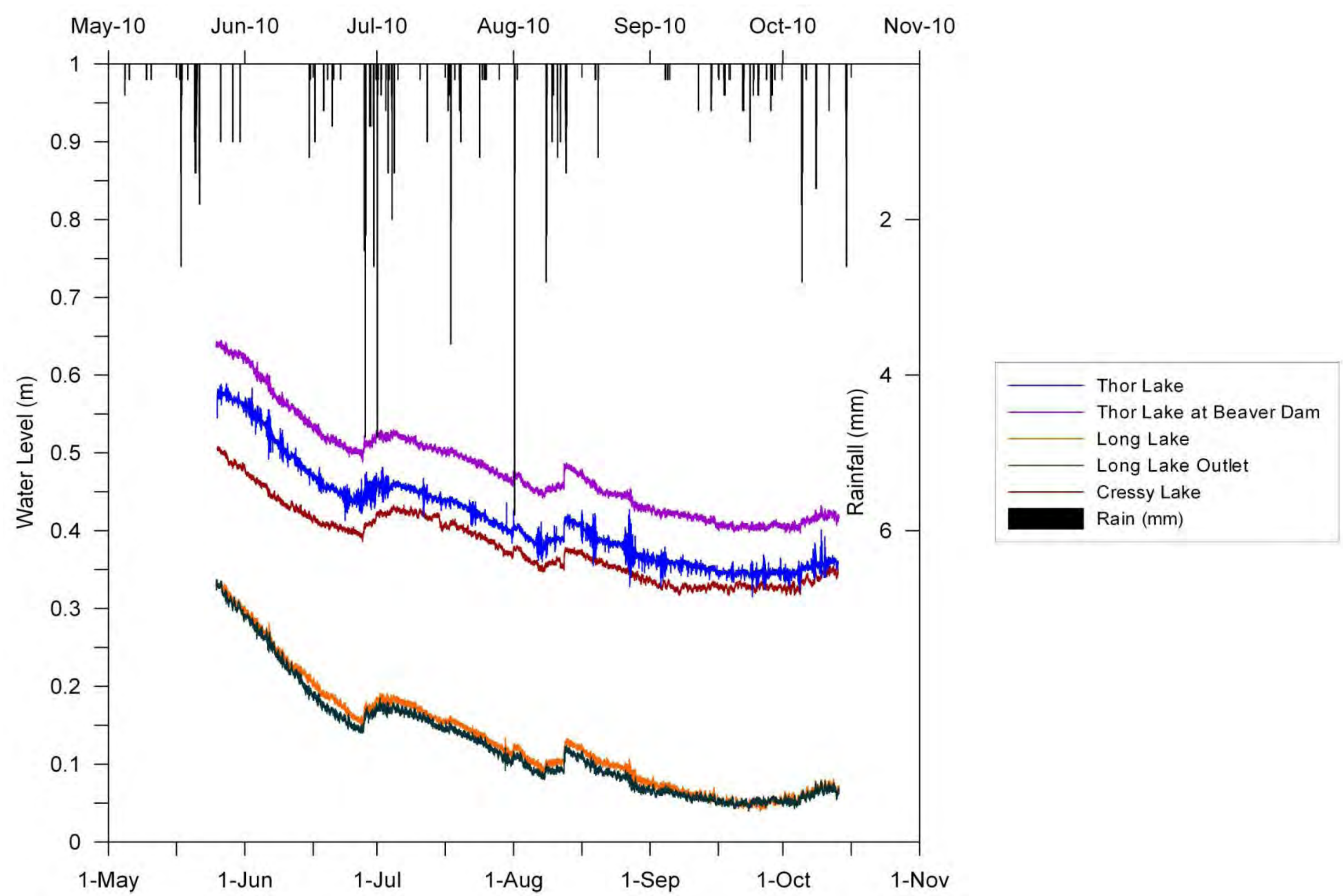

NOTES

1. Lake level elevations are on a relative datum and do not reflect absolute water level differences between the lakes.
2. Figure Source: Figure 4.14. Stantec 2010a.

