); two exceptions were noted within the Reference Lake Group (Kinnikinnick Lake in 2009 and Redemption Lake in 2010). At stations sampled in both years, richness was similar or lower in 2010, with the exception of Ring Lake (higher richness in September 2010 than 2009).

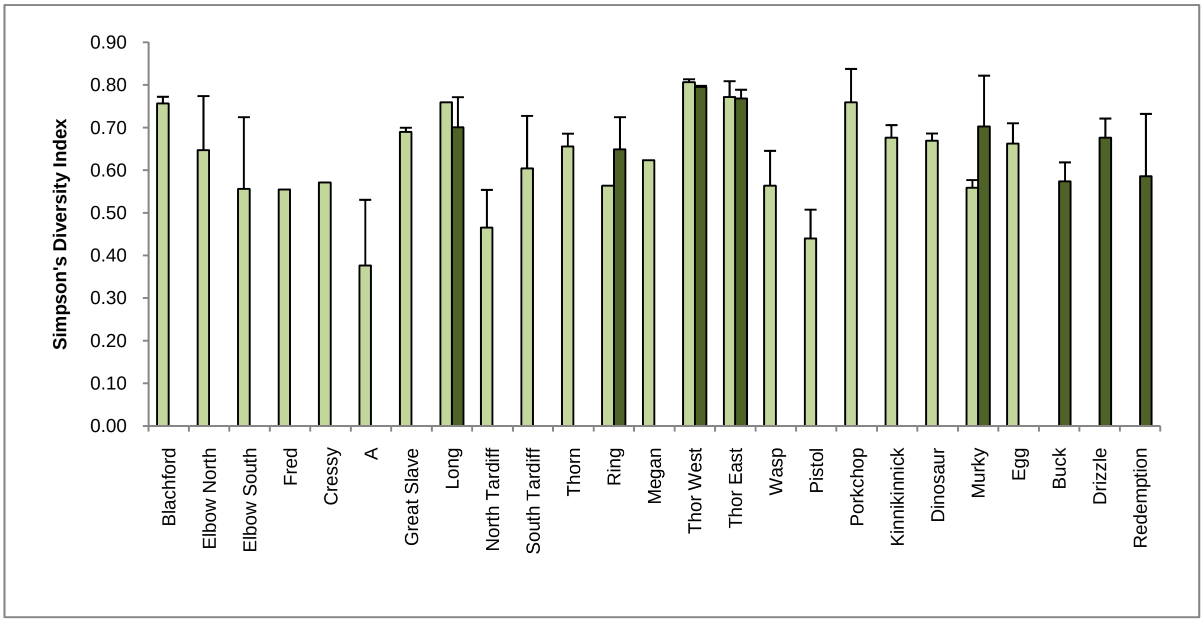
Figure 6-41: Richness of Zooplankton across the Study Area in June and September of 2009 and 2010



6.3.2.3 Diversity

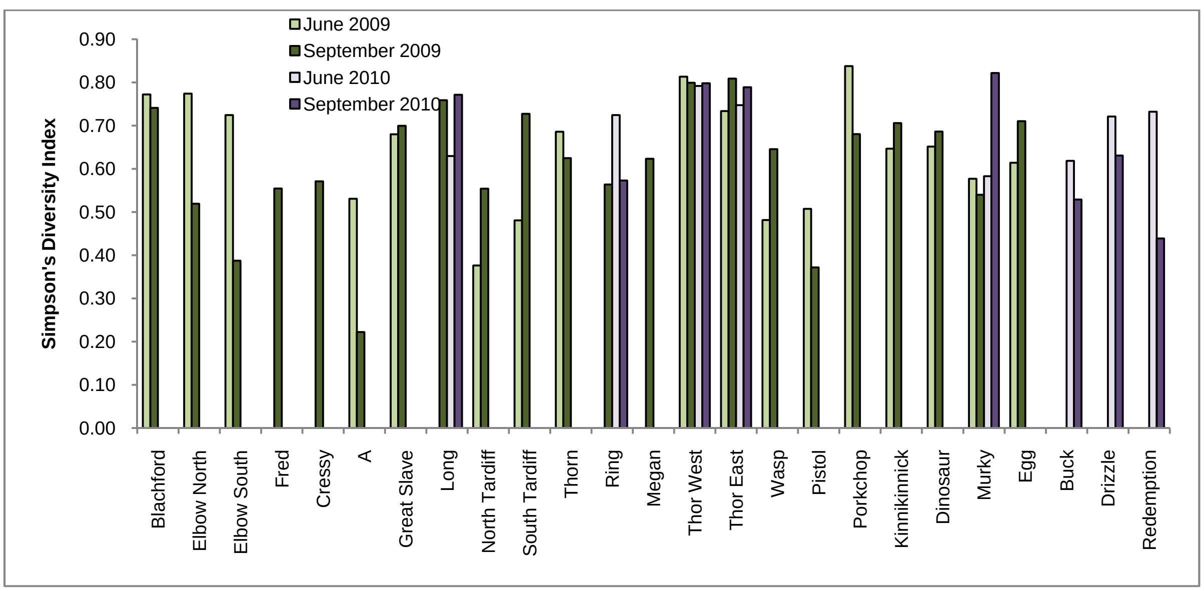
Mean diversity ranged from 0.38 (A Lake) to 0.81 (Thor West) in 2009 and from 0.50 (Buck) to 0.80 (Thor West) in 2010 (Figure 6-42). In 2010, diversity was higher in samples from Ring and Murky lakes, lower in Long Lake, and similar in Thor East and Thor West.

Figure 6-42: Mean and Maximum Diversity of Zooplankton across the Study Area in 2009 (light bars) and 2010 (dark bars)



Within lakes diversity varied in June and September, either increasing or decreasing (Figure 6-43). At stations sampled in both years, diversity values were similar between corresponding seasons, except at Murky having greater diversity in September 2010 than 2009.

Figure 6-43: Diversity of Zooplankton across the Study Area in June and September of 2009 and 2010



6.3.2.4 Taxonomic Composition

Taxonomic composition across the study area in 2009 and 2010 is described in Appendix I, with predominant and common taxa summarized in Table 6-7.

The rotifer *Kellicottia longispina* was the only taxon present in all 22 study lakes during 2009. In 2010, the rotifer *Kellicottia longispina* and three copepods (Diaptomidae, unidentified Cyclopoida and Calanoida) were present at all eight stations sampled. *Kellicottia longispina* was common (5% or greater) or predominant (25% or greater) in all lakes except Fred Lake (FL-01). Other predominant taxa included rotifers (*Keratella cochlearis*, *Polyartha* sp.), copepods (unidentified Cyclopoida and Calanoida), and the cladoceran *Bosmina longirostris.*

Table 6-7: Predominant and Common Zooplankton Taxa across the Study Area in 2009 and 2010

Taxon	Sample Station[1,2]																								
	BL-02	EL-01	EL-02	FL-01	FL-02	FL-03	GL-01	LL-02	NT-01	ST-01	TL-03	TL-04	TL-05	TL-06	TL-07	UN-04	UN-05	UN-07	UN-08	UN-09	UN-10	UN-11	UN-12	UN-13	UN-14
Phylum: Rotifera (Rotifers)																									
Kellicottia longispina	C	P	P		P	C	P	C	P	P	P	P	P	P	C	P	P	C	C	P	P	P	P	P	P
Keratella cochlearis	P	P	P	C		P	P	P	C	C		P		P	P	C	C	C	P	P	C	P	C	C	P
Keratella quadrata		C																							
Filinia															C										
Conochilus															C										
Asplanchna														C											
Polyartha	P	C	C	P			C	C		C	C		C	C	C			C	C						C
Unidentified Rotifers	C			C			C	C				C			C			C	C					C	C
Phylum: Arthropoda Order: Cladocera (Daphnia)																									
Bosmina longirostris														C	C										C
Subclass: Copepoda (Copepods)																									
Family: Diaptomidae						C					C						C				C		C		
Leptodiaptomus pribilofensis										C	C	C								C	C	C			
Limnocalanus macrurus							C																		
Unidentified Cyclopoida		C	C				P	C	C	C	P	C		C	C	C	C	C			C	C		C	
Unidentified Calanoida/ Cyclopoida	C	C	C		P		P	C	C	C	P	P	C	C	C	P	P	P	C	C	P	C	P	C	P

NOTE:
[1] See Table 6-1 for sample station locations
[2] P = Predominant (>25% abundance); C = Common (5 to 25% abundance)

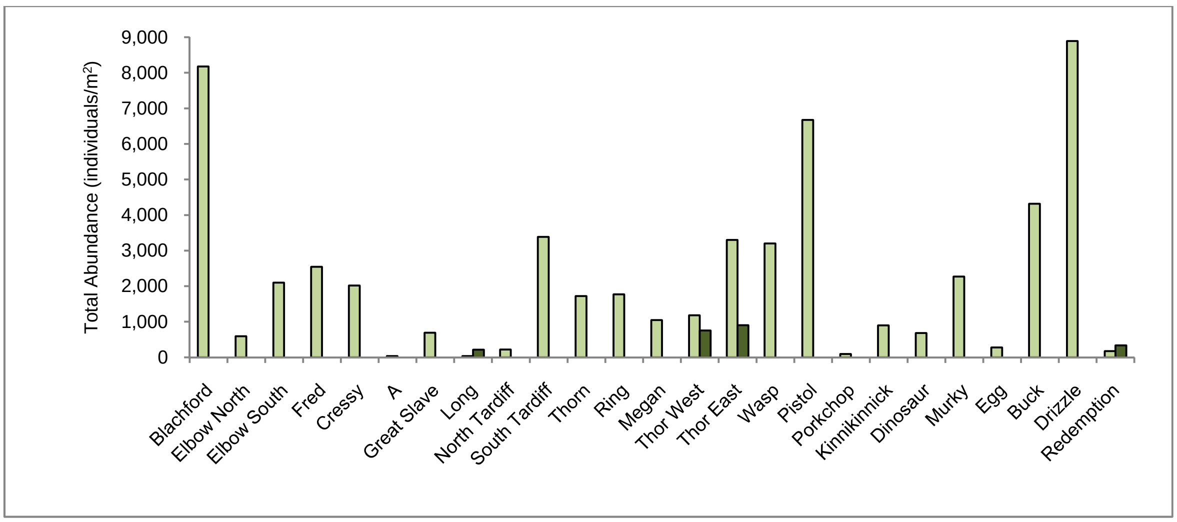
6.3.3 Benthic Invertebrates

The 25 study area lakes were sampled for benthic invertebrates in September 2009, with further sampling of Thor (two stations), Redemption and Long lakes in 2010. More detailed discussion for individual lakes and groups of lakes is provided in Section 7.

6.3.3.1 Abundance

Total abundance of benthic invertebrates in samples collected in September 2009 ranged from 34 organisms/m^2 (Long and A lakes) to 8,892 organisms/m^2 (Drizzle Lake), as shown in Figure 6-44. Stations sampled in both 2009 and 2010 had similar numbers for Long, Thor West and Redemption lakes and greater variability for Thor East (lower in 2010, but more similar to Thor West).

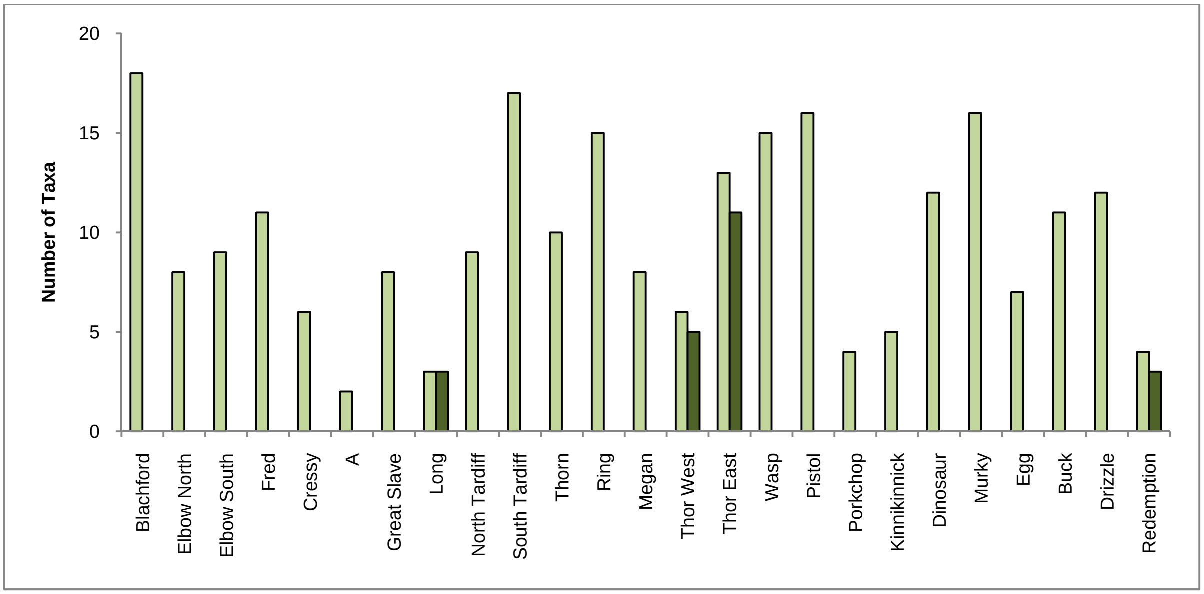
Figure 6-44: Abundance of the Benthic Invertebrate Community across the Study Area in 2009 (light bars) and 2010 (dark bars)



6.3.3.2 Richness

Richness, the number of taxa per sampling station (at the family level) ranged from 2 (A and Long lakes) to 18 (Drizzle Lake) in 2009. Stations sampled in both 2009 and 2010 had similar numbers of taxa (Figure 6-45), despite the increase in sampling intensity (twice the volume of sediment collected and sieved for benthos).

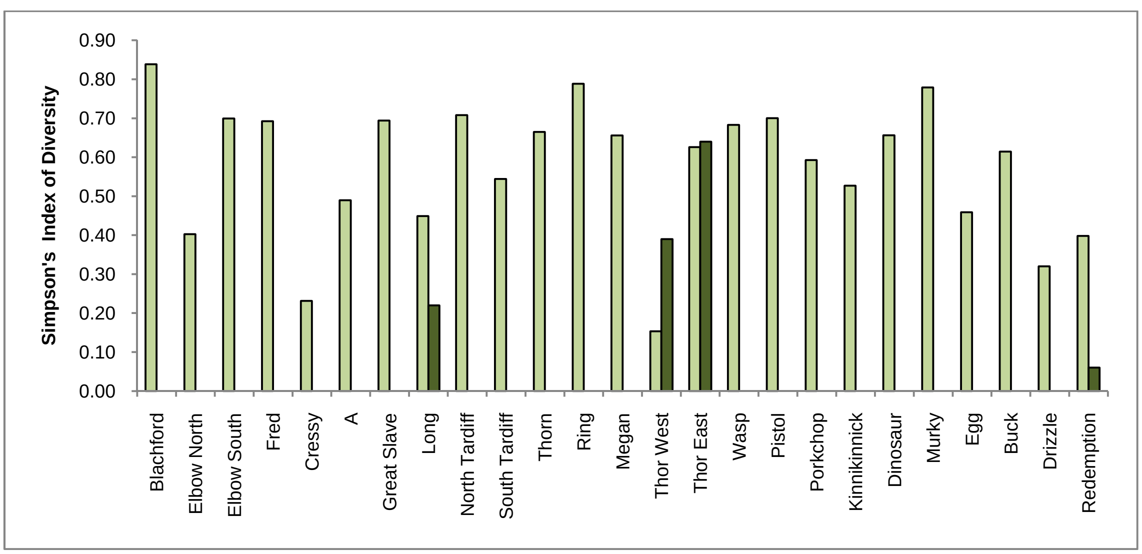
Figure 6-45: Richness of the Benthic Invertebrate Community across the Study Area in 2009 (light bars) and 2010 (dark bars)



6.3.3.3 Diversity

In 2009, diversity ranged from 0.15 (Thor West) to 0.84 (Blachford Lake). There was considerable variability among years for Thor West (increase), and Redemption and Long lakes (decrease) but not for Thor East, all of which were also sampled in 2010 (Figure 6-46).

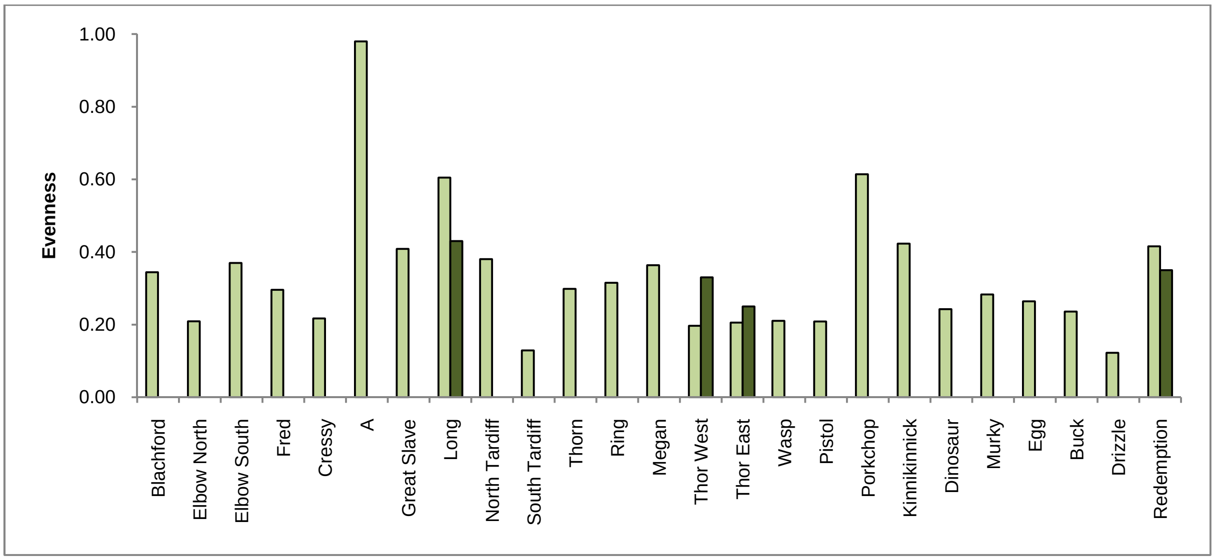
Figure 6-46: Diversity of the Benthic Invertebrate Community across the Study Area in 2009 (light bars) and 2010 (dark bars)



6.3.3.4 Evenness

In 2009, evenness, an indication of community structure, ranged from 0.12 (Drizzle Lake), suggesting a heterogeneous community, to 0.98 (A Lake), suggesting a homogenous community (Figure 6-47). Evenness for lakes sampled again in 2010 were similar for Redemption and Thor East, decreased for Long Lake and increased for Thor West, generally similar to the trend for diversity.

Figure 6-47: Evenness of the Benthic Invertebrate Community across the Study Area in 2009 (light bars) and 2010 (dark bars)



6.3.3.5 Taxonomic Composition

Chironomidae and Sphaeriidae were the most ubiquitous taxa in 2009, being reported from 25 and 23 stations, respectively (Table 6-8). Chironomidae comprised 3 to 92% and Sphaeriidae comprised 2 to 55% abundance. Chironomidae were also the most common taxa in 2010, present at all four stations at 10 to 97% abundance. Predominant and common taxa included three Diptera (true fly) families (*Ceratopogonidae, Chaoboridae, Chironomidae*), two copepod orders (*Calanoida, Cyclopoida*), two crustacean families (*Amphipoda, Ostracoda*), one clam family (*Sphaeriidae*), two snail taxa (*Gastropoda, Valvatidae*), one aquatic earthworm (*Tubificidae*) and one nematode taxon (*Nemata*).

Table 6-8 Predominant and Common Benthic Invertebrate Taxa across the Study Area in 2009 and 2010

Taxa	Sample Station[1,2]																								
	BL-02	EL-01	EL-02	FL-01	FL-02	FL-03	GL-01	LL-02	NT-01	ST-01	TL-03	TL-04	TL-05	TL-06	TL-07	UN-04	UN-05	UN-07	UN-08	UN-09	UN-10	UN-11	UN-12	UN-13	UN-14
Family: Ceratopogonidae										C		C					C	P			C		C	C	
Family: Chaoboridae													C							C					C
Family: Chironomidae	C	P	C	C	P	P	C	C	P	P	P	P	C	P	P	P	P	P	P	P	P	C	P	P	P
Order: Calanoida								P			C		C									C			
Order: Cyclopoida						P																			
Family: Amphipoda	P		C	P			P			C		P	C			P	C				C	P	C		
Family: Ostracoda	C											C						C		C					
Family Sphaeriidae	C	C	P	C			P	C	P	C	P	C	P	C	P	C	C		C	C	P		C		
Order: Gastropoda									C						C										
Family: Valvatidae									C																
Sub-Family: Tubificidae		C	C								C								C			C			
Phylum: Nemata	C																	C							

NOTE:
[1] See Table 6-1 for sample station locations
[2] P = Predominant (>25% abundance); C = Common (5 to 25% abundance)

6.4 Fish Studies

6.4.1 Species Presence and Catch Rate

Fish were captured or observed in 11 of the 20 fisheries study lakes (Table 6-9; Figure 6-48 in Appendix A). Three large bodied species (northern pike, lake whitefish, lake cisco) and two small bodied species (slimy sculpin and ninespine stickleback) were most common, and were all present in Thor, Long, Elbow, A, and Redemption lakes. Lake trout was captured in Carrot and Great Slave lakes (the deepest lakes), and lake chub was captured in Kinnikinnick Lake. Only northern pike were caught in Murky and U lakes. No fish were caught in Ball, Buck, Cressy, Drizzle, Megan, North Tardiff, Ring or Thorn lakes. Blachford, Dinosaur, Egg, Pistol, Porkchop and Wasp lakes were not fished, as they were not expected to be directly affected by the project and were not being considered as fisheries reference lakes.

A previous study (SRC 1989) reported trout-perch in Thor Lake. No trout-perch were captured or observed in this study. Trout-perch typically inhabit deeper waters during the day and move into shallow areas at night; they are most commonly caught by seining at night (Scott and Crossman, 1998). No night seines were completed for this study, but a fine mesh gill net set in the littoral zone overnight did not capture any trout-perch.

Eight species were captured in the proposed seasonal dock site bay on Great Slave Lake (Table 6-9). For Great Slave Lake, the goals were to identify species that use habitat within the seasonal dock site bay and to characterize the fish habitat. The list of species in Table 6-9 is not a complete list of species that use the bay, as fish can travel freely in and out of the bay.

No fish were captured during winter sampling of Fred Lake in two daytime sets (9 hours and 7.25 hours) of two panels of a gang gill net in March 2009. The minnow traps set under the ice also did not catch any fish.