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THOR LAKE PROJECT

Lake Water Levels and Rainfall 2010

PROJECT NO.	DWN	CKD	REV
V15101007.006	SL	RH	0
OFFICE	DATE		
EBA-VANC	May 9, 2011		

Figure 2.5-6

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2.5.4 Stream Flow Data

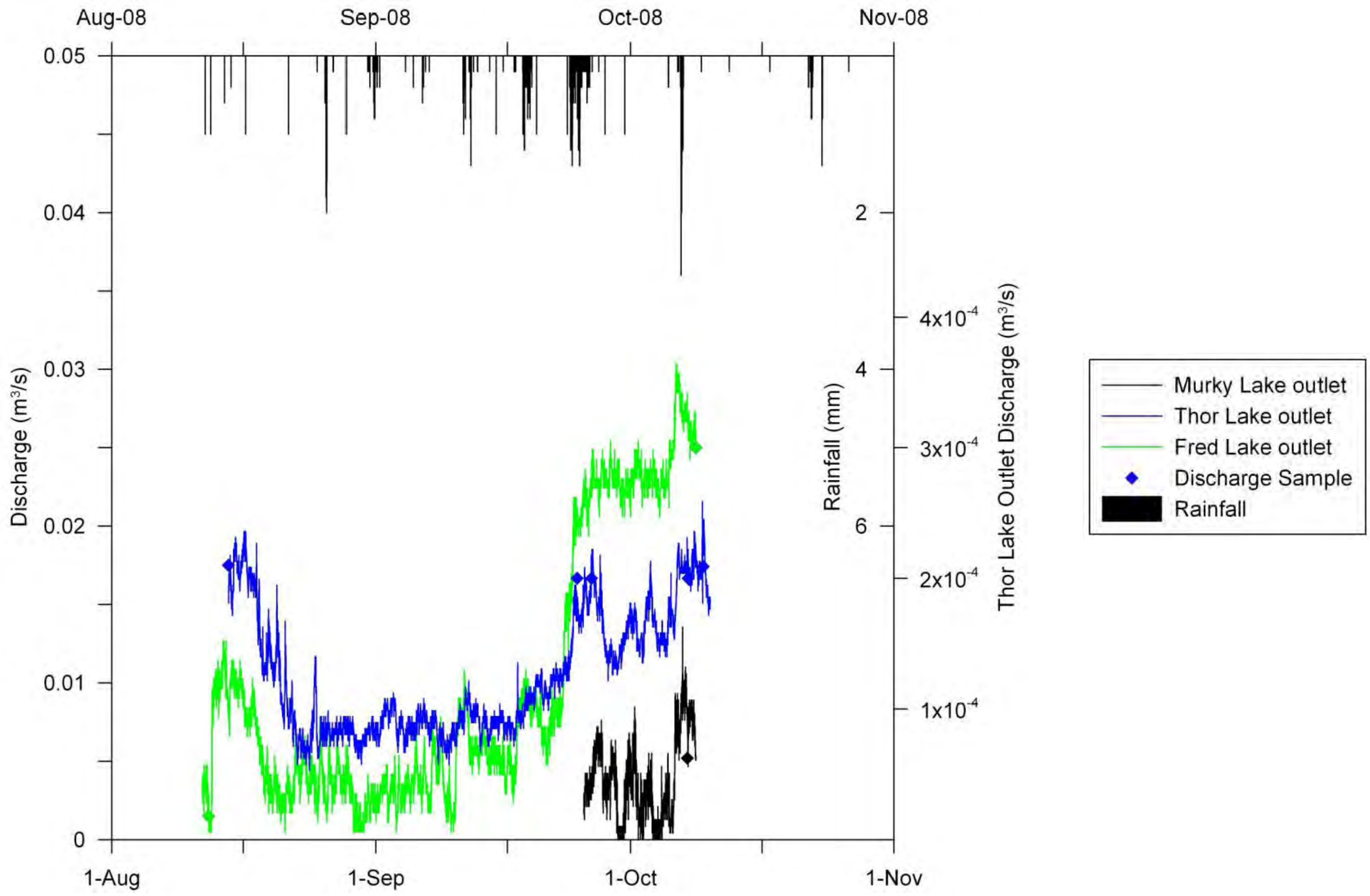
Hydrographs for the Murky, Thor, and Fred lakes outflow streams, and corresponding daily rainfall levels are provided in Figures 2.5-7 to 2.5-9. Monthly summaries based on stream gauge measurements are provided in Table 2.5-1. Stream flow measurements were carried out from August, 2008, to October, 2010 during open water seasons (Stantec 2010a). Stream gauge locations are shown in Figure 2.5-3). Instrumentation at each site included installation of a staff gauge and a HOBO pressure transducer. Stream measurements included continuous water level gauging and manual stream flow. The manual stream flow measurements, which were conducted at several times during the field program, were related to water levels to develop a stage-discharge relationship (Stantec 2010a).

As would be expected, seasonal streamflow patterns closely follow changes in lake levels, which in turn, are governed by snowmelt, runoff, and rainfall characteristics. Large differences in stream flow from year to year reflect interannual variability in precipitation, snowpack, and temperature, as well as situational factors, such as flow blockages which can occur naturally. For example, a debris blockage at the Thor Lake outlet, coupled with low summer rainfall in 2008, resulted in very low flows between Thor Lake and Fred Lake (Figure 2.5-7).

Higher stream flow rates in 2009 at the Thor Lake outlet resulted from higher water levels in Thor Lake due to a relatively wet fall in 2008, a higher than average snowpack, the probability of high antecedent moisture conditions in the ground in the spring of 2009, and removal of the outlet debris blockage on June 2, 2009. Based on the low responses to rainfall events in the fall of 2009, it is likely that the system had a high storage capacity during the late summer.

Snow melt was rapid in April 2010, resulting in relatively high stream flows at each of the gauging stations (Figure 2.5-9). It is probable that annual maximum streamflows preceded installation of instrumentation at the three gauging stations.

While stream flow within the Project area is influenced considerably by meteorological conditions, it also reflects the nature and timing of the various water storage processes. For example, in 2009, despite large rainfall during the late summer, stream flow response was relatively low, possibly because the lake had greater storage capacity. The non-linear maximum stream flows in 2008 and 2009 provides another example that suggests lake storage and/or near surface groundwater storage have an important effect on the overall water balance at the site (Stantec 2010a).



NOTES

1. Figure Source: Figure 4.15. Stantec 2010a.

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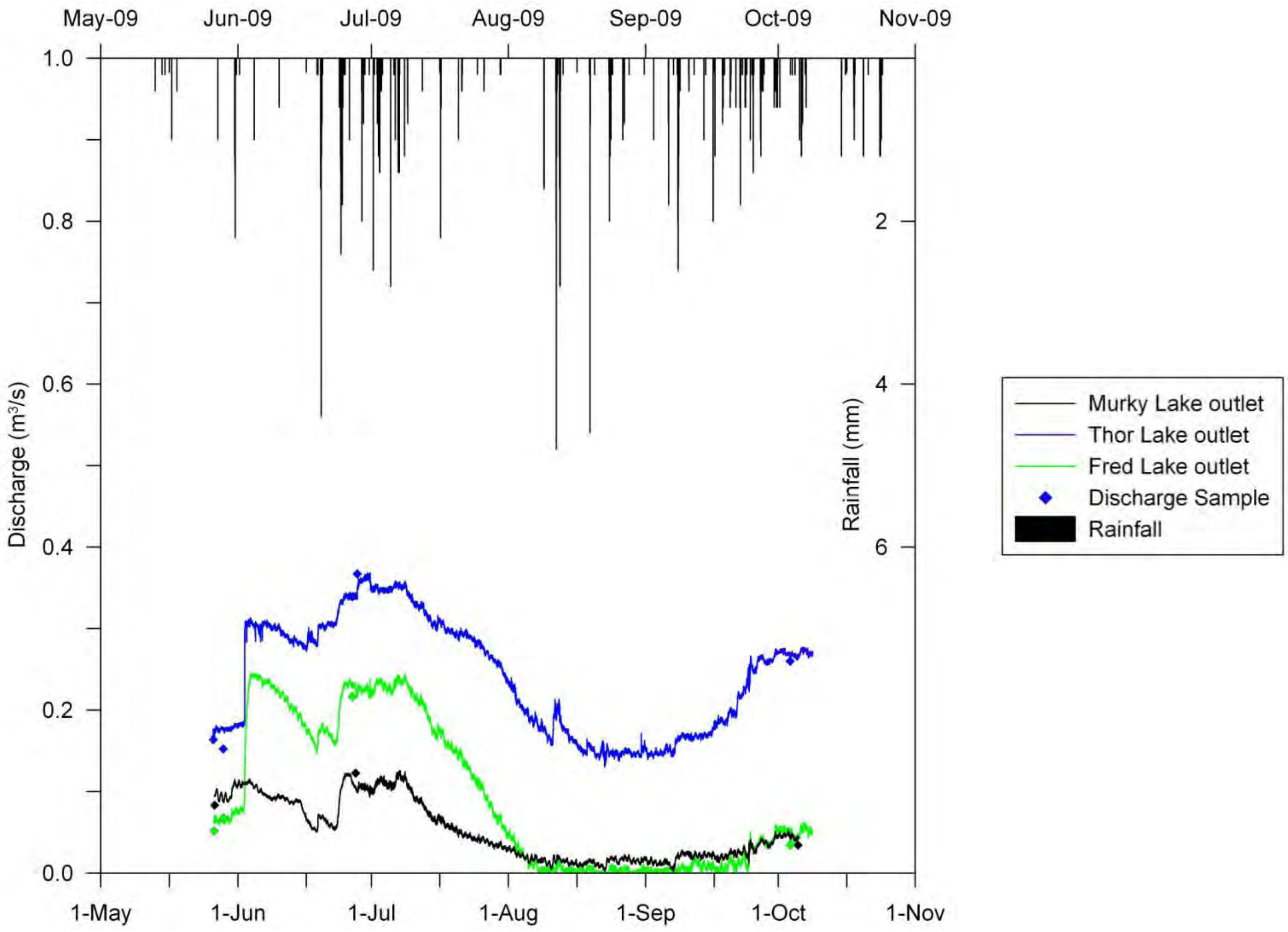
THOR LAKE PROJECT