Table 6-9: Fish Species Observed or Captured during the 2008 and 2009 Field Programs

Lake	Fish Species[1]						
	NP	LWF	LC	SSC	STB	LT	CH
A	✓	✓	✓	✓	✓		
Ball							
Buck							
Carrot		✓	✓	✓	✓	✓	
Cressy							
Drizzle							
Elbow	✓	✓	✓	✓	✓		
Fred	✓	✓	✓				
Great Slave[2]	✓	✓	✓			✓	
Kinnikinnick	✓		✓	✓			✓

Lake	Fish Species[1]						
	NP	LWF	LC	SSC	STB	LT	CH
Long	✓	✓	✓	✓	✓		
Megan							
Murky	✓						
North Tardiff							
Redemption	✓	✓	✓	✓	✓		
Ring							
South Tardiff							
Thor	✓	✓	✓	✓	✓		
Thorn							
U	✓						

NOTES
[1] Northern pike (NP), lake whitefish (LWF), lake cisco (LC), slimy sculpin (SSC), ninespine stickleback (STB), lake trout (LT), lake chub (CH)
[2] The following species were also captured at Great Slave Lake: arctic grayling (*Thymallus arcticus*), burbot (*Lota lota*), longnose sucker (*Catostomus catostomus*), round whitefish (*Prosopium cylindraceum*)

Ring, Buck, Drizzle, Murky, Kinnikinnick, and Redemption were added to the sampling program in 2009; these lakes were sampled again in 2010 except for Kinnikinnick, which was rejected as a potential reference lake. Ball Lake was added to the sampling program in 2010.

The four gear types used for this study captured different species and sizes of fish. Only large bodied species (northern pike, lake whitefish, lake cisco and lake trout) were captured in the gill nets, except for one adult lake chub captured in Kinnikinnick Lake. Smaller fish (slimy sculpin, ninespine stickleback, and juvenile northern pike) were captured in the beach seines and by dip netting. Juvenile lake chub and one adult lake whitefish were also captured in a beach seine. One fish, a ninespine stickleback in Carrot Lake, was captured in a minnow trap.

Catch rates (CPUE) varied from 0.1 fish per hour (northern pike and lake cisco in several lakes; Figure 6-49) to 8.4 (lake cisco in Great Slave Lake). Northern pike was consistently the least abundant species caught, except in Kinnikinnick Lake, and in Murky and U lakes where no other species were caught. Fishing effort and catch in each lake for each year are presented in Table 6-10.

The average CPUE, calculated using data from all lakes in which a species was caught in at least one year, was highest for lake cisco and lake whitefish (1.2 fish/hour) and lowest for northern pike (0.3 fish/hour). However, the average CPUE for lake cisco was influenced by the high catch rates in Great Slave Lake; the average CPUE for lake cisco, excluding the Great Slave Lake catch rates, was 0.5 fish/hour. Lake cisco catch rates were the most variable of the three large bodied species; possibly due to the schooling behavior of these smaller fish.

Figure 6-49: Catch per unit Effort (Fish per Hour) for Lake Cisco, Lake Whitefish and Northern Pike by for each Lake and Year

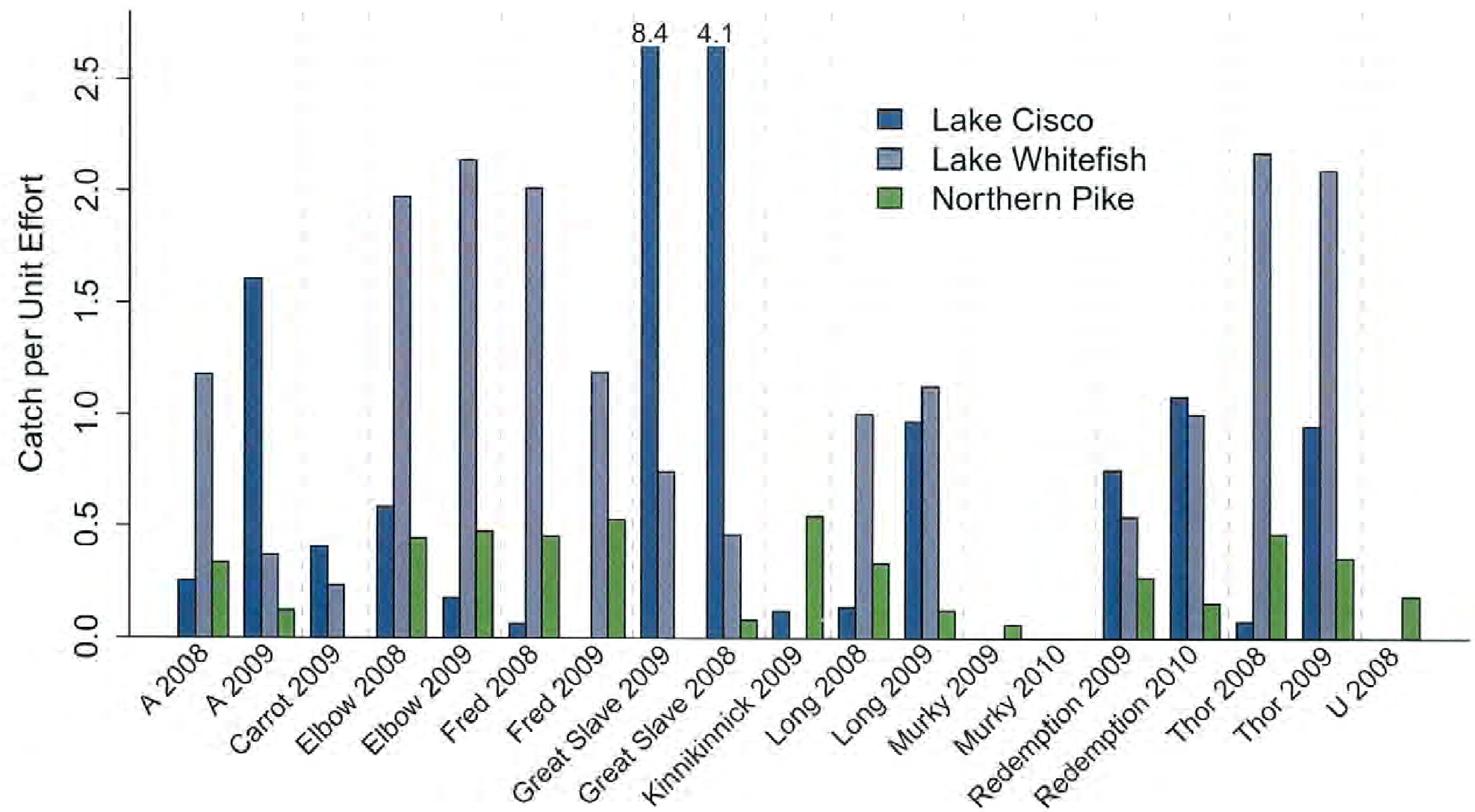


Table 6-10: Catch rate (CPUE) of Large Bodied Species Captured in Gill Nets
(Effort is measured in hours and number of nets set is shown in parentheses. CPUE is measured in fish per hour and total number of fish is shown in parentheses. (–) indicates that no nets were set.)

Lake	2008				2009				2010			
	Effort (hours)	NP[1] (fish/h)	LWF[1] (fish/h)	LC[1] (fish/h)	Effort (hours)	NP[1] (fish/h)	LWF[1] (fish/h)	LC[1] (fish/h)	Effort (hours)	NP[1] (fish/h)	LWF[1] (fish/h)	LC[1] (fish/h)
A	23.8 (1)	0.3 (8)	1.2 (28)	0.3 (6)	16.2 (1)	0.1 (2)	0.4 (6)	1.6 (26)	–	–	–	–
Ball	–	–	–	–	–	–	–	–	21.4 (1)	0	0	0
Buck	–	–	–	–	17.6 (1)	0	0	0	18.3 (1)	0	0	0
Carrot	–	–	–	–	34.4 (2)	0	0.2 (8)	0.4 (14)	–	–	–	–
Cressy	31.3 (2)	0	0	0	17.1 (1)	0	0	0	–	–	–	–
Drizzle	–	–	–	–	15.8 (1)	0	0	0	23.5 (1)	0	0	0
Elbow	36.0 (2)	0.4 (16)	2.0 (71)	0.6 (21)	33.7 (2)	0.5 (16)	2.1 (72)	0.2 (6)	–	–	–	–
Fred	15.4 (1)	0.5 (7)	2.0 (31)	0.1 (1)	15.2 (1)	0.5 (8)	1.2 (18)	0	–	–	–	–
Great Slave	37.0 (2)	0.1 (3)	0.5 (17)	4.1 (150)	36.3 (2)	0	0.7 (27)	8.4 (304)	–	–	–	–
Kinnikinnick	–	–	–	–	33.1 (2)	0.5 (18)	0	0.1 (4)	–	–	–	–
Long	71.9 (4)	0.3 (24)	1.0 (72)	0.1 (10)	32.1 (2)	0.1 (4)	1.1 (36)	1.0 (31)	–	–	–	–
Megan	20.9 (1)	0	0	0	16.8 (1)	0	0	0	–	–	–	–
Murky	–	–	–	–	16.4 (1)	0.1 (1)	0	0	18.3 (1)	0	0	0
Redemption	–	–	–	–	33.3 (2)	0.3 (9)	0.5 (18)	0.8 (25)	38.1 (2)	0.2 (6)	1.0 (38)	1.1 (41)
Ring	–	–	–	–	18.7 (1)	0	0	0	14.8 (1)	0	0	0
South Tardiff	15.0 (1)	0	0	0	17.1 (1)	0	0	0	–	–	–	–
Thor	38.7 (2)	0.5 (18)	2.2 (84)	0.1 (3)	30.7 (2)	0.4 (11)	2.1 (64)	0.9 (29)	–	–	–	–
Thorn	21.3 (1)	0	0	0	15.9 (1)	0	0	0	–	–	–	–
U	37.0 (2)	0.2 (7)	0	0	–	–	–	–	–	–	–	–

NOTES:
[1] NP=Northern Pike, LWF=Lake Whitefish, LC=Lake Cisco

CPUE values are influenced by many factors, including available habitat, type of gang gill net (floating or sinking), positions of gill nets within the lake, season, and time of day. The nets were all set overnight at the same time of year, but the positions within the lakes purposefully differed between years and habitats within the lakes were different as well. The types of nets set in each lake were generally the same between years: two nets (one floating and one sinking) were set in all larger lakes, and a single gill net was set in each smaller lake. All the smaller lakes were shallow enough that there was no functional difference between a floating net and a sinking net (both spanned the water column), except for A Lake (a sinking net was set in 2008, and a floating net in 2009).

Species catch rates were generally similar between years in each lake, and differences were generally attributed to the position of the nets within the lakes. The notable between year differences in CPUE occurred in A Lake for lake whitefish and lake cisco, and in Fred Lake for lake whitefish. In A Lake, from 2008 to 2009, the CPUE for lake whitefish decreased from 1.2 to 0.4 fish/hour, and the CPUE for lake cisco increased from 0.3 to 1.6 fish/hour. A Lake is deep but small, and was sampled with different gear types in the two years. The decrease in lake whitefish CPUE and increase in lake cisco CPUE is consistent with the switch from a sinking gill net to a floating gill net and sampling of different habitat, as lake whitefish frequently forage in benthic habitats and lake cisco typically forage in limnetic (upper water column) habitats. In Fred Lake there was a decrease in CPUE for lake whitefish of 0.8 fish/hour between 2008 and 2009. This change is difficult to interpret because Fred Lake is rare among the fish-bearing lakes studied, as it is suspected to be a sink habitat; for further discussion of Fred Lake please see the Cressy Group section below (Section 7.3).

6.4.2 Fish Habitat

Of the 20 lakes included in the fisheries study, 12 are fish-bearing (Table 6-11). All lakes that are considered non-fish-bearing are isolated from other water bodies and do not directly contribute food or nutrients to fish-bearing waters. Therefore, they are not considered fish habitat under the *Fisheries Act*, which defines “fish habitat” as *spawning grounds and nursery, rearing, food supply and migration areas on which fish depend directly or indirectly in order to carry out their life processes*.

Table 6-11: Fish-bearing Status and Criteria for Designation; (–) Indicates No Data Collected

Lake	Fish Caught	Isolated[1]	Winter DO[2] (mg/L)	Years of Fishing[3]	Large Plankton[4]	Fish-bearing	Confidence[5]
A	Y	Y	2.84 – 10.7	2	Y	Y	High
Ball	N	Y	–	1	–	N	High
Buck	N	Y	0.55 – 1.13	2	Y	N	High
Carrot	Y	–	–	1	–	Y	High
Cressy	N	Y	0.07 – 4.15	2	N	N	High
Drizzle	N	N	0.39 – 0.60	2	Y	Y[6]	Moderate
Elbow	Y	Y	3.63 – 11.3	2	N	Y	High
Fred	Y	N	0.24 – 4.98	2	N	Y[7]	High
Great Slave	Y	N	13.1 – 15.4	2	N	Y	High

Lake	Fish Caught	Isolated[1]	Winter DO[2] (mg/L)	Years of Fishing[3]	Large Plankton[4]	Fish-bearing	Confidence[5]
Kinnikinnick	Y	–	6.68 – 11.4	1	N	Y	High
Long	Y	N	0.25 – 10.10	2	N	Y	High
Megan	N	Y	0.14 – 2.31	2	N	N	High
Murky	Y	N	0.33 – 1.36	2	Y	Y[8]	High
North Tardiff	N	Y	0.38 – 0.47	2	Y	N	High
Redemption	Y	–	0.45 – 9.48	2	Y	Y	High
Ring	N	Y	0.44 – 1.50	2	Y	N	High
South Tardiff	N	Y	0.38 – 0.62	2	Y	N	High
Thor	Y	N	0.67 – 7.96	2	N	Y	High
Thorn	N	Y	0.25 – 5.93	2	Y	N	Moderate
U	Y	–	0.15 – 1.62	1	–	Y	High

NOTES

1 Indicates whether the lake is isolated from other lakes that are fish-bearing. See Section 4.1.

2 The range of DO concentrations measured in March 2008 and 2009 and April 2010 is shown (see Appendix E). Values less than 5 mg/L are below the minimum guideline for the Protection of Aquatic Life (CCME, 1999).

3 Years of fishing includes only fishing conducted as part of the 2008-2010 baseline study.

4 Large plankton include *Daphnia galeata* and species in the genera *Chaoborus* and *Heterocope* (see Appendix I).

5 Confidence is moderate if one of the criteria for the designation of non-fish-bearing waters was not met, or if no fish were captured in a lake that is considered fish-bearing.

6 Drizzle Lake is connected to Murky Lake and could be inhabited by fish. It is suspected to be a sink habitat due to low winter DO concentrations, although northern pike are known to tolerate very low dissolved oxygen concentrations.

7 Fred Lake is very shallow and has low winter DO concentrations. It is suspected to be a sink habitat for lake whitefish and lake cisco, into which fish migrate during the freshet and die during the winter.

8 Murky Lake is very shallow (<2 m) with low winter dissolved oxygen concentrations. It may be a sink habitat, but northern pike are known to tolerate very low dissolved oxygen concentrations so the population may be self sustaining.

Fish were captured in all the fish-bearing lakes except for one. No fish were captured in Drizzle Lake in two years of study, but Drizzle Lake is considered fish-bearing because Drizzle Out, the watercourse connecting it to Murky Lake, is passable to fish. However, the habitat quality is poor due to the seasonal barriers to migration (Drizzle Out is only passable during spring high flows) and the poor winter water quality. Any fish that does complete the migration from Thor Lake through Murky Lake to Drizzle Lake would probably die during the winter (the winter water quality in Murky Lake is also poor and would also likely result in winter kills).

Northern pike were caught in Murky and U lakes, despite their low winter DO concentrations. Northern pike tolerate low DO concentrations, so the fish may survive the winter in these lakes. However, fish passage is possible from Thor to Murky during the spring freshet so the fish presence in Murky may be a result of immigration. Fish passage in Murky Out is possible, but would be challenging for some fish due to dense vegetation in some locations, which may explain the absence of lake whitefish and lake cisco in Murky. Fish passage into U has not been investigated, and will not be investigated further as U is not considered a suitable reference lake for the project.

Northern pike, lake whitefish and lake cisco were caught in Fred Lake despite its low winter DO levels. As discussed above, northern pike may survive the winter in Fred Lake. However, no fish were caught in Fred Lake in March 2009 and fish passage from Thor to Fred is possible for all fish species. It is likely that any lake whitefish and lake cisco that enter Fred Lake during the spring do not survive the winter.

6.4.3 Fish Health

6.4.3.1 Length and Weight Measurements

Average fork length was calculated for northern pike (447 mm), lake whitefish (364 mm) and lake cisco (168 mm) caught in the study lakes (Table 6-12). Very few small northern pike and lake whitefish were caught; lake whitefish smaller than 100 mm were caught only in Redemption and Thor lakes, while northern pike smaller than 200 mm were caught only in A, Kinnikinnick, Long and Murky lakes. The largest fish of each species were a 825 mm northern pike in Redemption Lake, a 542 mm lake whitefish in Great Slave Lake, and a 405 mm lake cisco in A Lake. Fork length and weight measurements are presented in Appendix K.

Table 6-12: Average Length and Range of Length and Weight of Northern Pike, Lake Whitefish and Lake Cisco Caught in the Study Lakes (–) indicates no fish were caught

Lake	NP[1]		LWF[1]		LC[1]	
	Length (mm)	Weight[2] (g)	Length (mm)	Weight[2] (g)	Length (mm)	Weight[2] (g)
A	342 (25 – 509)	130 – 998	467 (263 – 525)	245 – 2,210	205 (112 – 312)	15 – 469
Carrot	–	–	311 (148 – 520)	38 – 1,976	164 (130 – 196)	29 – 76
Elbow	521 (384 – 773)	400 – 4,410	418 (219 – 474)	113 – 1,641	132 (117 – 203)	15 – 104
Fred	324 (220 – 442)	80 – 615	309 (135 – 446)	154 – 1,541	170 (114 – 205)	16 – 120
Great Slave	756 (729 – 793)	3,000 – 4,500	410 (338 – 542)	449 – 2,461	163 (108 – 405)	15 – 806
Kinnikinnick[3]	443 (152 – 694)	–	–	–	187 (133 – 241)	26 – 184
Long	430 (110 – 626)	115 – 1,580	351 (140 – 441)	96 – 1,140	144 (105 – 215)	11 – 124
Murky	177	38	–	–	–	–
Redemption	562 (280 – 825)	164 – >4,000	271 (97 – 528)	11 – 2,346	208 (106 – 292)	15 – 365
Thor	454 (250 – 631)	131 – 1,589	347 (71 – 440)	15 – 1,160	156 (116 – 219)	17 – 142
U	259 (250 – 284)	100 – 250	–	–	–	–

NOTES
[1] N=northern pike, LWF=lake whitefish, LC=lake cisco
[2] Weight measurements in were to the nearest 10 g in 2008 and 0.1 g in 2009
[3] Weight measurements at Kinnikinnick Lake were not reported due to field difficulties with the scale

The size of fish that can be caught is related to the fishing gear used. The smallest fish were caught in the beach seine, which had a very small mesh (5 mm). The gang gill nets tended to catch larger fish in their larger mesh panels and smaller fish in the smaller mesh panels; the majority of the lake cisco were caught in the two smallest panels of the gang gill nets.

The best-fit length-weight relationships accounted for 94 to 99% of the variation in the log-transformed data (Table 6-13). Figure 6-50 presents the untransformed length-weight data for the three species, with the back-transformed best-fit lines. The length-weight curves for Thor and Redemption lakes were significantly different for lake whitefish, but not for the other two species.

6.4.3.2 Condition-Relative Weight

Relative weight of individual fish was calculated for the three large bodied species present in most of the fish-bearing study lakes: northern pike, lake whitefish and least cisco. The effects of lake and year on the relative weights of each species were examined using a two factor ANOVA. There was a strong lake effect but no year effect. Figure 6-51 presents the mean relative weights and standard deviations of the three large bodied species by lake. The mean relative weights of lake whitefish and lake cisco were highest in Fred Lake (112 and 102, respectively). Lake whitefish relative weight was lowest in Carrot Lake (88), followed by Long Lake (90), while the lowest relative weight for lake cisco was in Elbow Lake and Great Slave Lake (74). The mean relative weight of northern pike was highest in U Lake (112), followed by Great Slave Lake (104), and lowest in Elbow Lake (82).

The sample timing for this study (September and early October) may explain why northern pike tended to have lower relative weights in this study compared to lake whitefish. Relative weights vary throughout the year due to seasonal patterns of sexual maturation, particularly for female fish. Lake whitefish and lake cisco spawn in late fall, and many were ripe when collected. Northern pike spawn in the spring, and had developing gonads when collected.

Table 6-13: Length-Weight Linear Regression Results for Northern Pike, Lake Whitefish and Lake Cisco

Model	Equation[1]	r^2	Source	df	Mean Squares	F-ratio	p
Northern Pike							
All lakes	$log_{10}W = (-5.02 \pm 0.18) + (2.94 \pm 0.07)\ log_{10}L$	0.98	$log_{10}L$	1	21.0	7,523	<0.01
			residuals	137	0.003		
Lake Whitefish[2]							
All lakes	$log_{10}\ W = (-5.25 \pm 0.09) + (3.15 \pm 0.04)\ log_{10}\ L$	0.98	$log_{10}L$	1	138	28,907	<0.01
			residuals	558	0.005		
Thor	$log_{10}\ W = (-5.15 \pm 0.25) + (3.11 \pm 0.10)\ log_{10}\ L$	0.96	lake	1	9.79	2,194	<0.01
Redemption	$log_{10}\ W = (-5.36 \pm 0.09) + (3.21 \pm 0.04)\ log_{10}\ L$	0.99	$log_{10}L$	1	70.2	15,734	<0.01
			residuals	189	0.004		
Lake Cisco							
All lakes	$log_{10}\ W = (-5.52 \pm 0.16) + (3.24 \pm 0.07)\ log_{10}\ L$	0.94	$log_{10}L$	1	63.8	8,250	<0.01
			residuals	524			

NOTES:
[1] Regression equations are presented with 95% confidence intervals for the model coefficients
[2] Thor and Redemption lakes significantly differed for lake whitefish. The comparative model results and lake-specific regression equations are presented

Figure 6-50: Length-weight Relationships of Northern Pike, Lake Whitefish and Lake Cisco

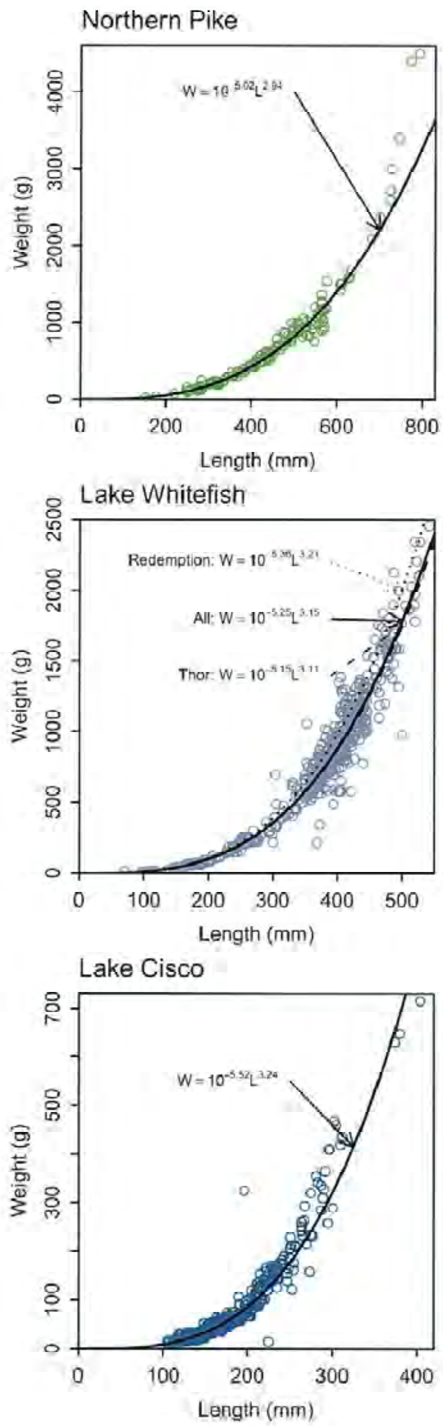
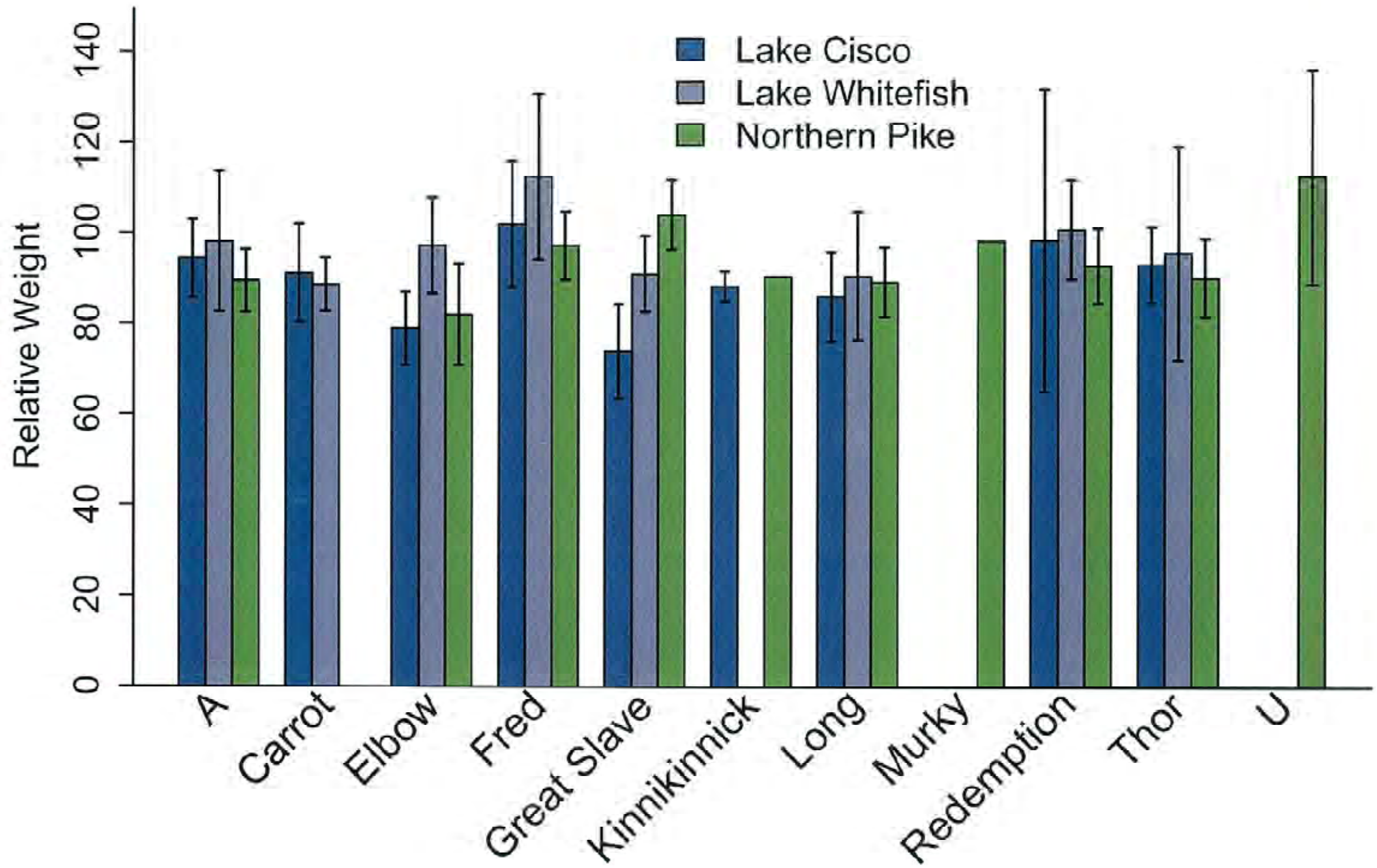


Figure 6-51: Mean Relative Weights with Standard Deviations of Northern Pike, Lake Whitefish and Lake Cisco by Lake



6.4.3.3 Age

Scales were used to age subsamples of the northern pike and lake whitefish collected in 2008. Otoliths were used to age subsamples of the lake whitefish and lake cisco collected in 2009 and 2010, and cleithra were used to age subsamples of the northern pike collected in 2009 and 2010. The range of ages for each species in each lake, for all years, is presented in Table 6-14.

Table 6-14: Age Ranges of Northern Pike Sampled in 2008 and 2009 and Lake Whitefish. A (–) indicates that no age structures were collected, or that the data are not yet available.

Lake	NP[1]	LWF[1]	LC[1]
A	2 – 5	6 – 28	1 – 11
Elbow	4 – 10	4 – 28	–
Fred	1 – 4	1 – 7	–
Great Slave	–	6 – 27	1 – 13
Kinnikinnick	2 – 10	–	–
Long	2 – 7	3 – 19	–
Murky	2	–	
Redemption	3 – 18	2 – 34	1 – 8
Thor	2 – 7	3 – 23	–
U	2 – 3	–	–

NOTE:
[1] N=northern pike, LWF=lake whitefish, LC=lake cisco

The oldest northern pike and lake whitefish were both captured in Redemption Lake (19 and 34 years, respectively). The oldest lake cisco was captured in Great Slave Lake. Very few one year old fish were captured; one lake whitefish and one northern pike were captured in Fred Lake, and five lake cisco were captured, three in A Lake and one each in Great Slave and Redemption lakes. The ages of subsampled fish are presented in Appendix K.

6.4.3.4 Organosomatic Indices

A subsample of fish caught in each lake was returned to the camp laboratory for further sample collection and measurements. The organosomatic indices are the ratios of organ weight to total body weight. The hepatosomatic index compares the liver weight to body weight, while the gonadosomatic index compares the gonad (ovary) weight to body weight. Gonad samples revealed that the lake whitefish and lake cisco were not yet mature, so the organosomatic index was not calculated for any of the study fish. The average hepatosomatic indices for each species in each lake are presented in Table 6-15. The hepatosomatic index tended to be highly variable among the lakes and appeared to vary with fish length, although the relationship between fish size and the index was not investigated (see Appendix J for data). Increases in relative liver weight can be an indication of poor health.

Table 6-15: Hepatosomatic Index Values (%) for Northern Pike, Lake Whitefish and Lake Cisco Collected in All Years

Lake	NP[1]		LWF[1]		LC[1]	
	n	mean ± SD	n	mean ± SD	n	mean ± SD
A	8	0.014 ± 0.003	16	0.013 ± 0.003	22	0.009 ± 0.004
Carrot	–	–	7	0.009 ± 0.001	11	0.014 ± 0.005
Elbow	23	0.016 ± 0.005	24	0.014 ± 0.004	–	–
Fred	15	0.035 ± 0.055	24	0.014 ± 0.005	–	–
Great Slave	–	–	24	0.013 ± 0.004	20	0.009 ± 0.004
Kinnikinnick	12	0.018 ± 0.004	–	–	–	–
Long	16	0.019 ± 0.011	24	0.014 ± 0.005	–	–
Murky	1	0.018	–	–	–	–
Redemption	13	0.014 ± 0.007	24	0.011 ± 0.003	24	0.008 ± 0.001
Thor	23	0.015 ± 0.004	24	0.014 ± 0.004	–	–
U	7	0.012 ± 0.002	–	–	–	–

NOTE:
[1] N=northern pike, LWF=lake whitefish, LC=lake cisco

6.4.3.5 External and Internal Parasites

Large, easily visible external parasites, primarily leeches, were observed on fish in Elbow, Long, Redemption and Thor lakes (Table 6-16). The proportion of parasitized fish was generally low. Elbow had the highest parasite frequency, and was the only lake in which external parasites were observed on northern pike. Lake whitefish had the highest parasite frequency of the three species; more than one third (37%) of lake whitefish in Elbow were parasitized.

The most common type of internal abnormality observed was cysts in the outer tissues of the gastrointestinal tract, sometimes extending to other organs associated with the gastrointestinal tract such as the liver (see photo 39 in Appendix C). The cysts were 1-2 mm across and were light coloured and shiny (metallic appearance). It is assumed that these cysts were caused by a parasite. Fish with large numbers of cysts tended to have soft, discoloured livers. In some fish with large numbers of cysts, the gonads were severely underdeveloped. Nematode worms were also observed inside some lake whitefish, usually in the swim bladder or the gut.

As with external parasites, Elbow had the highest frequency of internal parasites–100% of dissected lake whitefish had the cysts. Lake whitefish also had the highest frequency of internal parasites of the three species examined. A high frequency of internal parasites was also observed in whitefish from Thor Lake (16 of 24 fish).

Table 6-16: Incidence of External and Internal Parasites

Lake	External[1]			Internal[1]		
	NP[2]	LWF[2]	LC[2]	NP[2]	LWF[2]	LC[2]
A	0 (4)	0 (5)	1 (26)	0 (8)	3 (17)	2 (22)
Carrot	–	0 (9)	0 (14)	–	1 (7)	0 (11)
Elbow	3 (16)	27 (72)	1 (6)	0 (23)	24 (24)	–
Fred	0 (8)	0 (18)	0 (2)	0 (8)	0 (12)	–
Great Slave	–	0 (27)	0 (304)	–	3 (24)	1 (20)
Kinnikinnick	0 (18)	–	0 (4)	0 (12)	–	–
Long	0 (6)	8 (37)	1 (31)	0 (16)	5 (24)	–
Murky	0 (1)	–	–	0 (1)	–	–
Redemption	0 (14)	2 (59)	1 (66)	0 (11)	15 (24)	2 (24)
Thor	0 (12)	1 (64)	1 (29)	1 (23)	16 (24)	–

NOTES:
[1] Values indicate the number of fish with observed parasites, values in parentheses indicate the total number of fish examined.
[2] N=northern pike, LWF=lake whitefish, LC=lake cisco

6.4.3.6 Tissue Metals

Muscle samples from northern pike and lake whitefish were tested for total mercury, and livers from the three large bodied species were tested for a suite of metals. Composite liver samples from each species in each lake were tested for rare earth metals.

Mercury

Muscle total mercury levels exceeded the BCMOE (2006) maximum level for unrestricted human consumption (0.1 mg/kg wet weight) in all lakes except Murky and U for northern pike, and Great Slave Lake for lake whitefish (Figure 6-52). The relationships between fish weight and muscle total mercury were weak when data were combined from all lakes (r^2 of 0.2 for lake whitefish and 0.34 for northern pike), but were stronger when lakes were examined independently (r^2 of up to 0.73 for Redemption Lake northern pike). In general, the relationship between fish size and muscle mercury level appears to differ between species and among lakes in the Thor Lake area. Fish tissue metals data are presented in Appendix L.

The regression relationships for the whole data set and for Thor and Redemption Lakes are presented in Table 6-17; muscle mercury level tended to increase more with fish size in Redemption Lake and less in Thor Lake compared to the whole population. Analyses of covariance showed differences between Thor and Redemption Lakes for both species (Table 6-17). Deep lakes, such as Long, A, Kinnikinnick, and Elbow, tended to have higher mercury levels than shallower lakes. Mercury levels in northern pike were generally higher than in lake whitefish, as expected based on their diets.

Figure 6-52: Muscle Total Mercury Levels in Northern Pike and Lake Whitefish, with Regression Results for Thor, Redemption, and All Lakes. Red lines: BC MOE unrestricted consumption guideline. Study lakes identified by their first letter.

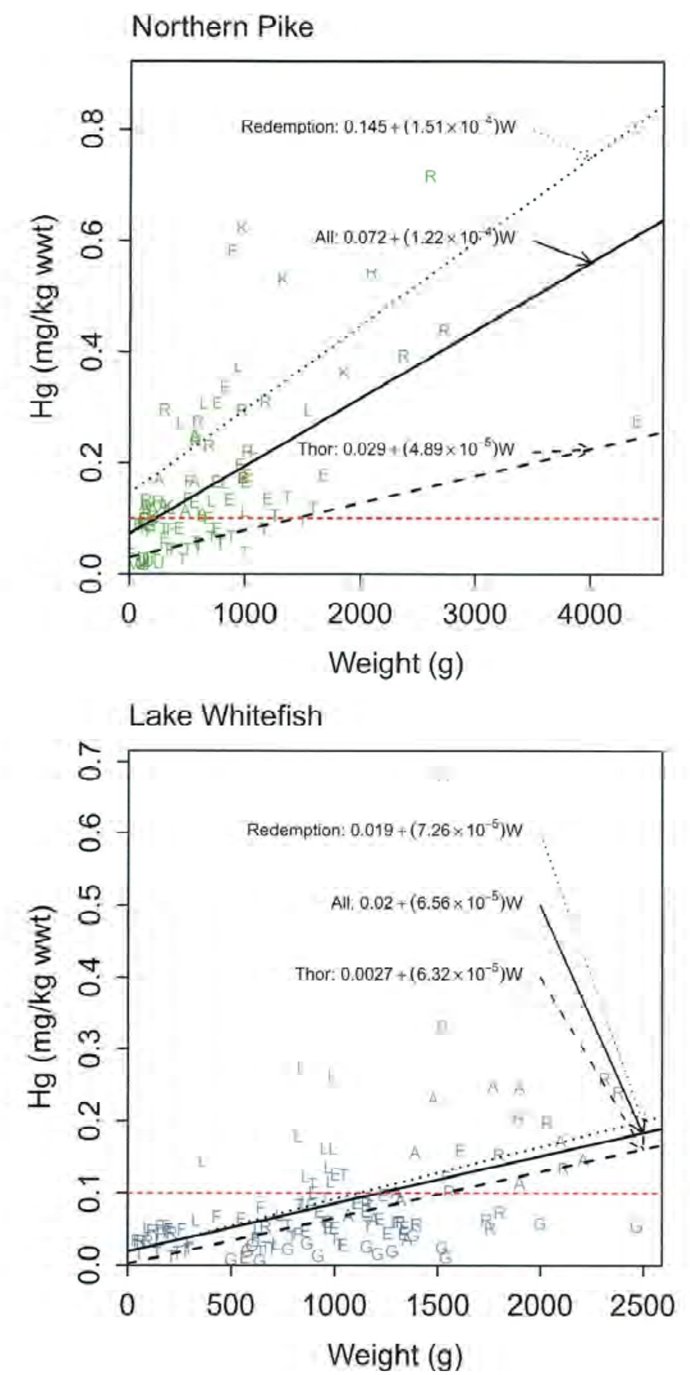


Table 6-17: Weight-Muscle Total Mercury Linear Regression Results for Northern Pike and Lake Whitefish

Model	Equation[1]	r^2	Source	df	Mean Squares	F-ratio	p
Northern Pike[2]							
All lakes	$Hg = (0.07 \pm 0.03) + (1.2 \text{ x } 10^{-4} \pm 3.4 \text{ x } 10^{-5})W$	0.34	weight	1	0.663	50.9	<0.01
			residuals	97	0.013		
Thor	$Hg = (0.03 \pm 0.02) + (4.9 \text{ x } 10^{-5} \pm 2.5 \text{ x } 10^{-5})W$	0.49	weight	1	$8.15 \text{ x } 10^{-3}$	16.6	<0.01
			residuals	17	$0.49 \text{ x } 10^{-3}$		
Redemption	$Hg = (0.14 \pm 0.09) + (1.5 \text{ x } 10^{-4} \pm 2.6 \text{ x } 10^{-5})W$	0.73	weight	1	0.238	29.8	<0.01
			residuals	11	0.008		
ANCOVA: Thor and Redemption			lake	1	0.511	121	<0.01
			weight	1	0.219	51.7	<0.01
			residuals	29	0.004		
Lake Whitefish[2]							
all lakes	$Hg = (0.02 \pm 0.03) + (6.6 \text{ x } 10^{-5} \pm 2.4 \text{ x } 10^{-5})W$	0.20	weight	1	0.175	29.7	<0.01
			residuals	119	0.702		
Thor	$Hg = (0.003 \text{ x } \pm 0.03) + (6.6 \text{ x } 10^{-5} \pm 2.4 \text{ x } 10^{-5})W$	0.42	weight	1	$8.92 \text{ x } 10^{-3}$	13.0	<0.01
			residuals	18	$0.69 \text{ x } 10^{-3}$		
Redemption	$Hg = (0.02 \pm 0.06) + (7.3 \text{ x } 10^{-5} \pm 4.1 \text{ x } 10^{-5})W$	0.43	weight	1	0.065	13.8	<0.01
			residuals	18	0.005		
ANCOVA: Thor and Redemption			lake	1	0.047	17.8	<0.01
			weight	1	0.073	28.0	<0.01
			residuals	37	0.003		

NOTES:

[1] Regression equations are presented with 95% confidence intervals for the model coefficients.

[2] Thor and Redemption lakes were not significantly different for either species. The results of the ANCOVA comparing the two lakes are not presented.

Metals Scan

Four metals (beryllium, bismuth, boron, and lithium) were below detection limits in all samples from all species. The majority of levels of the tested metals were low or within naturally expected ranges (Appendix L). Two metals that were elevated in the water and sediment samples, nickel and strontium, were generally below detection limits in tissue and did not show consistent patterns, although strontium levels were slightly elevated in fish from Fred Lake, where water and sediment strontium levels were also elevated.

Figure 6-53 shows mean values (with standard deviations) for eight metals. Aluminum, copper and uranium were included because they were elevated in some water and sediment samples, while arsenic, cadmium, lead, selenium, and thallium were included because they are known to be detrimental to fish health. Trends are as follows:

- Aluminum levels were frequently below detection limit in northern pike, but generally higher in lake whitefish. The variability was high, but the highest levels occurred in lake whitefish from Redemption Lake.
- Arsenic levels were generally above the US EPA (2000) guideline for unrestricted consumption for lake whitefish and lake cisco, but not for northern pike. The arsenic levels were highest in Great Slave Lake lake cisco.
- Cadmium levels were substantially higher in fish from Great Slave Lake than from the other lakes. In Great Slave Lake, the cadmium levels frequently exceeded the US EPA (2000) guideline for unrestricted consumption.
- Copper levels were highly variable in fish, although they appeared slightly higher in northern pike than lake whitefish. Copper was generally elevated in sediment samples.
- Lead levels were below BCMOE (2006) guidelines for consumption, and were usually below detection limits.
- Selenium levels were elevated for all species and lakes; many values were near or over the BCMOE (2006) guideline for the protection of aquatic life.
- Thallium was below the detection limit in most samples, except for the samples from Great Slave Lake (lake whitefish and lake cisco).
- Uranium was elevated in water samples from shallow lakes. Tissue uranium levels were highly variable; some high levels were detected in samples from Fred Lake (northern pike and lake whitefish), A Lake (lake whitefish) and Great Slave Lake (lake whitefish). However, the results differed depending on which lab did the analysis; results for samples sent to SRC were higher than samples sent to ALS.

Figure 6-53: Mean Al, As, Cd, Cu, Pb, Se, Tl, and U Values (mg/kg wet weight) from Northern Pike, Lake Whitefish and Lake Cisco Livers. Error Bars are Standard Deviations

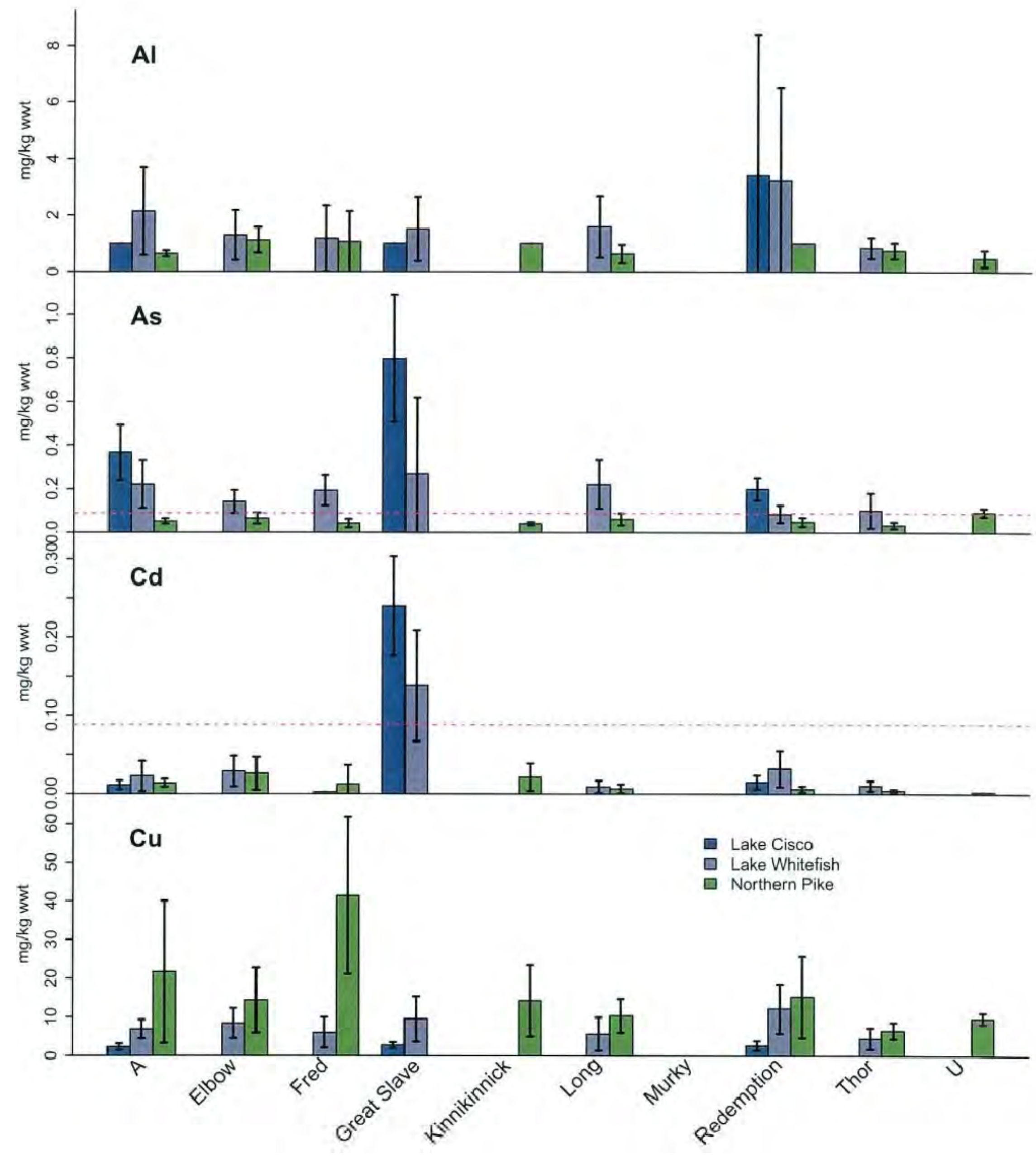
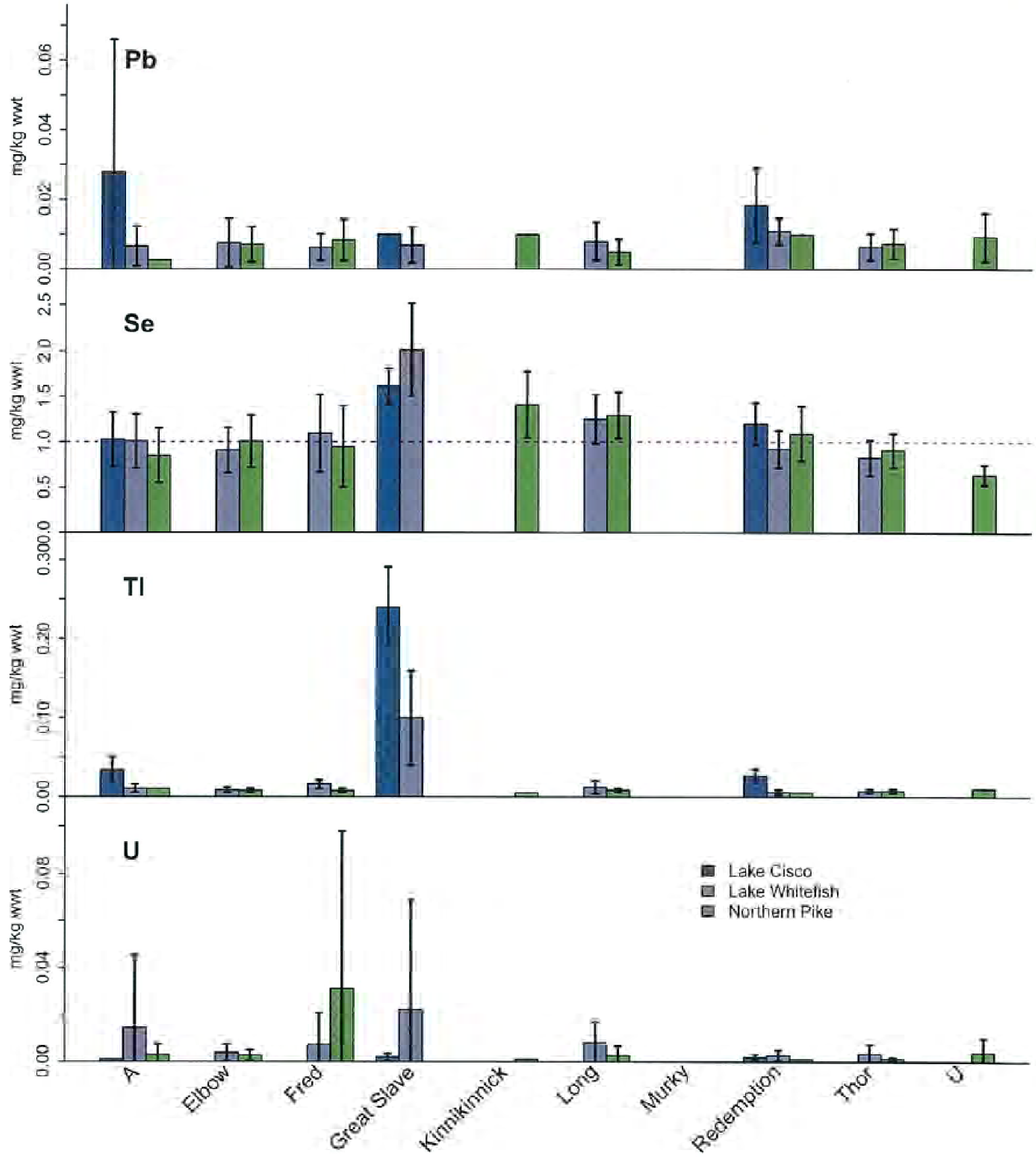