Stream Flow and Rainfall 2008

PROJECT NO.	DWN	CKD	REV
V15101007.006	SL	RH	0
OFFICE	DATE		
EBA-VANC	February 10, 2011		

Figure 2.5-7



NOTES

1. Figure Source: Figure 4.16. Stantec 2010a.

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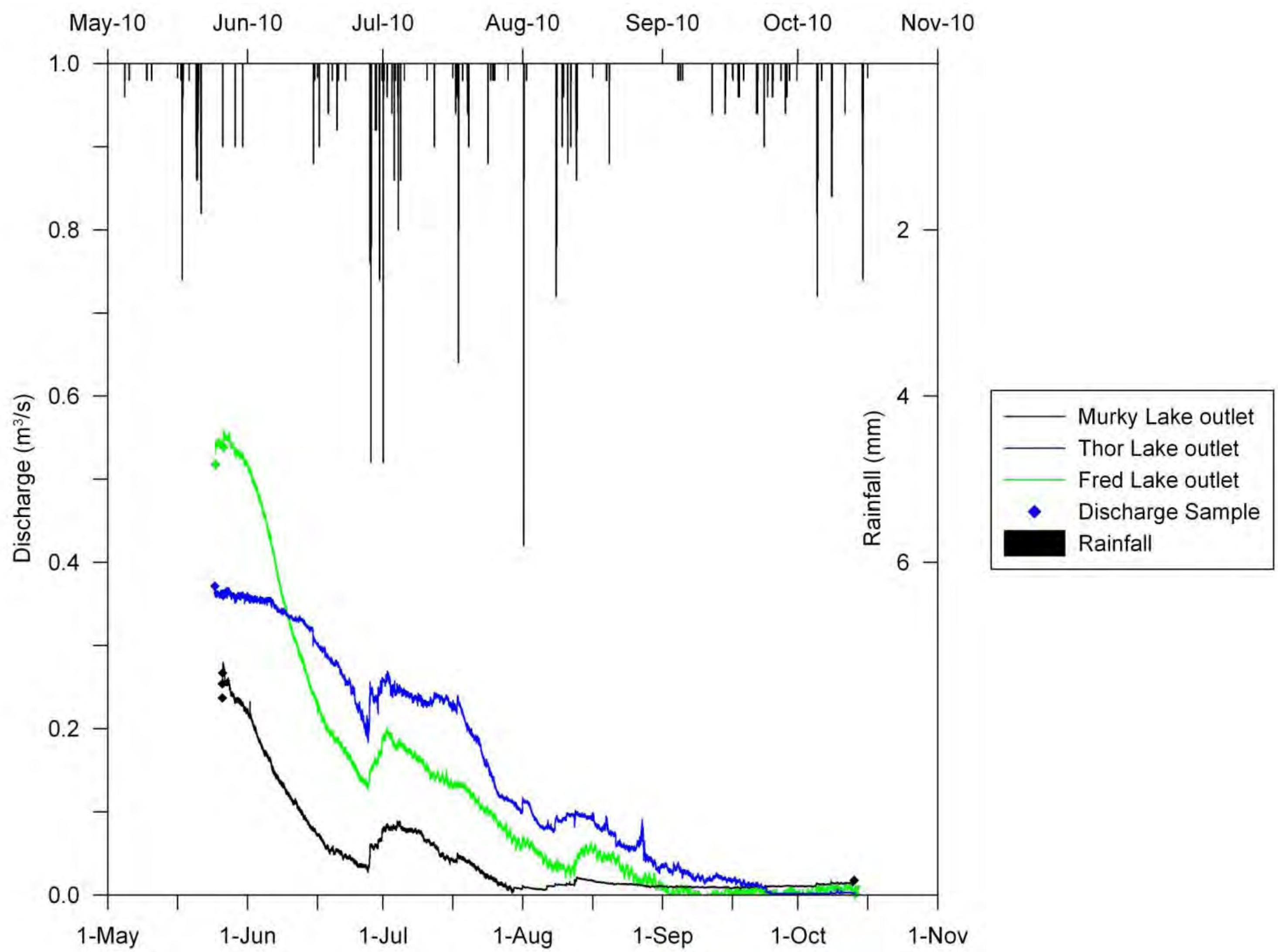
THOR LAKE PROJECT

Stream Flow and Rainfall 2009

PROJECT NO.	DWN	CKD	REV
V15101007.006	SL	RH	0
OFFICE	DATE		
EBA-VANC	May 9, 2011		

Figure 2.5-8



NOTES

1. Figure Source: Figure 4.17. Stantec 2010a.

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Stream Flow and Rainfall 2010