Figure 6-53: Continued



Rare Earth Elements

The rare earth element levels in the composite liver samples from all species and lakes were below detection limits, except for lake whitefish captured in 2008 from Great Slave Lake (cerium was 0.02 mg/kg wet weight and lanthanum was 0.01 mg/kg wet weight) and in 2009 from Fred Lake (lanthanum was 0.02 mg/kg wet weight).

QA/QC

Of the 105 analyses completed on field duplicates, 3 values differed by more than 30% of the mean of the two results (when the mean result was greater than ten times the detection limit). These were for calcium and iron in one lake whitefish collected in Thor Lake in 2009, and for calcium in one northern pike liver collected in Redemption Lake in 2009. Results of field duplicate analyses are presented in Appendix L.

The replicate analyses completed at ALS Laboratories were within the acceptable relative percent difference, and the percent recovery of metals from reference materials were within acceptable limits. QA/QC results from SRC are not available.

7 LAKE SURVEY RESULTS BY LAKE GROUP

This section presents the lake-specific key findings of the aquatics and fisheries baseline studies for each lake, organized by lake group. Table 6-1 lists the lakes by group.

7.1 Thor Group

The Thor Group is comprised of Thor and Long lakes and entirely overlies the Nechalacho ore body. Thor Lake has one defined inlet from Murky Lake and one defined outlet to Fred Lake (see Section 4.1). Long Lake has one defined inlet from South Tardiff and a potential second inlet from Porkchop; the inlet from Porkchop is depicted on topographical maps but was not investigated as it was outside the project footprint. Long Out, the stream between Thor and Long Lakes, appears to primarily flow from Long Lake to Thor Lake, but flows in the opposite direction at specific times of the year, (see Volume 1–Hydrology for more details).

7.1.1 Water and Sediment Chemistry

Water quality was assessed in both lakes from March 2008 to October 2010. The original stations were relocated to the deepest basins of each lake in October 2008 (two on Thor and one on Long). Both the original and the new stations were sampled in October 2008 and only the new stations were carried forward in the aquatics program.

The two stations sampled in Thor Lake (TL-06 and TL-07) had slight differences in maximum and mean values for some parameters (ammonia, nitrate, total phosphate, total aluminum and iron, and total and dissolved manganese and zinc). Observed differences may be related to proximity to shore

(Thor East (TL-07) is located approximately 5 m from a vertical bedrock cliff) and use of different sample depths.

Overall, both Thor and Long lakes are characterized by clear, hard water with low conductivity, low dissolved solids and a high acid-buffering capacity (high alkalinity, hardness and calcium). Nutrients, such as nitrate-nitrite, Total Kjeldahl Nitrogen, and phosphate (total and ortho) were typically low or below detection. Nitrate-nitrite typically increased during winter while Total Kjeldahl Nitrogen and total phosphate increased slightly in spring and/or fall. No guideline exceedances were observed for any metals during 2008 – 2010. One original Thor Lake station (TL-01) exhibited high total copper in March 2008 and Long Lake showed high dissolved cadmium and dissolved copper in September and October 2010, respectively, though these values are considered outliers.

Sediment chemistry at Thor and Long lakes indicated relatively high organic carbon and phosphorus levels, with some variability in total phosphorus. Arsenic exceeded CCME ISQG but not PEL in both lakes in 2009 and 2010, while nickel and copper also exceeded CCME ISQG in Long Lake in both years. In 2010, chromium exceeded CCME ISQG in both lakes, as did as nickel in Thor Lake. Particle size was variable between 2009 and 2010 in both lakes, indicating high fractions of silt and clay in 2009 and high fractions of sand and silt in 2010.

7.1.2 Aquatic Organisms

Chlorophyll *a* values fluctuated at the two Thor Lake stations: levels were higher at Thor East than Thor West except in September 2009. Chlorophyll *a* was generally higher in Thor East than at the Long Lake station; however values were generally similar in the two lakes in 2009 and 2010.

Phytoplankton data for 2009 and 2010 are summarized in Table 7-1. Thor Lake had higher phytoplankton taxon richness and diversity than Long Lake except in September 2010. Blue-green algae were predominant in Long Lake, and a variety of groups (blue-green, yellow-brown, diatom, cryptophyte) were predominant in Thor Lake. Phytoplankton taxon richness and diversity were similar at the two Thor stations in 2009 and 2010, but with some differences in composition.

Table 7-1: Thor Group Lakes: Phytoplankton and Zooplankton Richness, Diversity and Predominant Taxa in 2009 and 2010

Station	Phytoplankton			Zooplankton		
	Richness	Diversity	Taxa	Richness	Diversity	Taxa
June 2009						
Thor West	81	0.84	Blue-green (35%) Yellow-brown (33%) Diatoms (6%)	21	0.81	Rotifers (60%) Copepods (25%)
Thor East	81	0.84	Yellow-brown (36%) Blue-green (19%) Cryptophytes (12%) Diatoms (7%)	17	0.73	Rotifers (77%) Copepods (17%)
Long	63	0.73	Blue-green (86%)	–	–	–

Station	Phytoplankton			Zooplankton		
	Richness	Diversity	Taxa	Richness	Diversity	Taxa
September 2009						
Thor West	76	0.87	Blue-green (52%) Green (8%)	17	0.80	Rotifers (66%) Copepods (23%) Daphnia (7%)
Thor East	74	0.82	Blue-green (66%)	16	0.81	Rotifers (62%) Copepods (26%) Daphnia (9%)
Long	59	0.60	Blue-green (93%)	14	0.76	Rotifers (62%) Copepods (35%)
June 2010						
Thor West	85	0.86	Blue-green (42%) Cryptophytes (18%) Yellow-brown (17%)	17	0.79	Rotifers (62%) Copepods (28%)
Thor East	85	0.91	Yellow-brown (28%) Blue-green (16%) Cryptophytes (15%)	17	0.75	Rotifers (68%) Copepods (23%)
Long	54	0.77	Blue-green (58%) Yellow-brown (23%)	18	0.63	Rotifers (87%)
September 2010						
Thor West	109	0.68	Blue-green (84%)	16	0.80	Rotifers (56%) Copepods (33%) Daphnia (7%)
Thor East	100	0.50	Blue-green (81%)	13	0.79	Rotifers (47%) Copepods (42%) Daphnia (7%)
Long	76[a]	0.72[a]	Blue-green (87%)[a]	13[a]	0.77[a]	Rotifers (67%)[a] Copepods (23%)[a]

NOTE:
[a] Replicate sample was taken here; mean values are reported above

At the two Thor stations, zooplankton richness and diversity were similar in 2009 and 2010 and tended to be higher than in Long Lake (Table 7-1). Rotifers were predominant at all three stations and had similar predominant taxa. Copepods were common at all three stations (except Long in June 2010) and one cladoceran (*Bosmina longirostris*) was present at the Thor stations in the fall.

Benthic invertebrate data for 2009 and 2010 are summarized in Table 7-2. In 2009 and 2010, taxon richness and abundance were higher in Thor Lake than Long Lake. Richness, abundance and diversity were greatest at the Thor East station in 2009 and 2010 while evenness was greatest at Long Lake, showing a more homogenous benthic community than Thor Lake. Dominant taxa were the consistent between 2009 and 2010, being *Chironomidae* larvae at Thor West, *Calanoida* copepods at Long and co-dominance of *Chironomidae* larvae and fingernail clams (*Sphaeriidae*) at Thor East.

Table 7-2: Thor Group Lakes: Benthic Invertebrate Richness, Abundance, Diversity, Evenness and Predominant Taxa in 2009 and 2010

Station	Richness	Abundance (organisms/m^2)	Diversity	Evenness	Taxa
September 2009					
Thor West	6	1,180	0.15	0.20	Chironomidae (92%)
Thor East	13	3,300	0.63	0.21	Chironomidae (48%) Sphaeriidae (38%)
Long	3	34	0.45	0.60	Calanoida (71%) Sphaeriidae (14%) Chironomidae (14%)
September 2010					
Thor West	5	755	0.39	0.33	Chironomidae (75%) Sphaeriidae (20%)
Thor East	11	904	0.64	0.25	Chironomidae (42%) Sphaeriidae (42%) Gastropoda (6%)
Long	3	214	0.22	0.43	Calanoida (88%) Chironomidae (10%)

7.1.3 Fisheries

Both Thor and Long lakes are fish-bearing. The same five fish species (northern pike, lake whitefish, lake cisco, slimy sculpin and ninespine stickleback) were caught in both Thor and Long lakes. CPUE was approximately twice as high in Thor as in Long for lake whitefish (2.2 in 2008 and 2.1 in 2009 versus 1 and 1.1; see Figure 6-49). Lake cisco CPUE increased from 0.1 in both lakes in 2008 to roughly 9.5 in 2009.

The fish captured in the two lakes had similar size ranges and were comparable to other lakes in the study area (Table 6-12). Lake whitefish in Long Lake had a high external parasitism rate (8 of 37 fish) compared to other populations, many of which had no external parasites (Table 6-16). Lake whitefish in Thor Lake had a high internal parasitism rate (10 of 12 fish had cysts); three other populations had one or zero fish with observed internal parasites.

Northern pike and lake whitefish muscle mercury levels appeared to increase more with fish weight in Long Lake than in Thor Lake (this comparison was not tested statistically). Long Lake whitefish, in particular, had some of the highest mercury levels in muscle for fish of their size (Figure 6-52).

7.2 Cressy Group

The Cressy group consists of Cressy, Fred and A lakes. Cressy and Fred are contained within the Thor Lake syenite, outside of the ore body, while A is located within the Blachford Intrusive Complex, outside of the syenite.

Cressy is the headwater lake for this drainage system and has no defined inlet channel. Cressy Out is located at the west end of the lake and drains overland and through the ground to Fred Lake (there is no defined surface channel connecting Cressy and Fred Lakes). Fred Lake has one defined inlet (Thor Out) and one defined outlet (Fred Out) leading to A Lake. A Lake has two defined inlets (Fred Out and an unnamed inlet from the northwest) and one defined outlet. This drainage continues through several more lakes to Great Slave Lake at a point approximately 18 km from Thor Lake.

7.2.1 Water and Sediment Chemistry

Water quality was assessed in the Cressy group of lakes from March 2008 to September 2009. General parameters tended to be similar among the lakes; however, Fred and Cressy typically had greater variability in levels. All three lakes appeared to have a high acid-buffering capacity, indicated by high alkalinity, hardness and calcium. Total and dissolved iron typically exceeded CCME guidelines by up to 26 times in Fred Lake during winter. Fred Lake is one of the small, shallow lakes that shows strong seasonal fluctuations; large increases in iron during winter were accompanied by increases in conductivity, hardness, dissolved solids, ammonia, Total Kjeldahl Nitrogen, barium, manganese and strontium. There were no guideline exceedances for metals in Cressy or A lakes.

Guideline exceedances for metals in sediment in September 2009 included arsenic and zinc in Cressy Lake (both parameters exceeded the CCME PEL), and nickel in A Lake. Mercury was also relatively high in Cressy (0.111 mg/kg), though it did not exceed its guideline (0.17 mg/kg).

7.2.2 Aquatic Organisms

Chlorophyll *a* values were low (less than 1.0 µg/L) in all three lakes in June 2009. Fred Lake had the lowest chlorophyll *a* of all sampled lakes in June (0.294 µg/L). Chlorophyll *a* increased in September 2009, with Cressy exhibiting the highest value of the three lakes (3.39 µg/L) (Figure 6-30).

Though Fred Lake had low phytoplankton biomass in June 2009, it had the greatest richness and diversity of the three lakes (Figures 6-35 and 6-37 and Table 7-3). Phytoplankton richness and diversity increased in the three lakes from June to September with one exception (at A Lake, diversity decreased). Fred Lake continued to have the highest richness of the three lakes in September 2009; however, Fred and Cressy had similar diversity values. A replicate phytoplankton sample was taken at Cressy in September and showed moderately high mean values for richness and diversity.

In June 2009, a single cryptophyte (*Chroomonas acuta*) was the predominant phytoplankton taxon in Fred Lake, while the yellow-brown (*Dinobryon* sp.) was predominant in Cressy and A lakes. In September, three blue-green species (*Anacystis* cf. *elachista, Lyngbya limnetica* and *Agmenellum tenuissima*) were predominant in Fred, two cryptophytes (*C. acuta* and *Cryptomonas ovate/erosa*) were predominant in A Lake, and the yellow-brown *Dinobryon* sp. and cryptophyte *C, acuta* were predominant in Cressy. There were slight differences in the composition of the Cressy replicate samples in September, including the green alga *Sphaerocystis schroeteri* common in one sample and the blue-green alga *A.* cf. *elachista* in the other.

Table 7-3: Cressy Group Lakes: Phytoplankton and Zooplankton Richness, Diversity and Predominant Taxa in 2009

Station	Phytoplankton			Zooplankton		
	Richness	Diversity	Taxa	Richness	Diversity	Taxa
June 2009						
Cressy	64	0.65	Yellow-brown (57%) Green (8%) Cryptophytes (8%) Blue-green (8%)	–	–	–
Fred	74	0.85	Cryptophytes (31%) Yellow-brown (24%) Blue-green (6%) Green (6%)	–	–	–
A	53	0.81	Yellow-brown (60%) Cryptophytes (13%) Diatoms (6%) Green (5%)	21	0.53	Rotifers (61%) Copepods (19%)
September 2009						
Cressy	71[a]	0.89[a]	Yellow-brown (30%)[a] Cryptophytes (22%)[a] Blue-green (13%) Green (10%)	12[a]	0.57[a]	Copepods (56%)[a] Rotifers (34%)[a]
Fred	87	0.89	Blue-green (44%) Green (10%)	16	0.55	Rotifers (79%)
A	58	0.70	Cryptophytes (65%) Yellow-brown (6%) Green (5%)	10	0.22	Rotifers (98%)

NOTE:
[a] Replicate sample was taken here; mean values are reported above

Due to equipment issues, zooplankton samples were not collected from Fred and Cressy lakes in June 2009. In A Lake, taxon richness (21 taxa) was among the highest of all lakes studied, diversity was moderate, and the sample was dominated by two rotifers (*Keratella cochlearis* and *Kellicottia longispina*; Table 7-3) in June. In September 2009, taxon richness (10 taxa) and diversity were low compared with other lakes, and the community continued to be dominated by rotifers. Also, in Fred Lake, taxon richness was among the highest in the study area (16 taxa), while Cressy was near average (12 taxa). Both lakes had a median level of diversity, with three rotifer taxa (*Polyartha, K. cochlearis* and unidentified rotifers) dominating in Fred and a rotifers and copepods in Cressy Lake.

Benthic invertebrate taxon richness and abundance in A Lake was among the lowest of the study area (2 taxa, 303 organism/m^2), as shown in Figures 6-44 and 6-45 and Table 7-4 for September 2009. A Lake had a median level of diversity and a high evenness value, implying a homogenous community, which was dominated by *Cyclopoida* copepods and *Chironomidae*, with no other taxa present. Of the three lakes, Fred had the highest taxon richness (11 taxa), abundance and diversity, with a predominance of amphipods, fingernail clams (*Sphaeriidae*) and *Chironomidae*. *Chironomidae* were predominant in Cressy.

Table 7-4 Cressy Group Lakes: Benthic Invertebrate Richness, Abundance, Diversity, Evenness and Predominant Taxa in 2009

Station	Richness	Abundance (organisms/m^2)	Diversity	Evenness	Taxa
Cressy	6	2,020	0.23	0.22	Chironomidae (87%)
Fred	11	2,540	0.69	0.30	Amphipoda (47%) Sphaeriidae (23%) Chironomidae (16%)
A	2	34	0.49	0.98	Cyclopoida (57%) Chironomidae (43%)

7.2.3 Fisheries

Northern pike, lake whitefish and lake cisco were caught in A and Fred lakes. Slimy sculpin and ninespine stickleback were also caught in A Lake. No fish were caught in Cressy Lake.

In A Lake, the CPUE for lake whitefish decreased from 1.2 to 0.4 between 2008 and 2009, while CPUE for lake cisco increased from 0.3 to 1.6. These large changes are likely a result of the type of gill nets employed in the two years. A sinking net, which targets fish feeding and travelling near the lake bottom, was used in 2008, while a floating net, which targets limnetic fish, was used in 2009.

A and Fred lakes are fish-bearing (Table 6-11). However, Fred Lake may be a habitat sink (i.e., the population is sustained by immigration, not by reproduction within the lake). Fred is shallow (less than 2 m) and has low winter DO levels (0.24 to 4.98 mg/L), which could result in fish mortality, particularly for lake whitefish and lake cisco (pike are more tolerant of low oxygen levels). Fish passage from Thor Lake to Fred Lake is unimpeded during the spring freshet, so fish could be travelling to Fred from Thor. Winter fishing effort in March 2009 did not yield any fish in Fred Lake, supporting the hypothesis that fish do not survive winter conditions in Fred Lake.

Cressy Lake is considered non-fish-bearing due to its isolation from other lakes, low winter DO and multiple years of fishing effort with no catch (Table 6-11). Because it does not contribute food or nutrients directly to downstream fish-bearing waters, Cressy Lake is not considered fish habitat.

In A Lake, lake whitefish and lake cisco were generally larger than average (Table 6-12). The average length of lake whitefish caught in A Lake was the highest of any lake (467 mm), while the average length of lake cisco was the second highest (205 mm).

All of the species caught in Fred Lake had relative weights greater than 95.

Fish in both A and Fred had low parasite frequencies, except for internal parasites in lake whitefish in A Lake (three of 17 fish had cysts –Table 6-16).

7.3 Ring Group

The Ring Group consists of Ring, Ball, Buck, Drizzle, Murky and Egg lakes and is entirely contained within the Thor Lake syenite, outside the ore body. Ring is the headwater lake of this drainage system and drains through a wetland past Ball Lake to Buck Lake, which drains overland without a channel into Drizzle Lake. Drizzle Lake is connected to Murky Lake through a channel that is seasonally passable to fish. Egg Lake drains through the ground and overland into Drizzle.

7.3.1 Water and Sediment Chemistry

Water quality in Ring and Murky lakes was studied from March 2008 to October 2010. Egg Lake was sampled from March 2008 to September 2009. Buck and Drizzle were added to the baseline program in September 2009 after review of preliminary information from the prefeasibility study and were sampled until October 2010. Ball was not sampled in the aquatics program.

In Ring and Murky lakes during 2008-2010 and in Buck and Drizzle during 2009 – 2010, mean values of conductivity, hardness, total suspended solids, nitrate, ammonia and total phosphate were similar, with a slightly greater range of values for Ring Lake; these lakes appear to have high acid-buffering capacity. Mean values for most parameters tend to be lower and less variable in Egg Lake than in the others. Ring, Buck, Drizzle and Murky are all small, shallow lakes with strong seasonal fluctuations in water chemistry. Egg Lake is larger and deeper (maximum depth about 10 m).

Winter water quality was comparable in Ring, Buck Drizzle and Murky lakes, exhibiting anoxic and very hard water, with increased levels of several metals. Total and dissolved iron levels in Ring, Buck, Drizzle and Murky lakes were 17 to 42 times higher than the CCME guidelines in winter. Total iron exceeded the guideline in Egg Lake in March 2009, associated with TSS and turbidity and low dissolved iron levels.

Sediment was sampled in September 2009. Arsenic in sediment exceeded CCME ISQG in Ring, Drizzle, Murky and Egg lakes. The mean mercury level was also relatively high in Egg Lake (0.103 mg/kg) but did not exceed its guideline (0.17 mg/kg).

7.3.2 Aquatic Organisms

Chlorophyll *a* levels in Ring and Murky lakes were relatively high in June 2009 (2.52 and 2.14 µg/L, respectively), but though were lower in June 2010 (0.732 and 0.949 µg/L, respectively). Chlorophyll *a* levels in Buck and Drizzle were higher than those in Ring and Murky in June 2010 (1.37 and 1.65 µg/L, respectively). Phytoplankton biomass increased in Ring, Buck, Drizzle and Murky between June and September of both years; however, a greater increase was noted in 2010 than 2009 (Figures 6-32 and 6-33), likely related to differences in weather and sampling dates between years (see Section 6.3.1.1). The chlorophyll *a* sample from Egg Lake in June 2009 broke in transit; however, September 2009 chlorophyll *a* values were similar to other lakes in the study area.

Phytoplankton taxon richness and diversity were high and relatively similar among the Ring Group lakes in 2009 and 2010, with one exception of low diversity at Drizzle in September 2010 (Figures 6-34 to 6-37 and Table 7-5). Blue-green algae were predominant in all Ring Group lakes in 2009 and

2010, and there were similar common and predominant species. In Ring and Murky (sampled in 2009 and 2010), richness and diversity were similar in the spring and fall of both years and Murky had the highest levels of all eight lakes sampled in September 2010. Common and predominant species were generally similar in Ring and Murky through 2009 and 2010. A replicate phytoplankton sample was taken from Buck Lake in June 2010 and mean richness and diversity values were intermediate within the range for the lakes.

Table 7-5: Ring Group Lakes: Phytoplankton and Zooplankton Richness, Diversity and Predominant Taxa in 2009 and 2010

Station	Phytoplankton			Zooplankton		
	Richness	Diversity	Taxa	Richness	Diversity	Taxa
June 2009						
Ring	63	0.87	Blue-green (51%) Yellow-brown (22%) Diatoms (5%)	–	–	–
Murky	76	0.84	Blue-green (57%) Yellow-brown (9%)	17	0.58	Rotifers (57%) Copepods (39%)
Egg	78	0.70	Blue-green (46%) Yellow-brown (29%) Diatoms (7%)	17	0.61	Rotifers (87%) Copepods (6%)
September 2009						
Ring	66	0.79	Blue-green (86%)	11	0.56	Copepods (69%) Rotifers (23%)
Murky	79	0.85	Blue-green (73%)	14	0.54	Rotifers (71%) Copepods (26%)
Egg	75	0.85	Blue-green (74%)	14	0.71	Rotifers (58%) Copepods (39%)
June 2010						
Ring	67	0.82	Blue-green (75%)	16	0.72	Rotifers (64%) Copepods (30%)
Buck	66[a]	0.81[a]	Blue-green (79%)[a] Diatoms (5%)	18[a]	0.62[a]	Copepods (60%)[a] Rotifers (28%)[a]
Drizzle	82	0.85	Blue-green (51%) Diatoms (8%) Yellow-brown (7%)	16	0.72	Rotifers (76%) Copepods (16%)
Murky	72	0.89	Blue-green (66%) Yellow-brown (8%)	16	0.58	Rotifers (58%) Copepods (32%)

Station	Phytoplankton			Zooplankton		
	Richness	Diversity	Taxa	Richness	Diversity	Taxa
September 2010						
Ring	73	0.82	Blue-green (55%) Yellow-brown (14%) Diatoms (7%)	12	0.57	Rotifers (60%) Copepods (30%)
Buck	90	0.84	Blue-green (73%) Yellow-brown (10%)	15	0.53	Rotifers (61%) Copepods (31%)
Drizzle	74	0.57	Blue-green (76%)	15	0.63	Rotifers (62%) Copepods (28%)
Murky	86	0.89	Blue-green (69%)	11	0.82	Copepods (44%) Rotifers (31%)

NOTE:
[a] Replicate sample was taken here; mean values are reported above

Blue-green algae (two to four taxa of *Anacystis* cf. *elachista, Agmenellum tenuissima, Lyngbya* cf. *limnetica, Lyngbya cf. contorta, Anacystis cf. limneticus,* and *Anacystis* sp.) were predominant in all lakes of the Ring Group in 2009 and 2010. A yellow-brown alga (*Dinobryon* sp.) and a diatom (*Cyclotella glomerata*) were present in most lakes of the Ring Group in spring.

Richness and diversity values for zooplankton were higher in June than September in lakes of the Ring Group, though rotifers remained predominant (Table 7-5). Between 2009 and 2010, taxon diversity was similar in Ring and Murky and there was a slight decrease in taxon richness for Murky; however, in general, richness and diversity values were similar in all lakes of the Ring Group. *Kellicottia longispina* and/or *Keratella cochlearis* were typically the predominant rotifer species in all lakes, with copepods (unidentified *Calanoida/Cyclopoida*, *Leptodiaptomus pribilofensis, Diaptomidae*) also comprising a large proportion. Field equipment issues prevented collection of a zooplankton sample at Ring Lake in June 2009.

Benthic invertebrate data for 2009 are summarized in Table 7-6. Of the Ring group lakes sampled in 2009, Ring and Murky had the highest taxon richness (15 and 16 taxa, respectively) and diversity, while Egg had lowest richness, abundance and diversity. Evenness values were relatively low and similar among four of the five lakes and imply a relatively heterogeneous benthic invertebrate community comprised of several taxa. Across the study area in 2009, Drizzle showed the highest abundance (8,892 organisms/m^2), with low evenness (0.12) and moderately low diversity (0.32). These results are likely due to the predominance of one taxa (low diversity) but presence and relatively low abundance of 11 other taxa (more heterogeneous). *Chironomidae* were predominant in Buck and Drizzle and *Amphipoda* were predominant in Egg. In Ring, *Chironomidae* and *Amphipoda* were predominant and in Murky, *Chironomidae* and *Sphaeriidae* were predominant.

Table 7-6: Ring Group Lakes: Benthic Invertebrate Richness, Abundance, Diversity, Evenness and Predominant Taxa in 2009

Station	Richness	Abundance (organisms/m^2)	Diversity	Evenness	Taxa
Ring	15	1,770	0.79	0.32	Amphipoda (31%) Chironomidae (26%) Sphaeriidae (19%) Ostracoda (7%) Ceratopogonidae (6%)
Buck	11	4,320	0.61	0.24	Chironomidae (57%) Sphaeriidae (17%) Amphipoda (17%) Ceratopogonidae (8%)
Drizzle	12	8,890	0.32	0.12	Chironomidae (82%) Ceratopogonidae (8%)
Murky	16	2,270	0.78	0.28	Chironomidae (29%) Sphaeriidae (26%) Ceratopogonidae (21%) Amphipoda (15%)
Egg	7	279	0.46	0.26	Amphipoda (72%) Chaoboridae (9%) Tubificidae (7%) Calanoida (5%)

7.3.3 Fisheries

Egg Lake was not fished because it is outside of and upstream from the project area. Ring, Buck, Drizzle and Murky were fished in 2009 and 2010, and Ball Lake was fished in 2010. One northern pike was captured in Murky Lake and were also observed in Murky Lake near the outlet (May 2009) and the inlet from Drizzle Lake (May 2010). The captured northern pike was 177 mm long, weighed 38.1 g and was 2 years old. The relative weight of this one fish was good (98.2). It was immature and had no parasites.

Murky and Drizzle lakes are fish-bearing (Table 6-11); although no fish were captured in Drizzle Lake it is possible for fish to migrate from Murky Lake in the spring. Ring, Ball and Buck lakes are not fish-bearing (no fish captured in two years of effort—one year for Ball) and are not accessible to fish.

7.4 Reference Group

The Reference Group includes Kinnikinnick, Redemption, Carrot, and U lakes. These lakes are not connected by drainage, but were grouped together as they were examined as potential reference lakes. Kinnikinnick Lake is contained within the Thor Lake syenite, while Redemption, Carrot and U are located outside the Blachford Intrusive Complex. Carrot and U lakes were excluded as potential reference lakes after the initial fisheries assessment and water quality and aquatic biota data were not collected.

Surface drainage has not been investigated, but is inferred from topographic maps. Kinnikinnick Lake appears to have two inlets and one outlet, draining south through a series of small lakes into Great Slave Lake. Redemption Lake appears to have two inlets at its northeast and northwest basins, and one outlet draining south and west through a similar sized lake into Blachford Lake. Carrot Lake appears to drain to Great Slave Lake through two smaller lakes. U Lake appears to drain to Great Slave Lake by eventually joining the same watercourse that drains from Thor Lake.

7.4.1 Water and Sediment Chemistry

Water quality data was collected at Kinnikinnick Lake from March 2008 to September 2009. Redemption Lake was added to the baseline program in September 2009 and was sampled to October 2010. Though the lakes are not connected by drainage, general chemistry is typical of large, deep lakes in the study area (maximum depth of 20 and 15 m, respectively). Water quality is characterized by clear, moderately hard water (89 to 103 mg/L in Kinnikinnick and 86 to 99 mg/L in Redemption) with low conductivity, nutrients and organic carbon, and a low buffering capacity. No exceedances of WQG for metals were noted for Kinnikinnick or Redemption lakes and most metal concentrations were low and relatively stable in the seasons sampled.

Sediment chemistry at Kinnikinnick Lake indicates high total phosphorus (1,740 mg/kg) and moderate organic carbon (23.4 mg/kg) and Total Kjeldahl Nitrogen (2.38 mg/kg) levels. Copper and nickel exceeded ISQG, and cadmium was close to its ISQG. In Redemption Lake between 2009 and 2010, total phosphorus, organic carbon and Total Kjeldahl Nitrogen levels were similar, though lower than in Kinnikinnick Lake. Copper, nickel and arsenic exceeded CCME ISQG in all Redemption samples in 2009 and 2010 and arsenic exceeded the PEL in two of three replicate samples in 2009. Chromium exceeded its ISQG in two of three replicate samples in 2010.

7.4.2 Aquatic Organisms

Chlorophyll *a* in Kinnikinnick Lake was low in June and September 2009 (1.40 and 1.14 µg/L, respectively), suggesting ultraoligotrophic conditions. Chlorophyll *a* in Redemption was low in June 2010 (1.87 µg/L) and eight times higher in September 2010 (15 µg/L)

Phytoplankton richness in Kinnikinnick Lake in 2009 was moderate compared with other lakes in the study area. Diversity was relatively high in June and lower in September. Three blue-green algae (*Pseudanabaena*, *Lyngbya* cf. *limnetica* [June], *Lyngbya limnetica* [September]) were predominant in Kinnikinnick Lake in 2009 (Table 7-7).

Table 7-7: Reference Group Lakes: Phytoplankton and Zooplankton Richness, Diversity and Predominant Taxa in 2009 and 2010

Station	Phytoplankton			Zooplankton		
	Richness	Diversity	Taxa	Richness	Diversity	Taxa
June 2009						
Kinnikinnick	67	0.74	Blue-green (71%) Green (6%)	15	0.65	Rotifers (73%) Copepods (22%)
September 2009						
Kinnikinnick	71	0.44	Blue-green (75%)	16	0.71	Rotifers (83%)
June 2010						
Redemption	67	0.79	Blue-green (58%) Cryptophytes (7%) Yellow-brown (5%)	29	0.73	Rotifers (54%) Copepods (28%)
September 2010						
Redemption	62	0.22	Blue-green (88%)	20	0.44	Rotifers (88%) Cladoceran (5%)

Phytoplankton richness and diversity in Redemption Lake were moderate in June 2010 and lower in September (the lowest richness and diversity of all eight lakes sampled in 2010). Two blue-green algae (*Pseudanabaena catenata, Lyngbya limnetica*) were predominant in the spring and *Lyngbya limnetica* was predominant in September.

Zooplankton taxon richness was relatively low in Kinnikinnick Lake in 2009, with moderate diversity compared with other study area lakes (Table 7-7). Rotifers (three species, dominated by *Keratella cochlearis*) were predominant in 2009 and copepods were common in June.

In Redemption Lake, zooplankton taxon richness was the highest among the eight lakes sampled in June 2010 (Figures 6-40 and 6-41), with moderately high diversity. Richness was lower in September 2010 but still higher than the other eight lakes, with the lowest diversity of all eight lakes. Rotifers (*Kellicottia longispina, Keratella cochlearis*) were predominant in 2010 and unidentified *Calanoida/Cyclopoida* copepods (June) and the cladoceran *Bosmina longirostris* (September) were also common.

Benthic invertebrate data for 2009 and 2010 are summarized in Table 7-8; Kinnikinnick Lake was sampled in 2009 and Redemption Lake was sampled in both years. In 2009, taxon richness was low in Kinnikinnick and Redemption lakes, with moderate levels of diversity and evenness. *Chironomidae* were predominant in both lakes. In Redemption Lake, richness and predominant taxa were similar in 2009 and 2010, though diversity was lower in 2010 and lowest of all lakes sampled in 2010.

Table 7-8 Reference Group Lakes: Benthic Invertebrate Richness, Abundance, Diversity, Evenness and Predominant Taxa in 2009 and 2010

Station	Richness	Abundance (organisms/m^2)	Diversity	Evenness	Taxa
September 2009					
Kinnikinnick	5	899	0.53	0.42	Chironomidae (64%) Tubificidae (22%) Sphaeriidae (11%)
Redemption	4	173	0.40	0.42	Chironomidae (75%) Chaoboridae (19%)
September 2010					
Redemption	3	337	0.06	0.35	Chironomidae (97%)

7.4.3 Fisheries

All four potential reference lakes that were considered in 2008 and 2009 are fish-bearing, but only one, Redemption, has a fish species assemblage suitable for comparison with lakes that would be directly affected by project activities, particularly Thor Lake. All these lakes are known to have northern pike, lake whitefish, lake cisco, slimy sculpin and ninespine stickleback. Kinnikinnick Lake may be a suitable near-field reference lake for fisheries if lake whitefish are captured (northern pike, lake cisco, slimy sculpin, ninespine stickleback and lake chub were caught in Kinnikinnick). Lake trout, lake whitefish, lake cisco and ninespine stickleback were captured in Carrot Lake, but no northern pike. The presence of lake trout disqualifies Carrot as a potential reference lake for fisheries. U Lake was shallow and is known to support only northern pike; its shallow depth and lack of lake whitefish disqualify U as a potential reference lake for fisheries.

All size classes of fish present in other lakes in the study area were present in Redemption Lake (Table 6-12). The second largest (528 mm) and second smallest (110 mm) lake whitefish caught in the baseline study were caught at Redemption (a 542 mm lake whitefish was caught in Great Slave and a 71 mm lake whitefish was caught at Thor). The largest northern pike (825 mm) in the study was caught in Redemption and, while the lake cisco did not set study maxima or minima, a broad range of sizes were present (106 – 292 mm; whole project range 105 – 405 mm).

The frequency of internal and external parasites in fish from Redemption Lake was in the middle of the range documented for other lakes in the study area (Table 6-16).

The length-weight relationship for lake whitefish in Redemption Lake was significantly different from that in Thor Lake (Figure 6-50 and Table 6-13); however, this difference may not be biologically significant. Mercury levels were generally higher in fish from Redemption Lake than Thor Lake, and the relationships between fish weight and liver total mercury were significantly different for northern pike and lake whitefish (Figure 6-53 and Table 6-17). Metals levels in liver were generally similar in Thor and Redemption lakes, although aluminum levels in lake whitefish were higher on average in

Redemption Lake (3.2 mg/kg wet weight) than Thor Lake (0.8 mg/kg wet weight). This difference was not investigated statistically.

7.5 Tardiff Group

The Tardiff Group includes North Tardiff and South Tardiff lakes, which are located south of Thor Lake and contained within the Nechalacho ore body. North Tardiff Lake has one outlet, which is primarily a peaty wetland with surface and subsurface flows but no defined channel; an inlet was not located. South Tardiff has one defined outlet with surface and subsurface flows, draining south into Long Lake through a discontinuous channel. North Tardiff and South Tardiff lakes have been identified as possible thermokarst lakes, formed from and currently affected by the meltwater of underlying thawing permafrost (see Volume 4 – Terrain, Soils and Permafrost).

7.5.1 Water and Sediment Chemistry

Water quality data were collected from North Tardiff and South Tardiff lakes from March 2008 to September 2009. Generally, the two lakes are highly colored with high DOC levels, and relatively low mean values for conductivity, pH, hardness, alkalinity, and acid buffering capacity. Mean nutrient concentrations of the Tardiff lakes are comparable to other small shallow lakes in the study area, though they tend to have slightly greater nitrate and phosphate (total and ortho) concentrations. The two lakes exhibit strong season fluctuations in general chemistry, with conductivity, hardness, dissolved solids, nutrients and several metals increasing 2 to 32-fold in concentration during winter. Aluminum (total) and iron (total and dissolved) exceeded guidelines during winter in both lakes; dissolved aluminum also exceeded the BC guideline during winter at North Tardiff Lake.

High total and dissolved iron levels appear to be relatively consistent through all seasons in North Tardiff Lake (ranging from 232 to 3,110 µg/L dissolved iron). The dissolved iron BC guideline was also exceeded in June and September 2009. High iron concentrations through the year may be related to high DOC levels (mean of 56.9 mg/L), which provide organic compounds that act as chelators and prevent precipitation of iron from the water column in the open water season (Dodds 2002). South Tardiff also had a high mean DOC level (44.2 mg/L) but did not exhibit high iron levels in spring through fall. The disparity in iron concentrations between the two lakes may indicate differences in iron speciation, phytoplankton community composition and subsequent differences in phytoplankton-iron interactions (Öztürk, *et al.* 2003). High DOC levels, combined with higher nutrient and iron levels in the Tardiff lakes may be a result of the surrounding peatlands, given that peatlands are a major source of DOC, phosphorus and iron (Dillon and Molot 1997), and may also be influenced by the release of carbon and nutrients from the thermokarst process (Mack, *et al.* 2004).

The Tardiff lakes had the two highest levels of sediment organic carbon (38.4 mg/kg at North Tardiff and 41.2 mg/kg at South Tardiff) and Total Kjeldahl Nitrogen (3.11 mg/kg at North Tardiff and 3.41 mg/kg at South Tardiff) across the study area. However, low levels of metals in sediment were generally reported, with no exceedances of the CCME ISQG.

7.5.2 Aquatic Organisms

The Tardiff lakes had relatively high chlorophyll *a* levels in June, and South Tardiff had highest chlorophyll *a* level of any study area lakes (5.73 µg/L). Chlorophyll *a* levels were lower in both lakes in September.

South Tardiff Lake also had high phytoplankton richness and diversity in June compared to other lakes sampled in 2009; levels remained relatively high in September (Figures 6-36 to 6-37 and Table 7-9). Phytoplankton diversity in North Tardiff was also relatively high in June and September 2009. Predominant taxa in June 2009 were various species of blue-green algae (*Anacystis* cf. *aeruginosa* in North Tardiff Lake and *Anabaena flos-aquae* in South Tardiff Lake). Predominant taxa shifted in September were green algae in North Tardiff (primarily *Botryococcus braunii*) and cryptophytes (*Chroomonas acuta, Cryptomonas ovata/erosa*) and the green alga *B. braunii* in South Tardiff.

Table 7-9: Tardiff Group Lakes: Phytoplankton and Zooplankton Richness, Diversity and Predominant Taxa in 2009

Station	Phytoplankton			Zooplankton		
	Richness	Diversity	Taxa	Richness	Diversity	Taxa
June 2009						
North Tardiff	64	0.78	Blue-green (44%) Cryptophytes (12%) Green (11%)	21	0.38	Rotifers (78%) Copepods (9%)
South Tardiff	77	0.81	Blue-green (36%) Yellow-brown (21%) Diatoms (8%)	21	0.48	Rotifers (82%) Copepods (11%)
September 2009						
North Tardiff	43	0.79	Green (47%) Cryptophytes (23%) Blue-green (18%)	10	0.55	Rotifers (71%) Copepods (23%)
South Tardiff	70	0.82	Cryptophytes (36%) Green (32%) Yellow-brown (9%)	16	0.73	Rotifers (58%) Copepods (28%)

Zooplankton taxon richness in the Tardiff lakes was among the highest across study area lakes in June 2009, although diversity was among the lowest, implying predominance of one or two taxa (Figures 6-47 and 6-48 and Table 7-9). Taxon richness was lower and diversity was higher in both lakes in September 2009, signifying a more heterogeneous community than in June. A single rotifer (*Kellicottia longispina*) was predominant in both lakes in June and September; however, copepods became predominant in September, while other rotifer species also increased in abundance.

Benthic invertebrate data for 2009 are summarized in Table 7-10. Richness and abundance were higher in South Tardiff than North Tardiff and richness was among the highest values reported in the study area (17 taxa). Diversity and evenness were higher in North Tardiff, suggesting a more diverse benthic community comprised of higher and more uniform abundances of several taxa, compared to

South Tardiff. *Chironomidae* were predominant in both lakes, along with fingernail clams (*Sphaeriidae*) in North Tardiff.

Table 7-10: Tardiff Group Lakes: Benthic Invertebrate Richness, Abundance, Diversity, Evenness and Predominant Taxa in 2009

Station	Richness	Abundance (organisms/m^2)	Diversity	Evenness	Taxa
North Tardiff	9	221	0.71	0.38	Chironomidae (46%) Sphaeriidae (26%) Gastropoda (9%) Valvatidae (7%)
South Tardiff	17	3,390	0.54	0.13	Chironomidae (66%) Amphipoda (10%) Sphaeriidae (9%) Ceratopogonidae (5%)

7.5.3 Fisheries

The Tardiff lakes are not considered fish-bearing because no fish were captured in either lake after two years of fishing effort, the lakes are shallow and have low winter DO levels (<1 mg/L), and neither lake is connected to fish-bearing habitat by a passable watercourse (Table 6-11).

7.6 Tributary Group

The Tributary Group includes all lakes considered to be upstream of the Thor Group, with the exception of the Tardiff lakes; it is comprised of Megan, Pistol, Porkchop, Thorn and Wasp lakes. Thorn Lake is situated partially within the Nechalacho ore body, while the others are located within the Thor Lake syenite.

Surface drainage has been investigated for Thorn and Megan lakes, which have no defined surface inlets or outlets. Surface drainage from Wasp, Pistol and Porkchop lakes are inferred from topographic maps. Wasp and Porkchop lakes appear to have one outlet each, flowing into the west end of Long Lake. Pistol Lake appears to have one outlet, flowing south through two small lakes into Porkchop Lake; this drainage appears to be the only inlet of Porkchop Lake.

7.6.1 Water and Sediment Chemistry

Water quality data within the Tributary Group were collected from March 2008 to September 2009. Generally, large variations in mean levels of general parameters were noted for this group of lakes, due to differences in lake morphometry. Pistol and Wasp are shallow lakes (maximum depth of 2.1 and 1.8 m, respectively) with strong seasonal fluctuations in water chemistry, while Thorn and Porkchop are deeper lakes (maximum depth of 5.9 and 17 m), with less seasonal variation. As mentioned in Section 6.2.1, Megan Lake is an exception, in that it is a deeper lake (maximum 6.6 m) with considerable seasonal variation compared to other lakes of similar depth.

Within this group, Megan Lake had the highest mean values of conductivity, pH, hardness and total dissolved solids, and higher levels of some nutrients and metals. These characteristics could be related to its possible closed basin, greater influence of groundwater (particularly in winter), or thermokarst processes of the adjacent peatland on the west shore, though this has not been confirmed.

Water chemistry in Pistol and Wasp lakes generally showed higher mean values for conductivity, hardness, ammonia, total phosphate and total iron and arsenic than most other lakes in this group. Winter values of total and dissolved iron exceeded guidelines in both lakes. In contrast, Thorn and Porkchop lakes are similar to each other in general chemistry, with intermediate mean levels of conductivity, pH and hardness and low nutrient and metals levels. Porkchop Lake had a high value of dissolved copper in October 2008, though this value is considered an outlier and was excluded from statistical calculations.