PROJECT NO.	DWN	CKD	REV
V15101007.006	SL	RH	0

OFFICE	DATE
EBA-VANC	May 9, 2011

Figure 2.5-9

TABLE 2.5-1: STUDY AREA DISCHARGE 2008 - 2010

Station	2008				2009							2010					
	Aug	Sep	Oct	Nov-Apr	May	Jun	Jul	Aug	Sep	Oct	Nov-Apr	May	Jun	Jul	Aug	Sep	Oct
Murky Lake Outlet																	
Mean	–	0.004	0.004	nm	0.097	0.090	0.071	0.071	0.023	0.045	nm	0.241	0.096	0.047	0.013	0.010	0.013
Maximum	–	0.008	0.014	nm	0.115	0.123	0.126	0.126	0.051	0.052	nm	0.280	0.233	0.089	0.022	0.012	0.016
Minimum	–	1.0E-04	1.0E-04	nm	0.087	0.051	0.026	0.026	0.003	0.040	nm	0.218	0.028	0.003	0.006	0.008	0.010
Fred Lake Outlet																	
Mean	0.005	0.010	0.025	nm	0.068	0.200	0.165	0.008	0.014	0.050	nm	0.537	0.274	0.131	0.038	0.003	0.006
Maximum	0.013	0.025	0.030	nm	0.081	0.245	0.244	0.053	0.060	0.062	nm	0.558	0.519	0.201	0.071	0.014	0.018
Minimum	0.001	0.001	0.021	nm	0.059	0.072	0.043	0.000	0.000	0.034	nm	0.516	0.126	0.054	0.006	1.0E-03	1.0E-03
Thor Lake Outlet																	
Mean	1.0E-04	1.0E-04	2.0E-04	nm	0.161	0.283	0.289	0.139	0.166	0.252	nm	0.361	0.298	0.200	0.077	0.016	0.002
Maximum	2.0E-04	2.0E-04	3.0E-04	nm	0.152	0.351	0.334	0.219	0.257	0.260	nm	0.369	0.364	0.269	0.117	0.039	0.007
Minimum	1.0E-04	1.0E-04	1.0E-04	nm	0.132	0.147	0.210	0.096	0.107	0.242	nm	0.350	0.183	0.098	0.026	0.002	0.001

Notes: – no station established

nm no measurements at station

2.5.5 Watershed Flow Analysis

An analysis of the affected watershed areas was completed for the Nechalacho Mine site area by Knight Piésold (2011b). The watershed analysis was used to estimate current pre-development flows based on the following:

- Average meteorological conditions from analysis of historical data from regional weather stations including precipitation (rainfall and snow), evaporation, temperature, and snowmelt.
- Probabilistic analysis to predict dry and wet conditions (5th and 95th percentiles, respectively), and
- Natural runoff coefficients from an analysis of regional flow discharge measurements.

No evaporation pans have been installed in the study area. Knight Piésold used regional (historic) average climate and evaporation data for the watershed analysis. Evaporation is not considered to be a critical consideration for the Project.

The main initial objective of this analysis was to estimate the pre-development monthly discharge volumes from the Drizzle Lake and Thor Lake watersheds. The watershed flow analysis was completed for a 12 month period to provide an estimate of pre-production flows. A deterministic approach was taken using average precipitation conditions and a probabilistic approach was used to determine wet and dry conditions. This pre-development analysis was used to assist in predicting changes in flows during the development and post-development phases of the Project as discussed in more detail in Section 6.3.1.

2.5.5.1 Watershed Regime

As previously shown in Figure 2.5-1, the large (2,100 ha) watershed area that reports to Thor Lake may be subdivided into several smaller watershed areas. The Ring and Buck lakes watershed (~151 ha) reports to the Drizzle Lake watershed. The Drizzle Lake watershed also receives flow from a large catchment area to the southeast (~479 ha) before reporting to the Murky Lake watershed (~170 ha).

Drainage from Murky Lake into Thor Lake (draining a total of ~800 ha) accounts for about 38% of the Thor Lake watershed. Thor Lake also receives flows from a large watershed to the southeast through Long Lake (~950 ha) accounting for 45% of the Thor Lake watershed. The remaining watershed reporting to Thor Lake (~350 ha) makes up the remaining 17% of the Thor Lake basin.

The Thor Lake watershed drains to Fred Lake which then ultimately reports to Great Slave Lake through numerous lakes and marshes along a drainage path flowing southwest, an estimated 18 km, that collects an additional 6,700 ha of watershed, as shown in Figure 2.5-1.

2.5.5.2 Annual Flow Estimations

The criteria used for the annual flow estimations developed by Knight Piésold (2011b, 2011c) were based on the meteorological parameters and site hydrological characteristics.