Sediment chemistry also shows high variation among lakes in this group. Thorn, Megan, Wasp and Porkchop lakes had median levels of organic carbon and nitrogen, while mean arsenic levels exceeded the CCME ISQG in all four lakes (range 6.36 to 14.07 mg/kg). Mean values for nickel and copper also exceeded their guidelines in Porkchop (21.9 and 49 mg/kg, respectively), while Thorn had an exceedance for mean nickel (16.7 mg/kg). Conversely, Pistol Lake exhibited relatively low values of total organic carbon (4.34 mg/kg) and Total Kjeldahl Nitrogen (0.286 mg/kg) in comparison to other shallow lakes in the study area and no metal exceedances were reported for this lake.

7.6.2 Aquatic Organisms

Chlorophyll *a* in the Tributary lake group varied among lakes and seasons. In June, Wasp had the highest chlorophyll *a* concentration of the group (3.36 µg/L) and Megan had the lowest (0.930 µg/L). Chlorophyll *a* concentrations were higher in September in Thorn, Megan and Pistol lakes and lower in Wasp and Porkchop lakes. Thorn Lake had the highest chlorophyll *a* in September (3.88 µg/L) and Porkchop the lowest (1.26 µg/L) within this group.

Phytoplankton richness and diversity were relatively high within the Tributary lake group. Porkchop showed the highest diversity across the study area in June 2009, though was lower than the average in September 2009 (Figure 6-38 and 6-39 and Table 7-11). Trends from June to September 2009 were mixed within the Tributary Group: richness and diversity was higher in some lakes and lower in others. Blue-green algae were predominant in Pistol, Porkchop and Wasp lakes in both months. In Megan Lake, the yellow-brown *Dinobryon* was predominant in June and two blue-green *Anacystis* sp. were predominant in September. In Thorn Lake, the green alga *Gloeocystis ampla* and cryptophyte *Chroomonas acuta* were predominant in June and only *C. acuta* was predominant in September.

Table 7-11: Tributary Group Lakes: Phytoplankton and Zooplankton Richness, Diversity and Predominant Taxa in 2009

Station	Phytoplankton			Zooplankton		
	Richness	Diversity	Taxa	Richness	Diversity	Taxa
June 2009						
Megan	55	0.74	Yellow-brown (44%) Blue-green (23%) Diatoms (13%)	–	–	–
Pistol	57	0.80	Blue-green (54%) Yellow-brown (19%)	20	0.51	Copepods (75%) Rotifers (21%)
Porkchop	77	0.89	Blue-green (21%) Diatoms (20%) Cryptophytes (12%) Green (6%)	18	0.84	Rotifers (68%) Copepods (29%)
Thorn	56	0.80	Green (36%) Cryptophyte (27%) Yellow-brown (18%)	16	0.69	Rotifers (53%) Copepods (42%)
Wasp	73	0.78	Blue-green (61%) Yellow-brown (14%)	17	0.48	Copepods (70%) Rotifers (20%)
September 2009						
Megan	61	0.59	Blue-green (73%)	13	0.62	Rotifers (74%) Copepods (21%)
Pistol	67	0.90	Blue-green (53%) Diatoms (9%) Green (7%)	10	0.37	Rotifers (77%) Copepods (18%)
Porkchop	60	0.47	Blue-green (72%) Cryptophytes (9%)	14	0.68	Rotifers (55%) Copepods (35%)
Thorn	71	0.79	Cryptophytes (43%) Blue-green (18%) Green (10%)	13	0.62	Copepods (47%) Rotifers (45%)
Wasp	64	0.83	Blue-green (72%) Green (5%)	10	0.65	Rotifers (64%) Copepods (32%)

In June 2009, zooplankton richness was greatest in Pistol Lake; however, diversity within the Tributary lake group and across the study area was greatest in Porkchop (Figures 6-40 and 6-43 and Table 7-11). In Wasp and Pistol lakes, zooplankton richness was among the lowest across the study area and within the Tributary lake group in September 2009. Diversity was also lowest in Pistol within the Tributary lake group in September and moderate in the other four lakes. Between June and September 2009, zooplankton richness and diversity decreased, with one exception (higher diversity at Wasp). Rotifers and copepods were predominant in the Tributary lake group (Porkchop and Thorn in June and September; Wasp in September). In Pistol, unidentified copepods and *Diaptomidae* were predominant in June and the rotifer *Kellicottia longispina* was predominant in September.

Benthic invertebrate data for 2009 are summarized in Table 7-12. Richness and abundance among the Tributary lake group was highest and evenness was lowest in Pistol and Wasp lakes, implying higher abundances of several taxa (more heterogeneous community). Diversity was similar in lakes of the Tributary group and evenness was highest in Porkchop Lake (indicating a more homogenous benthic community, with *Chironomidae* and *Ceratopogonidae* predominant). Predominant taxa in the other lakes included fingernail clams (*Sphaeriidae*) in Megan, *Chironomidae* in Pistol, *Chironomidae* and fingernail clams in Thorn, and *Chironomidae* and *Amphipoda* in Wasp Lakes.

Table 7-12 Cressy Group Lakes: Benthic Invertebrate Richness, Abundance, Diversity, Evenness and Predominant Taxa in 2009

Station	Richness	Abundance (organisms/m^2)	Diversity	Evenness	Taxa
Megan	8	1,050	0.66	0.36	Sphaeriidae (55%) Chaoborus (15%) Amphipoda (12%) Chironomidae (7%) Calanoida (6%)
Pistol	16	6,680	0.70	0.21	Chironomidae (48%) Amphipoda (18%) Ceratopogonidae (14%) Sphaeriidae (13%)
Porkchop	4	91	0.59	0.61	Chironomidae (47%) Ceratopogonidae (42%) Ostracoda (5%) Nemata (5%)
Thorn	10	1,720	0.67	0.30	Sphaeriidae (41%) Chironomidae (40%) Calanoida (6%) Tubifidinae (6%)
Wasp	15	3,200	0.68	0.21	Chironomidae (46%) Amphipoda (28%) Sphaeriidae (18%)

7.6.3 Fisheries

Fisheries data were collected only for Megan and Thorn lakes, neither of which are considered fish habitat (Table 6-11). No fish were caught in either lake in two years of fishing effort; winter DO levels were 0.14 to 2.31 mg/L in Megan and 0.25 to 5.93 in Thorn; and no outlet watercourses were identified. Although the winter DO level in Thorn was greater than 5 mg/L (the CCME guideline for protection of aquatic life) at the top of the water column, large bodied zooplankton were observed in Thorn Lake, indicative of a lack of fish predators and supporting the non-fish-bearing designation.

7.7 Blachford Group

The Blachford group of lakes includes Dinosaur Lake and the sampled bay in Blachford Lake. Both lakes are situated within the Blachford Lake Intrusive Complex, outside the Thor Lake syenite. Surface drainage from these lakes has not been investigated and is inferred from topographic maps. Dinosaur Lake appears to have one inlet and one outlet, draining north through a series of lakes into Blachford Lake. The sampled bay in Blachford Lake appears to have one inlet, draining from several small lakes in the study area.

7.7.1 Water and Sediment Chemistry

Water quality data were collected in the Blachford group lakes from March 2008 to September 2009. Due to the size and depth differences of the two lakes, general chemistry is dissimilar. Blachford Lake is a large, clear lake and water quality in the bay reflected this (lower mean conductivity, hardness, and nutrients, no metal exceedances). Higher nutrient and TSS levels were measured at a shallower location sampled in the bay in March 2008.

Dinosaur is a small lake, with a maximum depth of 4.9 m (not considered shallow). Dinosaur Lake generally displayed seasonal variation in general parameters, with highest conductivity, hardness and dissolved solids levels in winter. Nitrogen levels generally were low in Dinosaur Lake, though mean total phosphate was relatively high (29.6 µg/L) compared with other lakes in the study area. Total and dissolved iron levels were higher than applicable guidelines in winter and levels of several other metals (i.e., manganese, strontium, uranium) also were higher in winter.

Sediment chemistry is also dissimilar in these two lakes. Blachford Lake had low concentrations of organic carbon, Total Kjeldahl Nitrogen and phosphorus, with no exceedances of guidelines for metals. Dinosaur Lake had relatively high values of organic carbon, Total Kjeldahl Nitrogen and phosphorus, and arsenic was higher than the CCME ISQG.

7.7.2 Aquatic Organisms

Blachford Lake had relatively low chlorophyll *a* values in June and September (0.626 and 1.42 µg/L), and Dinosaur had high values (4.90 µg/L in June and 14.6 µg/L in September, the highest level in the study area in September).

Phytoplankton richness, diversity and predominant taxa were similar in both lakes in June and September 2009 (Table 7-13), with small differences in composition. In Blachford, the blue-green *Lyngbya limnetica* was common or predominant in June and September. In Dinosaur, the blue-greens *Lyngbya contorta, L limnetica,* and *Anacystis* cf. *elachista* were predominant in both months.

Table 7-13: Blachford Group Lakes: Phytoplankton and Zooplankton Richness, Diversity and Predominant Taxa in 2009

Station	Phytoplankton			Zooplankton		
	Richness	Diversity	Taxa	Richness	Diversity	Taxa
June 2009						
Blachford	67	0.77	Blue-green (44%) Yellow-brown (19%) Green (8%)	18	0.77	Rotifers (79%) Copepods (12%)
Dinosaur	66	0.80	Blue-green (66%) Yellow-brown (9%) Diatoms (6%)	16	0.65	Rotifers (80%) Copepods (11%)
September 2009						
Blachford	73	0.94	Blue-green (15%) Green (11%) Cryptophytes (9%)	14	0.74	Rotifers (73%) Copepods (17%)
Dinosaur	75	0.80	Blue-green (77%)	14	0.69	Rotifers (60%) Copepods (34%)

Zooplankton taxon richness and diversity were relatively high in both lakes, though higher in Blachford than Dinosaur in June 2009 (Figures 6-40 to 6-43 and Table 7-13). Taxon richness was higher in both lakes in June than September and diversity was similar over that time. Rotifers were predominant in both lakes in June and September, with three to four species in Blachford (*Keratella cochlearis*, *Kellicottia longispina*, unidentified rotifers, *Polyartha* sp.) and two species in Dinosaur (*Keratella cochlearis*, *Kellicottia longispina*). Copepods (unidentified Cyclopoida and *Leptodiaptomus pribilofensis*) became predominant with rotifers at Dinosaur in September.

Benthic invertebrate data for 2009 are summarized in Table 7-14. Due to the hard sand and silt substrate at the Blachford sample station, only nine partial grabs could be collected, resulting in analysis of lower volumes of benthic material. Regardless, taxon richness and diversity were higher in Blachford than in other lakes of the study area samples in 2009 (Figures 6-45 and 6-46). Richness and diversity values were moderate in Dinosaur, and evenness was moderately low in both lakes. *Amphipoda* and *Chironomidae* were predominant in Blachford and Dinosaur lakes.

Table 7-14: Blatchford Group Lakes: Benthic Invertebrate Richness, Abundance, Diversity, Evenness and Predominant Taxa in 2009

Station	Richness	Abundance (organisms/m^2)	Diversity	Evenness	Taxa
Blachford	18	8,176	0.84	0.34	Amphipoda (25%) Chironomidae (21%) Ceratopogonidae (13%) Sphaeriidae (12%) Nemata (10%) Ostracoda (8%)
Dinosaur	12	683	0.66	0.24	Chironomidae (55%) Sphaeriidae (14%) Chaoboridae (12%) Ostracoda (6%)

7.7.3 Fisheries

No fisheries data were collected in Dinosaur or Blachford lakes.

7.8 Elbow Lake

Elbow Lake is primarily situated on the Blachford Lake Intrusive Complex, outside the Thor Lake syenite. Surface drainage has been investigated at Elbow; it is relatively isolated from other lakes in the study area. Elbow has one defined outlet at its south bay, draining through several wetland areas and overland into Great Slave (Elbow Out has no defined channel). Topography data do not indicate any surface inlets.

7.8.1 Water and Sediment Chemistry

Water quality data were collected in Elbow Lake at two stations from March 2008 to September 2009. Elbow Lake had intermediate values of conductivity, hardness and dissolved solids. Mean levels of nitrate and total phosphate were higher in Elbow than other deep lakes of the study area (i.e., Long, Kinnikinnick) and greater variation in the dataset was observed. No metals exceeded CCME or BC guidelines, though one outlier was noted at Elbow South (total zinc, 40.3 µg/L). Generally the two stations had similar general chemistry, although pH was more variable and mean levels of nitrate, Total Kjeldahl Nitrogen and total phosphate were slightly higher at Elbow South than at Elbow North. These may be related to differences in sampling depth and lake morphometry at the two stations.

Sediment quality was similar at the two Elbow stations, with the exception of mean organic carbon at Elbow South (twice the concentration of Elbow North). Metal concentrations were similar at the two stations; mean nickel levels were at the CCME ISQG at Elbow North (16 mg/kg) and just below the guideline at Elbow South (13.6 mg/kg).

7.8.2 Aquatic Organisms

Chlorophyll *a* concentrations were intermediate in Elbow Lake in June 2009 compared to other study area lakes, and were higher in September than June. Levels were higher at Elbow South than Elbow North in June and September 2009, likely due to higher nutrient concentrations at this station.

Phytoplankton taxon richness and diversity in Elbow was intermediate among study area lakes in June and September 2009, and was similar at the two stations in June (Table 7-15). Richness and diversity were lower at both stations in September than June (and lower at Elbow North than Elbow south in September) (Figures 6-35 and 6-37). The blue-green algae *Lyngbya limnetica* and *Aphanizomenon* sp. were predominant at both stations in June and September. *Dinobryon* sp. (yellow-brown algae) was also common at both stations in June.

Table 7-15: Elbow Lake: Phytoplankton and Zooplankton Richness, Diversity and Predominant Taxa in 2009

Station	Phytoplankton			Zooplankton		
	Richness	Diversity	Taxa	Richness	Diversity	Taxa
June 2009						
Elbow North	64	0.65	Blue-green (77%) Yellow-brown (7%)	13	0.77	Rotifers (77%) Copepods (17%)
Elbow South	67	0.68	Blue-green (79%) Yellow-brown (5%)	15	0.72	Rotifers (77%) Copepods (19%)
September 2009						
Elbow North	47	0.29	Blue-green (91%)	12	0.52	Rotifers (75%) Copepods (19%)
Elbow South	60	0.38	Blue-green (93%)	10	0.39	Rotifers (88%) Copepods (6%)

Zooplankton taxon richness was relatively low in Elbow Lake compared with the other study lakes in June and September 2009 (Figure 6-41 and Table 7-15). Diversity was relatively high in June, implying predominance of more than one species, and moderate in September. The rotifers *Keratella cochlearis, Kellicottia longispina, Keratella quadrata, Polyartha* sp. were predominant at both stations in June and *K. cochlearis* and *Polyartha* sp. were predominant in September. Unidentified copepods were common in June and September at both stations.

Benthic invertebrate data for 2009 are summarized in Table 7-16. Benthic taxon richness was relatively low at both stations in Elbow Lake. Abundance and diversity varied, and was higher at Elbow South than Elbow North, perhaps related to its shallower maximum depth (8 m at Elbow South vs. 14 m at Elbow North) and higher nutrient and phytoplankton levels. Evenness was also greater at Elbow South, where there were several common taxa. Predominant taxa included *Chironomidae* at Elbow North and fingernail clams (*Sphaeriidae*) at Elbow South.

Table 7-16: Elbow Group Lakes: Benthic Invertebrate Richness, Abundance, Diversity, Evenness and Predominant Taxa in 2009

Station	Richness	Abundance (organisms/m^2)	Diversity	Evenness	Taxa
Elbow North	8	592	0.40	0.21	Chironomidae (76%) Sphaeriidae (9%) Tubificidae (6%)
Elbow South	9	2,102	0.70	0.37	Sphaeriidae (44%) Chironomidae (24%) Amphipoda (21%) Tubificidae (10%)

7.8.3 Fisheries

Elbow Lake is fish-bearing, with higher than average catch rates compared to other lakes (Figure 6-49) for northern pike (0.4 – 0.5 fish/hour vs. 0.3 fish/hour) and lake whitefish (2 – 2.1 fish/hour vs. 1 fish/hour), but a lower than average catch rate for lake cisco (0.2 – 0.6 fish/hour vs. 1.1 fish/hour).

The most remarkable characteristic of fish from Elbow Lake was their very high rate of parasitism, the highest in the study area for the three large bodied species (Table 6-16). Elbow Lake was the only lake in which any parasites were observed on northern pike (3 of the 16 northern pike had external parasites), and it also had the highest rates of external (38%) and internal (100%) parasitism for lake whitefish. Rates of external and internal parasitism for lake whitefish at other lakes varied from 0 to 21% (21% in Long Lake) for external parasites and 0 to 83% for internal parasites (83% in Thor Lake).

Levels of metals in tissue of Elbow Lake fish were not distinctly different from levels in other lakes.

7.9 Great Slave Lake

The small gravel bay on Great Slave Lake was included in the study due to the potential for construction and use of a seasonal dock in this bay during mine operation. One defined inlet (in two intertwined channels) is present in this bay, receiving water from Elbow Lake and two small ponds.

7.9.1 Water and Sediment Chemistry

Water quality data were collected from Great Slave Lake from October 2008 to September 2009. Low values for mean conductivity, hardness, dissolved solids, nutrients and metals were reported. However, nitrate levels were relatively high, similar to those of Cressy and South Tardiff lakes.

The sediment in Great Slave Lake was relatively hard and difficult to sample with the grab; only one sample was obtained. Sediment chemistry shows low values for organic carbon, Total Kjeldahl Nitrogen, phosphorus and most metals; nickel was higher than the CCME ISQG (22.6 mg/kg).

7.9.2 Aquatic Organisms

Chlorophyll *a* levels were similar in June and September 2009 (1.03 and 1.08 µg/L, respectively) and lower than at any of the other study lakes in September 2009.

In June, phytoplankton richness and diversity (replicate samples) was low, and lower than in the other study lakes (Figures 6-35 and 6-37). This trend was also noted for September for richness though diversity was intermediate. The cryptophyte *Chroomonas acuta* was predominant in June and September, along with the blue-green alga *Lyngbya limnetica* in September (Table 7-17). Composition was similar in the replicate samples collected in June.

Table 7-17: Great Slave Lake: Phytoplankton and Zooplankton Richness, Diversity and Predominant Taxa in 2009

Station	Phytoplankton			Zooplankton		
	Richness	Diversity	Taxa	Richness	Diversity	Taxa
June 2009						
Great Slave	39[a]	0.48[a]	Cryptophytes (71%)[a] Blue-green (7%)[a] Diatoms (5%)	13[a]	0.68[a]	Copepods (82%)[a] Rotifers (11%)[a]
September 2009						
Great Slave	28	0.71	Cryptophytes (45%) Blue-green (35%) Yellow-brown (6%)	12	0.70	Rotifers (89%)

NOTE:
[a] Replicate sample was taken here; mean values are reported above

In June, zooplankton richness (replicate samples) was low, and among the lowest for the study lakes (Figure 6-41). Diversity in June was at an intermediate level and both richness and diversity remained similar from June to September. In June, copepods (unidentified *Calanoida/Cyclopoida*, unidentified *Cyclopoida*, *Limnocalanus macrurus*) and rotifers (*Keratella cochlearis, Kellicottia longispina*) were predominant. In September, *K. longispina*, *K. cochlearis*, unidentified rotifers and *Polyartha* were predominant (Table 7-17).

Benthic invertebrate data for 2009 are summarized in Table 7-18. Due to the hard silt and sand substrate at the Great Slave Lake station, only three grabs were obtained (instead of nine), resulting in a lower volumes of benthic material analyzed compared to the other lakes in the study area. Taxon richness and abundance were relatively low, perhaps related to the reduced sample volume analyzed. Diversity and evenness were intermediate, suggesting a moderately heterogeneous benthic community. Fingernail clams (*Sphaeriidae*) and amphipods (*Amphipoda*) were predominant and *Chironomidae* larvae were common.

Table 7-18: Great Slave Lake: Benthic Invertebrate Richness, Abundance, Diversity, Evenness and Predominant Taxa in 2009

Station	Richness	Abundance (organisms/m^2)	Diversity	Evenness	Taxa
Great Slave	8	693	0.69	0.41	Sphaeriidae (40%) Amphipoda (35%) Chironomidae (16%)

7.9.3 Fisheries

More species of fish were caught in Great Slave Lake than any other lake, as expected given the high known species and habitat diversity in Great Slave Lake (see Section 6.4.1). These included the largest lake whitefish (542 mm) and lake cisco (405 mm) in the fisheries study (Table 6-12). Catch rates were within the normal range for northern pike and lake whitefish, but were very high for lake cisco (8.4 fish/hour and 4.1 fish/hour in 2009 and 2008 respectively) compared to the study average (1.1 fish/hour). Parasite frequencies in Great Slave Lake were very low for all species (internal parasites were observed in one lake cisco of 20 dissected, and no other parasites were observed).

Total mercury levels in muscle of lake whitefish from Great Slave Lake generally were low. However, levels of metals (particularly cadmium and thallium) in livers of some lake whitefish and lake cisco were higher than in the other study lakes. Selenium and arsenic levels were also elevated in Great Slave Lake compared with the other lakes (Figure 6-53).

8 CLOSURE

Stantec has prepared this report for the sole benefit of Avalon Rare Metals Inc. for the purpose of documenting baseline conditions at its Thor Lake site. The report may not be relied upon by any other person or entity, other than for its intended purposes, without the express written consent of Stantec and Avalon. Any use of this report by a third party, or any reliance on decisions made based upon it, are the responsibility of such third parties.

The information provided in this report was compiled from existing documents and data provided by Avalon and field data compiled by Stantec. This report represents the best professional judgment of our personnel available at the time of its preparation. Stantec reserves the right to modify the contents of this report, in whole or in part, to reflect any new information that becomes available. If any conditions become apparent that differ significantly from our understanding of conditions as presented in this report, we request that we be notified immediately to reassess the conclusions provided herein.

This report addressed aquatics and fisheries issues that are typically examined by regulators during environmental assessments under the *Mackenzie Valley Resource Management Act*, as well as issues specifically requested by regulatory agencies (e.g., Fisheries and Oceans Canada). Long term monitoring requirements were also considered during the design of this study so that an effective monitoring plan can be efficiently prepared for the mine operation period.

9 LITERATURE CITED

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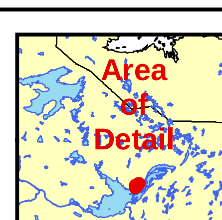
APPENDIX A

Maps

Hydrology Technical Data Report
Thor Lake Project, Nechalacho Deposit

Fisheries Stream Sites



AVALON RARE METALS INC.

PREPARED BY Stantec

DRAFT DATE 20/12/2010		SCALE 1:25,000	
REVISION DATE		PROJECT 123510431	FIGURE NO. 2-1
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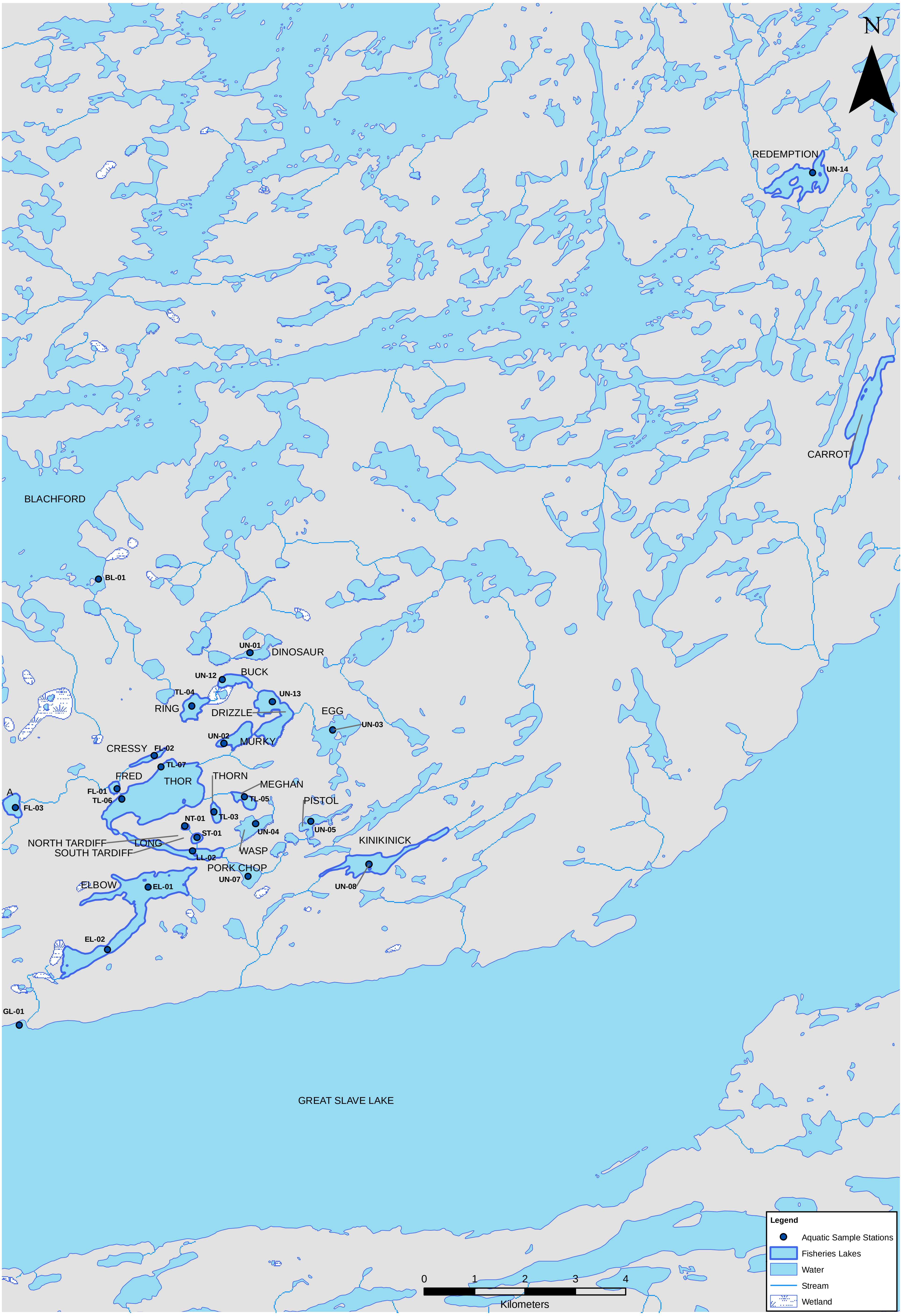
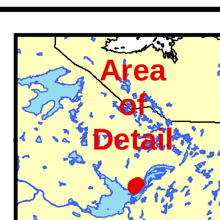


Hydrology Technical Data Report
Thor Lake Project, Nechalacho Deposit

Fisheries and Aquatic Lake Sites



PREPARED BY Stantec			
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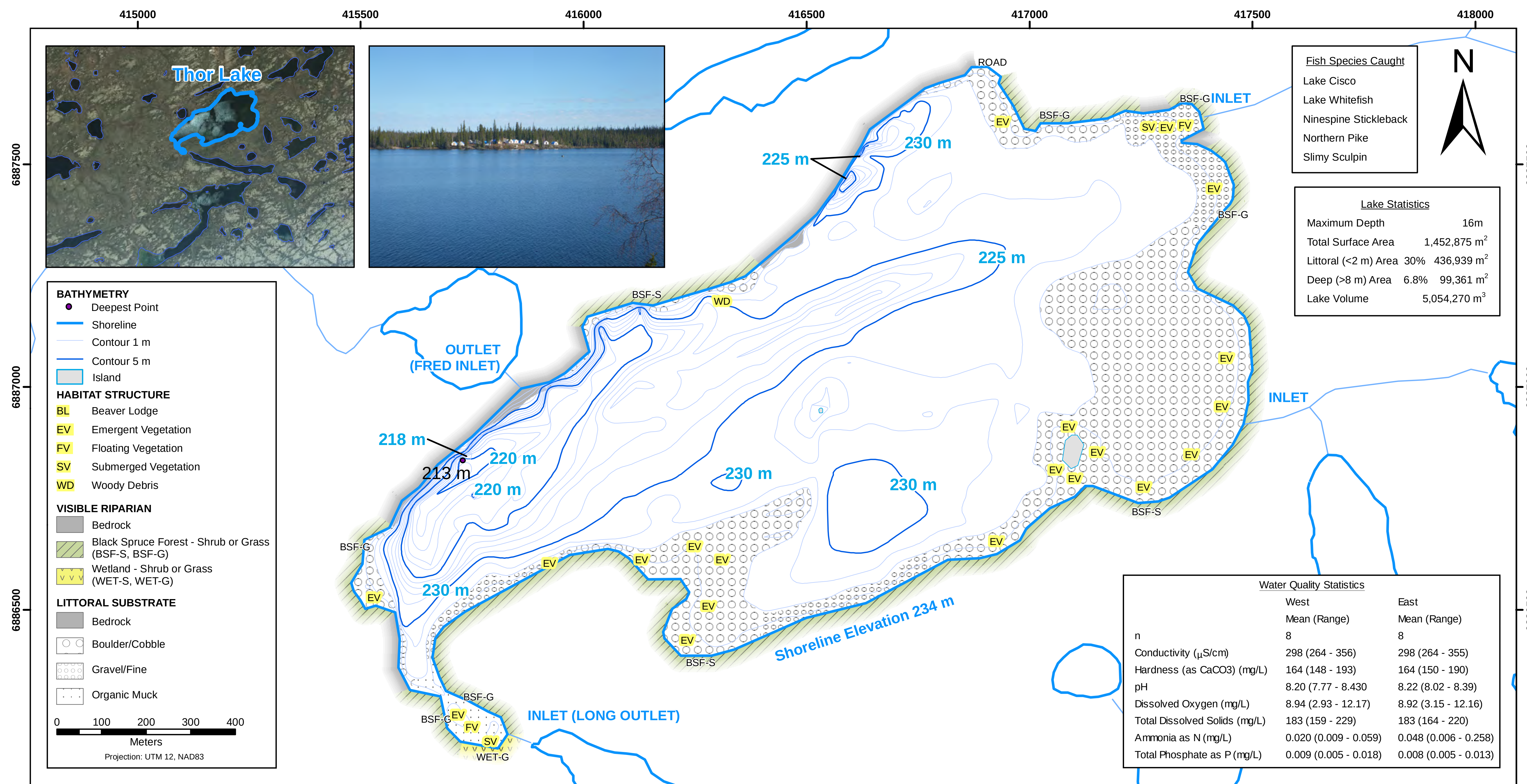

Lake Statistics

Maximum Depth		16m
Total Surface Area		1,452,875 m^2
Littoral (<2 m) Area	30%	436,939 m^2
Deep (>8 m) Area	6.8%	99,361 m^2
Lake Volume		5,054,270 m^3

Water Quality Statistics

	West Mean (Range)	East Mean (Range)
n	8	8
Conductivity (μS/cm)	298 (264 - 356)	298 (264 - 355)
Hardness (as CaCO3) (mg/L)	164 (148 - 193)	164 (150 - 190)
pH	8.20 (7.77 - 8.430	8.22 (8.02 - 8.39)
Dissolved Oxygen (mg/L)	8.94 (2.93 - 12.17)	8.92 (3.15 - 12.16)
Total Dissolved Solids (mg/L)	183 (159 - 229)	183 (164 - 220)
Ammonia as N (mg/L)	0.020 (0.009 - 0.059)	0.048 (0.006 - 0.258)
Total Phosphate as P (mg/L)	0.009 (0.005 - 0.018)	0.008 (0.005 - 0.013)

Thor Lake Rare Earth Metals Project

THOR LAKE HABITAT

Area of Detail

AVALON RARE METALS INC.

PREPARED BY Stantec

DRAFT DATE 11/08/2009			SCALE 1:8,500	
REVISION DATE 23/12/2010			PROJECT	FIGURE NO. 1
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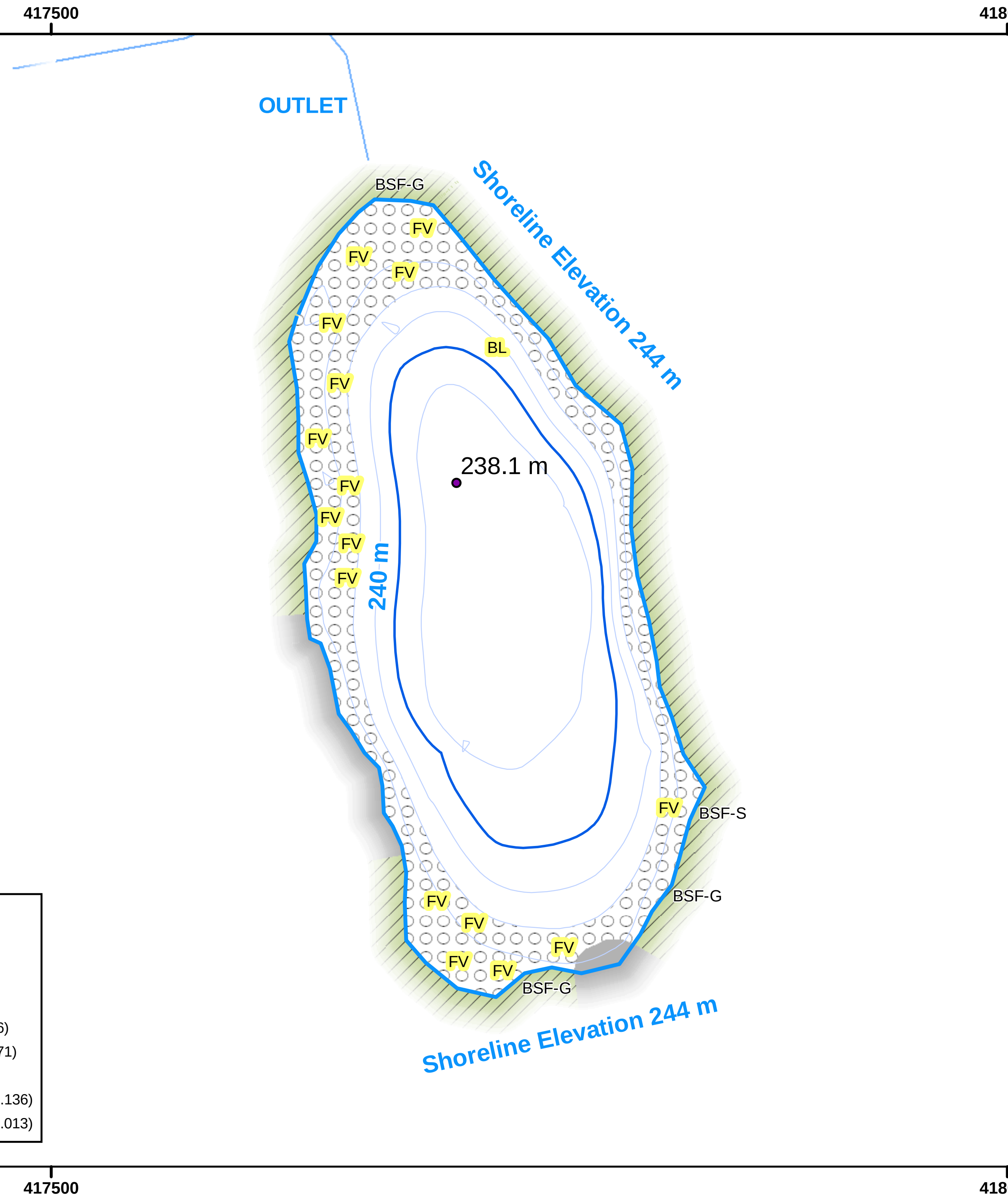

Fish Species Caught

No Fish Caught

BATHYMETRY
- Deepest Point
- Shoreline
- Contour 1 m
- Contour 5 m

HABITAT STRUCTURE
- BL Beaver Lodge
- EV Emergent Vegetation
- FV Floating Vegetation
- SV Submerged Vegetation
- WD Woody Debris

VISIBLE RIPARIAN
- Bedrock
- Black Spruce Forest - Shrub or Grass (BSF-S, BSF-G)
- Wetland - Shrub or Grass (WET-S, WET-G)

LITTORAL SUBSTRATE
- Bedrock
- Boulder/Cobble
- Gravel/Fine
- Organic Muck

0 40 80 120 160
Meters

Projection: UTM 12, NAD83

Water Quality Statistics

	Mean (Range)
n	5
Conductivity (μS/cm)	270 (238 - 310)
Hardness (as CaCO3) (mg/L)	156 (140 - 176)
pH	8.03 (7.77 - 8.26)
Dissolved Oxygen (mg/L)	7.12 (1.37 - 11.71)
Total Dissolved Solids (mg/L)	180 (162 - 205)
Ammonia as N (mg/L)	0.053 (0.022 - 0.136)
Total Phosphate as P (mg/L)	0.010 (0.008 - 0.013)

Lake Statistics

Maximum Depth		5.9 m
Total Surface Area		59,249 m^2
Littoral (<2 m) Area	34%	20,046 m^2
Deep (>8 m) Area	0%	0 m^2
Lake Volume		184,822 m^3

Thor Lake Rare Earth Metals Project

THORN LAKE HABITAT

Area of Detail

AVALON RARE METALS INC.

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DRAFT DATE	SCALE
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REVISION DATE 22/12/2010	PROJECT
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APPROVED NL	VOL
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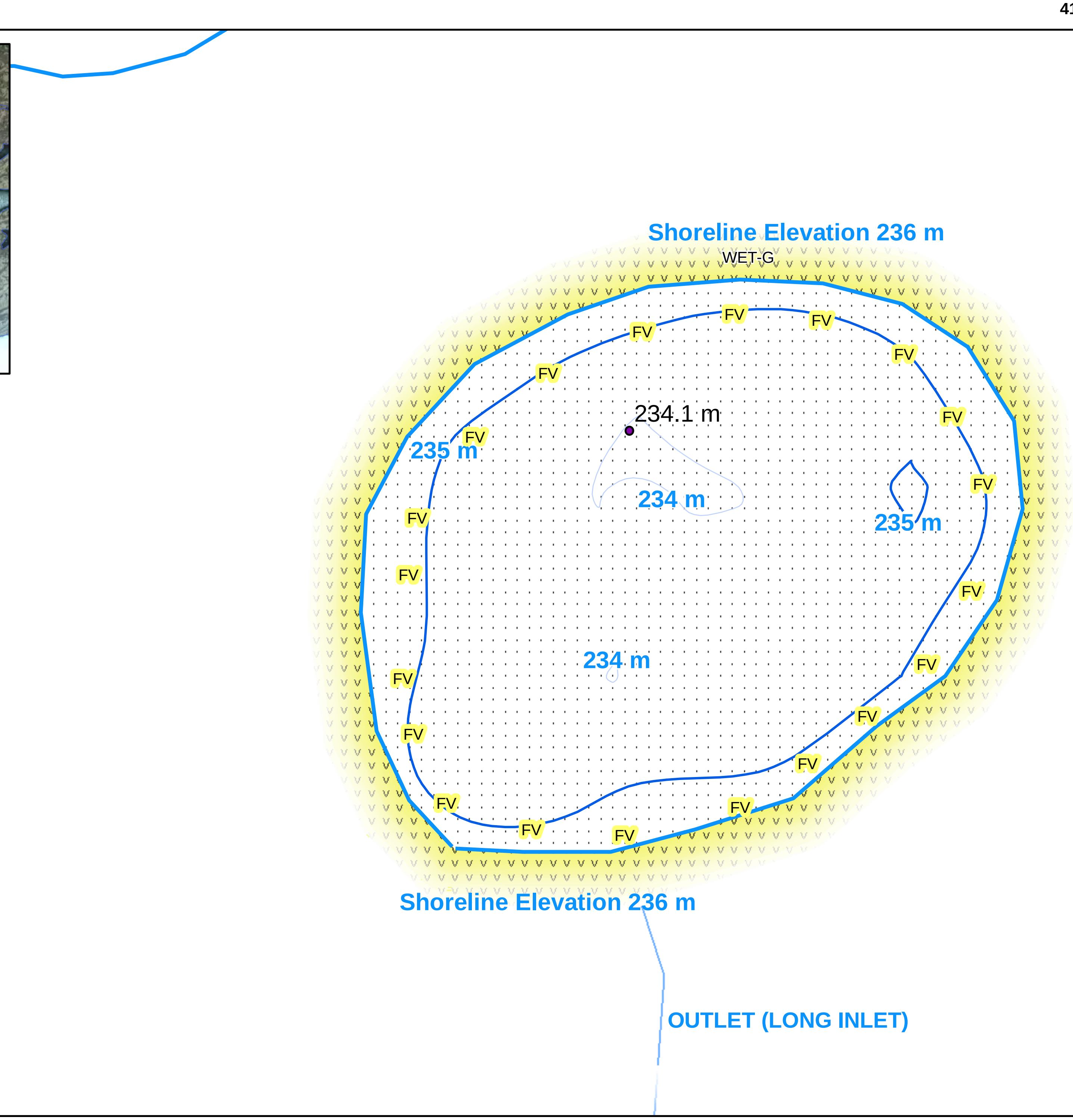


Fish Species Caught

No Fish Caught

N

BATHYMETRY
- Deepest Point
- Shoreline
- Contour 1 m
- Contour 5 m

HABITAT STRUCTURE
- BL Beaver Lodge
- EV Emergent Vegetation
- FV Floating Vegetation
- SV Submerged Vegetation
- WD Woody Debris

VISIBLE RIPARIAN
- Bedrock
- Black Spruce Forest - Shrub or Grass (BSF-S, BSF-G)
- Wetland - Shrub or Grass (WET-S, WET-G)

LITTORAL SUBSTRATE
- Bedrock
- Boulder/Cobble
- Gravel/Fine
- Organic Muck

0 20 40 60 80
Meters
Projection: UTM 12, NAD83

Water Quality Statistics

	Mean (Range)
n	5
Conductivity (μS/cm)	166 (96 - 283)
Hardness (as CaCO3) (mg/L)	100 (58 - 172)
pH	7.66 (7.47 - 7.95)
Dissolved Oxygen (mg/L)	6.09 (0.45 - 11.06)
Total Dissolved Solids (mg/L)	180 (107 - 317)
Ammonia as N (mg/L)	0.365 (0.027 - 1.310)
Total Phosphate as P (mg/L)	0.025 (0.014 - 0.044)

Lake Statistics

Maximum Depth		1.9 m
Total Surface Area		37,018 m^2
Littoral (<2 m) Area	100%	37,018 m^2
Deep (>8 m) Area	0%	0 m^2
Lake Volume		39,693 m^3

417000 417500

Thor Lake Rare Earth Metals Project

SOUTH TARDIFF LAKE HABITAT

Area of Detail

AVALON RARE METALS INC.

PREPARED BY Stantec

DRAFT DATE	SCALE		
11/08/2009	1:2,000		
REVISION DATE 22/12/2010	PROJECT	FIGURE NO. 3	
DRAWN LF	CHECKED SN	APPROVED NL	VOL

417000

6886500

Fish Species Caught
No Fish Caught

N

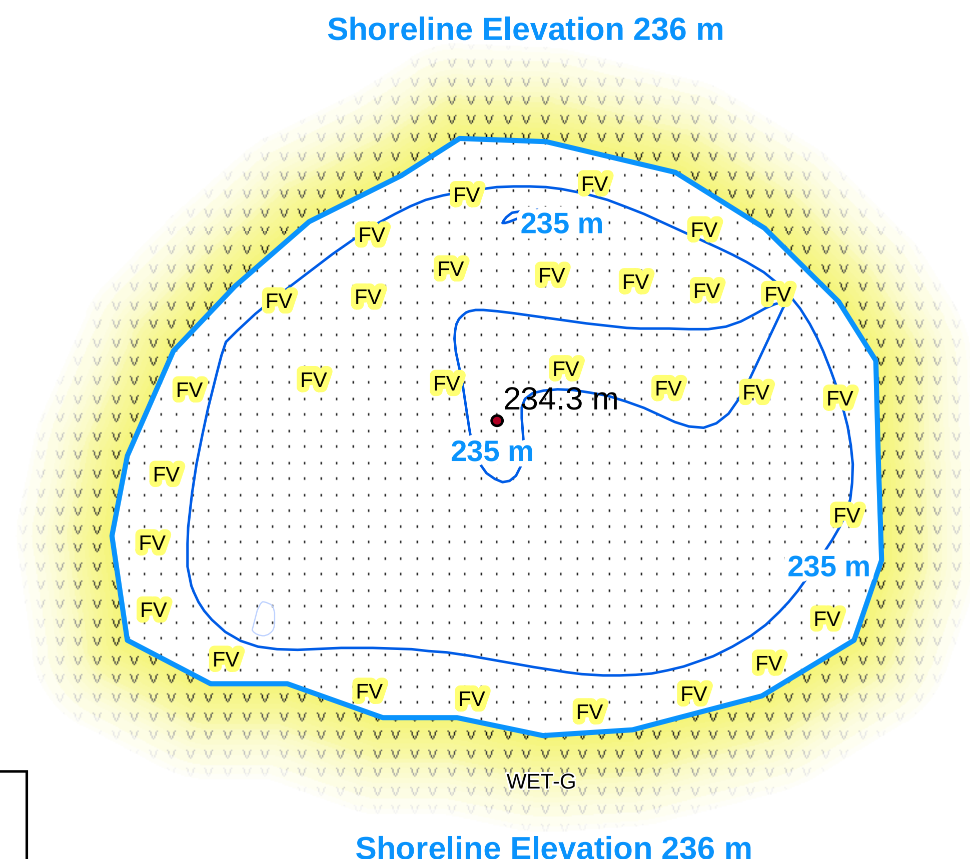
BATHYMETRY
- Deepest Point
- Shoreline
- Contour 1 m
- Contour 5 m

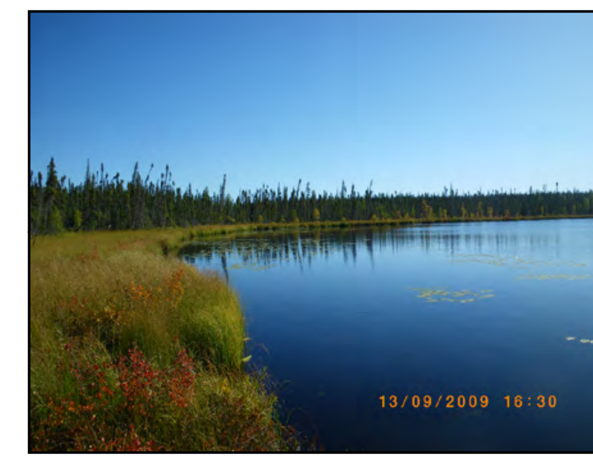
HABITAT STRUCTURE
- BL Beaver Lodge
- EV Emergent Vegetation
- FV Floating Vegetation
- SV Submerged Vegetation
- WD Woody Debris

VISIBLE RIPARIAN
- Bedrock
- Black Spruce Forest - Shrub or Grass (BSF-S, BSF-G)
- Wetland - Shrub or Grass (WET-S, WET-G)