Rather than assume one runoff coefficient for the entire year, an average net runoff coefficient for each month, as determined by the aforementioned reviews, was applied. The maximum runoff coefficient occurs during the month of May.

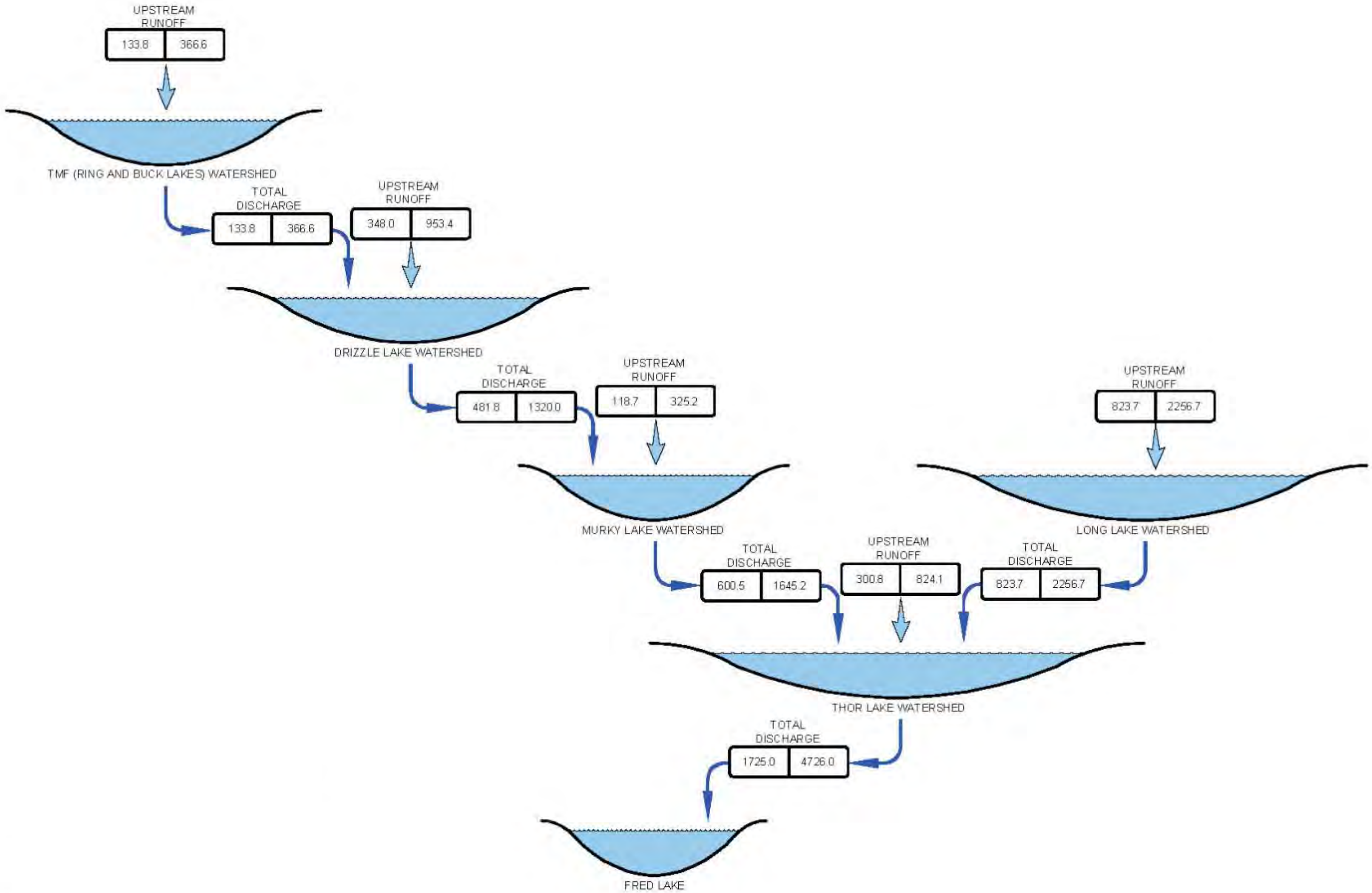
The current (pre-production) flow analysis was completed using a spreadsheet approach for a twelve month period. The model estimated the flow of water between the watersheds on a monthly basis using various inputs including watershed areas, runoff coefficients and effective precipitation data. The volume of water reporting to each watershed was calculated on a monthly basis by summing inputs from other watersheds (if applicable), and direct runoff within the watershed area.

The same runoff coefficients were applied to each watershed area, by month, and varied between 17% in August and 49% in May. The runoff coefficients were based on the average for recorded regional data.

It was assumed that any additional water inputs for a watershed would also be output from the watershed during the same month. This is based on the principle that the various lakes and rivers maintain relatively steady volumes and surplus water resulting from rainfall cycles through the various watersheds is discharged downstream.