LITTORAL SUBSTRATE
- Bedrock
- Boulder/Cobble
- Gravel/Fine
- Organic Muck

0 20 40 60 80
Meters
Projection: UTM 12, NAD83





Water Quality Statistics	Mean (Range)
n	5
Conductivity (µS/cm)	157 (82 - 290)
Hardness (as CaCO3) (mg/L)	100 (50 - 193)
pH	7.58 (7.34 - 7.77)
Dissolved Oxygen (mg/L)	6.05 (0.47 - 11.00)
Total Dissolved Solids (mg/L)	206 (106 - 398)
Ammonia as N (mg/L)	0.474 (0.032 - 1.710)
Total Phosphate as P (mg/L)	0.044 (0.010 - 0.080)

Lake Statistics		
Maximum Depth		1.7 m
Total Surface Area		14,109 m^2
Littoral (<2 m) Area	100%	14,109 m^2
Deep (>8 m) Area	0%	0 m^2
Lake Volume		14,260 m^3

417000

Thor Lake Rare Earth Metals Project

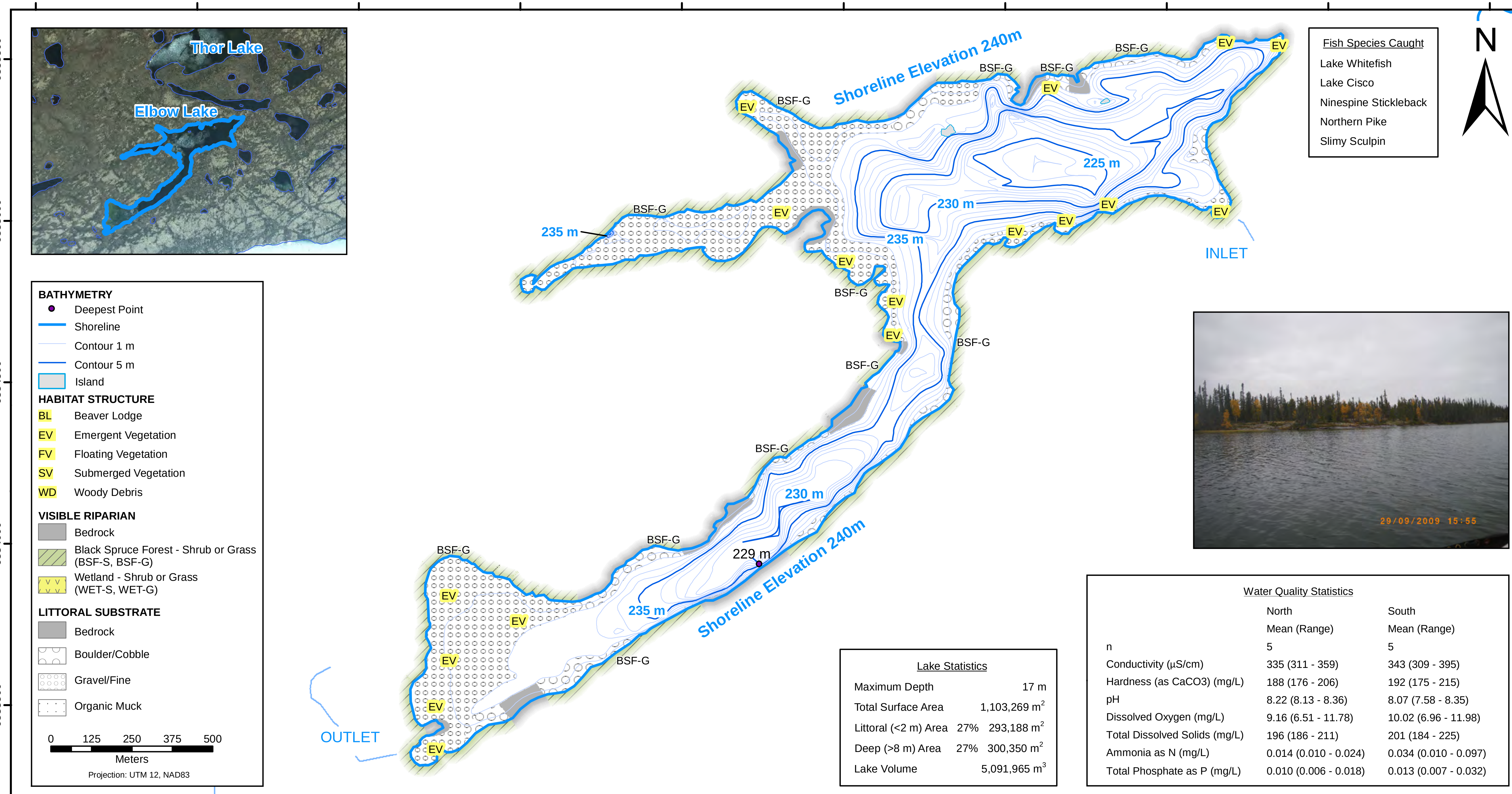
NORTH TARDIFF LAKE HABITAT

Area of Detail

AVALON RARE METALS INC.

PREPARED BY Stantec

DRAFT DATE	SCALE		
10/09/2009	1:1,500		
REVISION DATE 22/12/2010	PROJECT	FIGURE NO. 4	
DRAWN LF	CHECKED SN	APPROVED NL	VOL



Lake Statistics

Maximum Depth		17 m
Total Surface Area		1,103,269 m^2
Littoral (<2 m) Area	27%	293,188 m^2
Deep (>8 m) Area	27%	300,350 m^2
Lake Volume		5,091,965 m^3

Water Quality Statistics

	North Mean (Range)	South Mean (Range)
n	5	5
Conductivity (µS/cm)	335 (311 - 359)	343 (309 - 395)
Hardness (as CaCO3) (mg/L)	188 (176 - 206)	192 (175 - 215)
pH	8.22 (8.13 - 8.36)	8.07 (7.58 - 8.35)
Dissolved Oxygen (mg/L)	9.16 (6.51 - 11.78)	10.02 (6.96 - 11.98)
Total Dissolved Solids (mg/L)	196 (186 - 211)	201 (184 - 225)
Ammonia as N (mg/L)	0.014 (0.010 - 0.024)	0.034 (0.010 - 0.097)
Total Phosphate as P (mg/L)	0.010 (0.006 - 0.018)	0.013 (0.007 - 0.032)

Thor Lake Rare Earth Metals Project

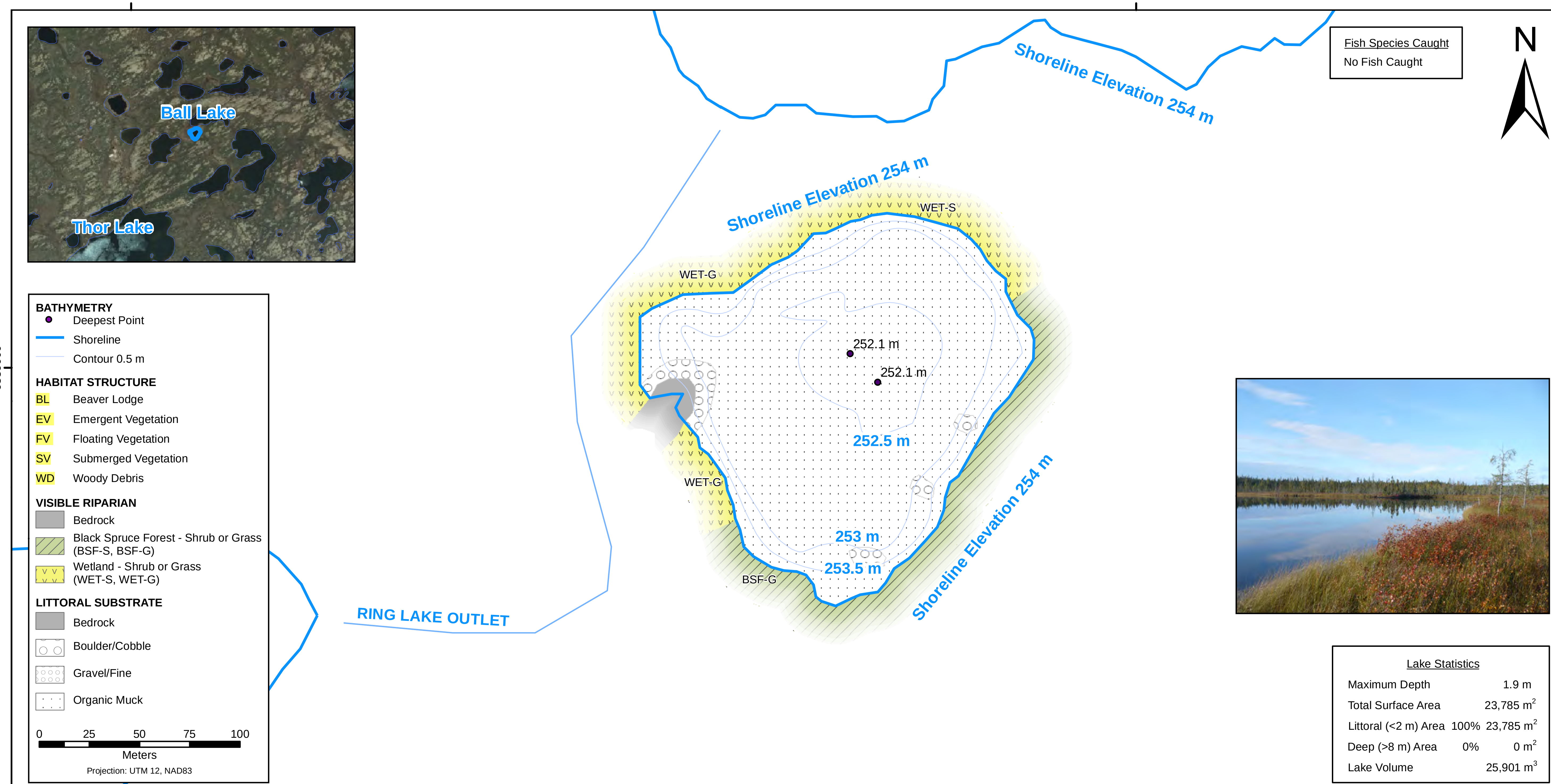
ELBOW LAKE HABITAT

Area of Detail

AVALON RARE METALS INC.

PREPARED BY Stantec

DRAFT DATE 27\07\2010			SCALE 1:12,000	
REVISION DATE 23\12\2010			PROJECT	FIGURE NO. 5
DRAWN LF	CHECKED SN	APPROVED NL	VOL	



Fish Species Caught

No Fish Caught

Lake Statistics

Maximum Depth		1.9 m
Total Surface Area		23,785 m^2
Littoral (<2 m) Area	100%	23,785 m^2
Deep (>8 m) Area	0%	0 m^2
Lake Volume		25,901 m^3

Thor Lake Rare Earth Metals Project

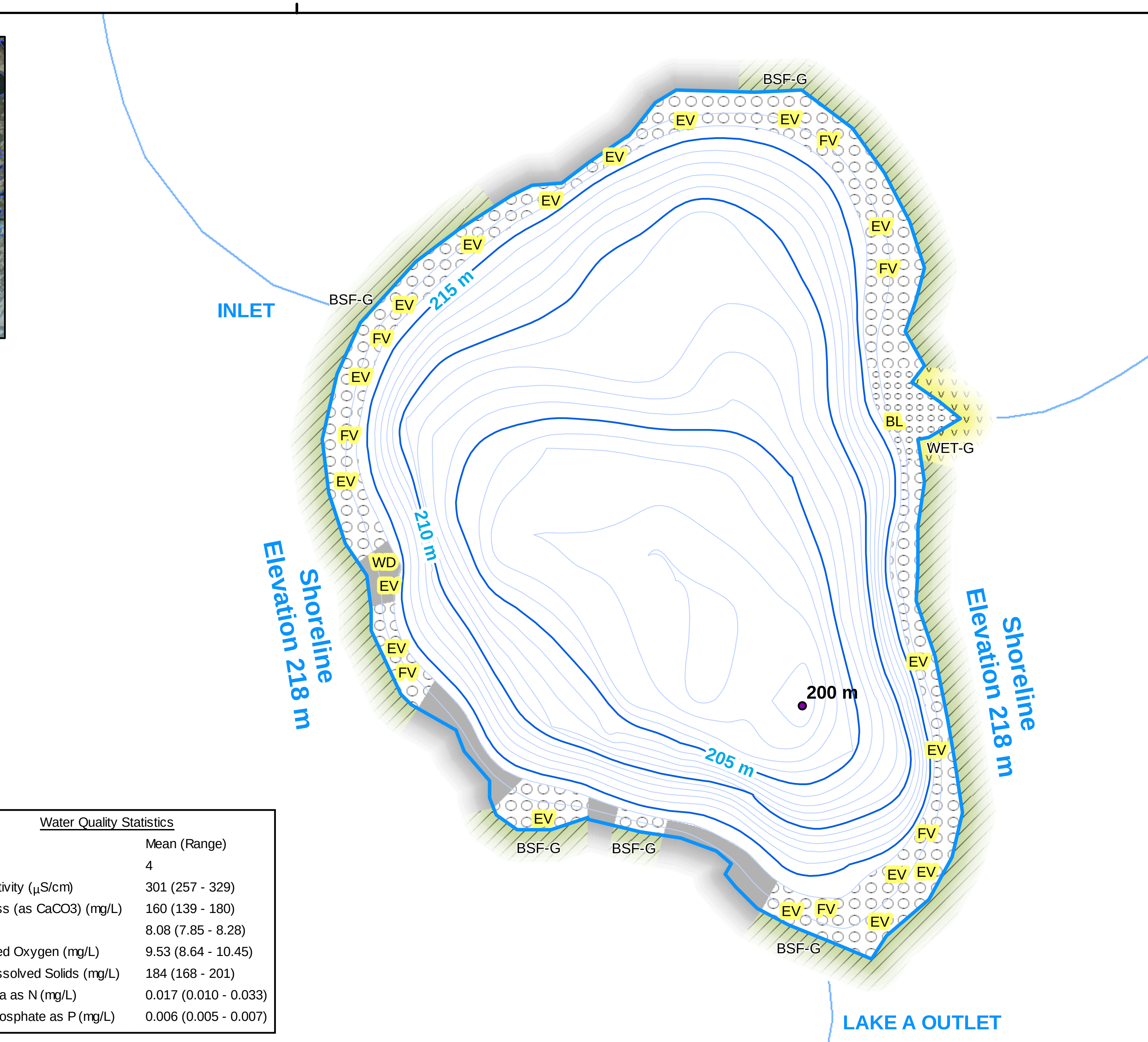
BALL LAKE HABITAT

Area of Detail

AVALON RARE METALS INC.

PREPARED BY Stantec

DRAFT DATE 10/12/2010		SCALE 1:2,000	
REVISION DATE 21/12/2010		PROJECT	FIGURE NO. 6
DRAWN LF	CHECKED SN	APPROVED NL	VOL



Fish Species Caught

- Lake Cisco
- Lake Whitefish
- Ninespine Stickleback
- Northern Pike
- Slimy Sculpin

BATHYMETRY

- Deepest Point
- Shoreline
- Contour 1 m
- Contour 5 m

HABITAT STRUCTURE

- BL Beaver Lodge
- EV Emergent Vegetation
- FV Floating Vegetation
- SV Submerged Vegetation
- WD Woody Debris

VISIBLE RIPARIAN

- Bedrock
- Black Spruce Forest - Shrub or Grass (BSF-S, BSF-G)
- Wetland - Shrub or Grass (WET-S, WET-G)

LITTORAL SUBSTRATE

- Bedrock
- Boulder/Cobble
- Gravel/Fine
- Organic Muck

0 40 80 120 160
Meters

Projection: UTM 12, NAD83

Water Quality Statistics

	Mean (Range)
n	4
Conductivity (μS/cm)	301 (257 - 329)
Hardness (as CaCO3) (mg/L)	160 (139 - 180)
pH	8.08 (7.85 - 8.28)
Dissolved Oxygen (mg/L)	9.53 (8.64 - 10.45)
Total Dissolved Solids (mg/L)	184 (168 - 201)
Ammonia as N (mg/L)	0.017 (0.010 - 0.033)
Total Phosphate as P (mg/L)	0.006 (0.005 - 0.007)

Lake Statistics

Maximum Depth		18 m
Total Surface Area		132,751 m^2
Littoral (<2 m) Area	19%	25,477 m^2
Deep (>8 m) Area	54%	71,083 m^2
Lake Volume		1,099,806 m^3

Thor Lake Rare Earth Metals Project

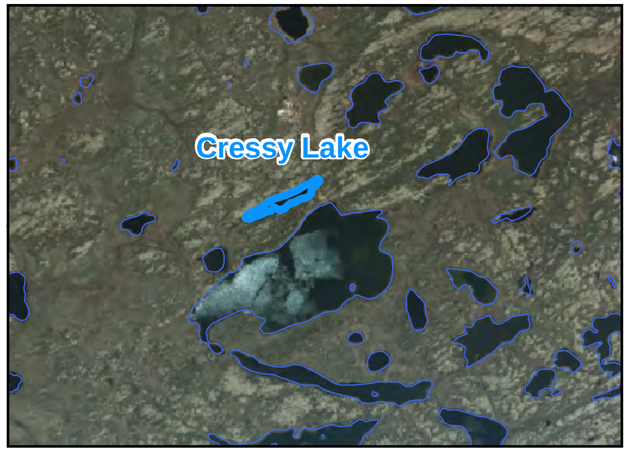
LAKE A HABITAT

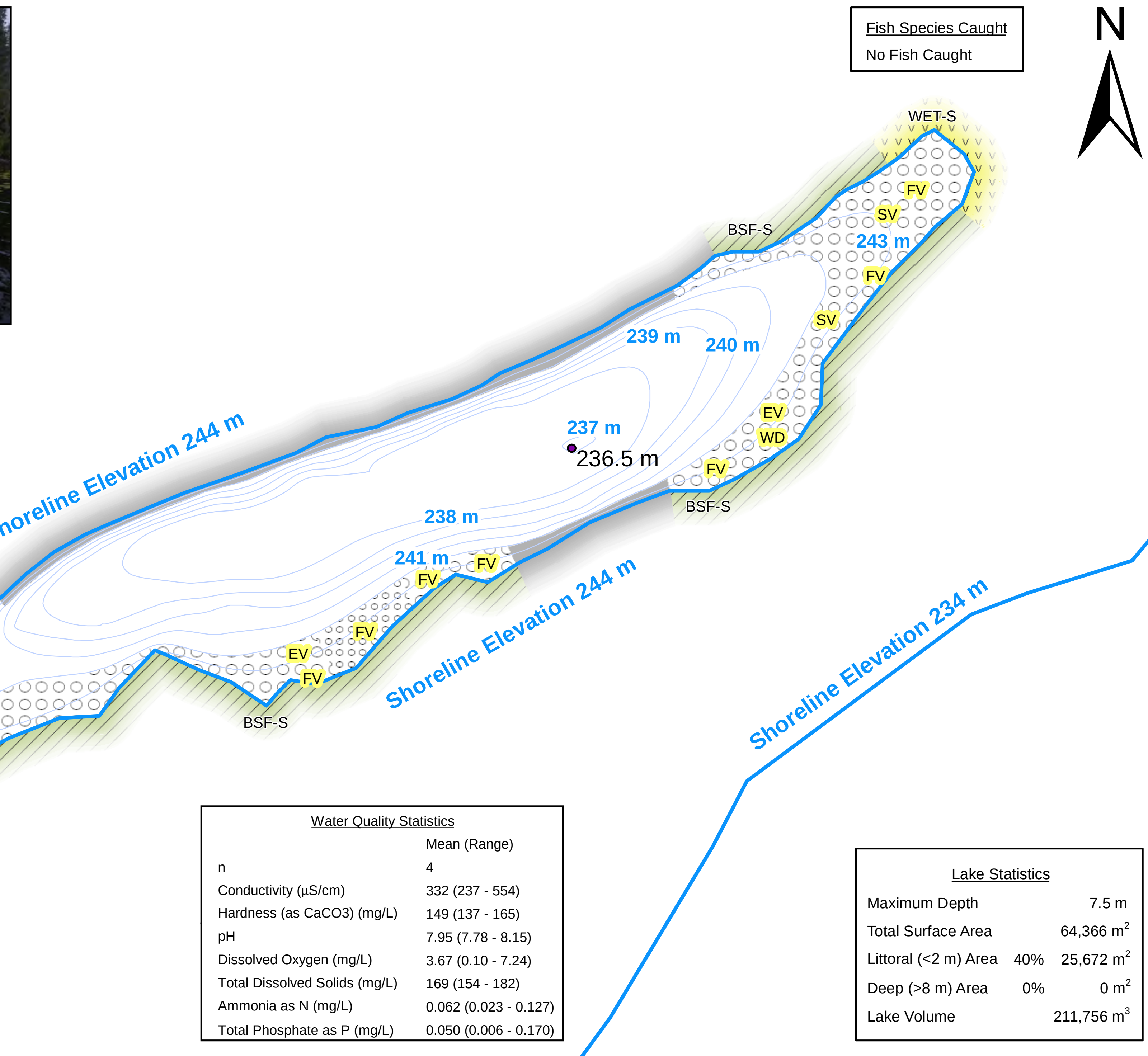
Area of Detail

AVALON RARE METALS INC.

PREPARED BY Stantec

DRAFT DATE	SCALE		
27\07\2010	1:3,000		
REVISION DATE 21\12\2010	PROJECT	FIGURE NO. 7	
DRAWN LF	CHECKED SN	APPROVED NL	VOL





Fish Species Caught

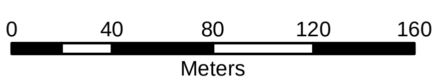
No Fish Caught

BATHYMETRY
- Shoreline
- Contour 1 m

HABITAT STRUCTURE
- BL Beaver Lodge
- EV Emergent Vegetation
- FV Floating Vegetation
- SV Submerged Vegetation
- WD Woody Debris

VISIBLE RIPARIAN
- Bedrock
- Black Spruce Forest - Shrub or Grass (BSF-S, BSF-G)
- Wetland - Shrub or Grass (WET-S, WET-G)

LITTORAL SUBSTRATE
- Bedrock
- Boulder/Cobble
- Gravel/Fine
- Organic Muck



Projection: UTM 12, NAD83

Water Quality Statistics

	Mean (Range)
n	4
Conductivity (µS/cm)	332 (237 - 554)
Hardness (as CaCO3) (mg/L)	149 (137 - 165)
pH	7.95 (7.78 - 8.15)
Dissolved Oxygen (mg/L)	3.67 (0.10 - 7.24)
Total Dissolved Solids (mg/L)	169 (154 - 182)
Ammonia as N (mg/L)	0.062 (0.023 - 0.127)
Total Phosphate as P (mg/L)	0.050 (0.006 - 0.170)

Lake Statistics

Maximum Depth		7.5 m
Total Surface Area		64,366 m^2
Littoral (<2 m) Area	40%	25,672 m^2
Deep (>8 m) Area	0%	0 m^2
Lake Volume		211,756 m^3

416000 416500

Thor Lake Rare Earth Metals Project

CRESSY LAKE HABITAT

Area of Detail

AVALON RARE METALS INC.

PREPARED BY Stantec

DRAFT DATE 10/09/2009		SCALE 1:3,000	
REVISION DATE 16/12/2010		PROJECT	FIGURE NO. 8
DRAWN LF	CHECKED SN	APPROVED NL	VOL