Figure 2.5-10 presents a flowsheet summarizing the estimated annual flows anticipated to occur within the Thor Lake system during the current pre-production conditions. The pre-production annual amount of water that discharges from Thor Lake to Fred Lake is estimated to be 1.725 million m^3 per year. The estimated annual discharge from the Ring and Buck lakes watershed (proposed Tailings Management Facility) is 133,800 m^3 per year or approximately 8% of the Thor Lake watershed discharge. Similarly the estimated annual discharge from the Drizzle Lake watershed is 481,800 m^3 per year or approximately 28% of the Thor Lake watershed discharge. Monthly flow estimates from each watershed are graphically shown in Figure 2.5-11.

A review of measured flows from the baseline work completed in the past two years by Stantec (2010a) indicates that the annual flows estimated by Knight Piésold are reasonable.



LEGEND:

ANNUAL FLOW IN THOUSAND m³/yr

AVERAGE FLOW IN m³/day

133.8	366.6

NOTES

1. Estimates are for average precipitation conditions and do not include extreme precipitation events.
2. Upstream runoff to each lake includes direct precipitation and evaporation on the lake.
3. Figure Source: Knight Piesold Consulting, March 2011 (Ref No. NB11-00132, Figure 3).

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THOR LAKE PROJECT

Annual Watershed Flowsheet Pre-Production

PROJECT NO.	DWN	CKD	REV
V15101007.006	SL	RH	0

OFFICE	DATE
EBA-VANC	March 18, 2011

Figure 2.5-10

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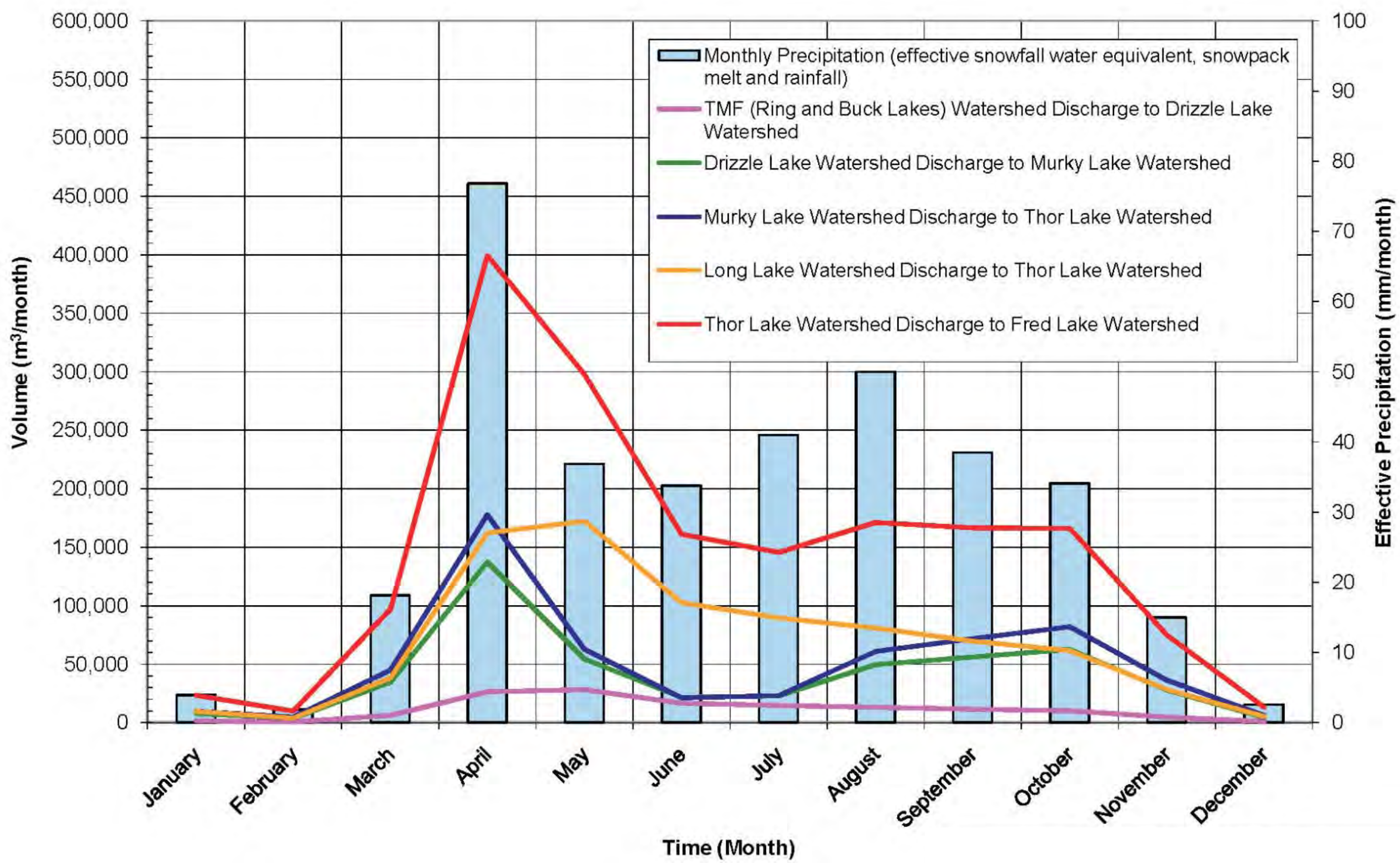

NOTES

1. Figure Source: Knight Piesold Consulting, March 2011 (Ref No. NB11-00132, Figure 4).

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THOR LAKE PROJECT

Estimated Watershed Discharge By Month Pre-Production Average Conditions

PROJECT NO.	DWN	CKD	REV
V15101007.006	SL	RH	0
OFFICE	DATE		
EBA-VANC	March 18, 2011		

Figure 2.5-11

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2.6 WATER AND SEDIMENT QUALITY

Water quality has been identified by the MVEIRB (2011) as a Key Line of Inquiry. The following section describes existing water quality conditions in the Nechalacho Mine site area based on historic and more recent sampling efforts. Other baseline sections of the DAR that relate to or are affected by water quality conditions include Climate (Section 2.3), Hydrology (Section 2.5), Hydrogeology (Section 2.7), and Fish and Fish Habitat (Section 2.8).

Potential effects of the Thor Lake Project on water quality are discussed in Section 7.0, including Surface Water Quality (Section 7.4), Hydrogeology (Section 7.5), Fish and Fish Habitat (Section 7.6), Great Slave Lake Docks and Barging Operation (Section 7.10), Biophysical Environmental Monitoring (Section 7.13), Accidents and Malfunctions (Section 8.0) and Cumulative Effects (Section 10.3).

Water and sediment quality data for the Nechalacho Mine site area have been collected as part of three studies:

1) An environmental baseline study in the present Nechalacho area was carried out in 1988 by the Saskatchewan Research Council (SRC; Melville et al. 1989) regarding potential mining of the Thor Lake Joint Venture ore body for beryllium and rare earth minerals. Aquatic studies at that time were designed to characterize existing water quality and large-fish lake populations in close proximity to the mine development site, and focussed on four watersheds:
   - Cressy Lake, which was identified as the prospective tailings disposal area, and included Fred Lake, Fred stream, and Lake A;
   - The watershed downstream of Den Lake, which flows north to Blachford Lake;
   - Thor Lake and its tributary lakes, including Ring Lake, which was proposed as the alternate tailings disposal lake; and,
   - Elbow Lake, which was the reference lake to which Thor Lake was compared.
2) Highwood Resources Ltd. commissioned an environmental baseline study by Golder Associates Ltd. (1998) to obtain fisheries and wildlife information for the Thor Lake Bulk Sample Project, in support of potential beryllium mining. Eight lakes in the Thor Lake area were sampled as part of the aquatic survey, which documented water and sediment quality, fish health, and fish habitat. The sampled lakes included: Thor, Den, B, C, D, Elbow, and Blachford lakes, and the Great Slave Lake docking area.
3) As part of exploration for, and potential development of, a rare earth metals mine in the Nechalacho Mine site, Avalon retained Stantec to carry out further baseline studies, which were conducted between 2008 and 2010. These water quality, aquatic ecology, and fish and fish habitat studies were carried out in 26 lakes and 13 watercourses, which were selected as water bodies:
   - potentially affected by the Project;
   - representing local aquatic conditions; and,

- potentially suitable as reference lakes.
- For the most part, information and data reported and discussed in this section are based on Stantec (2010c; Appendix A), and supplemented by information collected during previous field studies. The Stantec data are the most recent and comprehensive, and focussed directly on waterbodies that have the potential to be affected by the proposed Project.

Water, sediment, and ground water sampling locations were selected based on the direct Project footprint, potential future expansion, and known information about surface and groundwater characteristics in the Nechalacho Mine site area. All lakes and streams that would potentially directly interact with the mine footprint and operations (i.e., lakes above the underground excavations, and lakes and streams affected by water extraction and/or discharge), tailings storage areas, and ore transport routes were selected, as was the first lake downstream of the mine area.

Sampled lakes are shown in Figure 2.6-1 and are listed in Table 2.6-1. Two lakes, Carrot and U, were originally selected as potential reference lakes but were deemed to be unsuitable and will not be discussed further. Kinnikinnick Lake was selected as a suitable near-field reference lake, while Redemption Lake, located approximately 18 km northeast of the Nechalacho Mine site camp, was chosen as an appropriate far-field reference lake.

TABLE 2.6-1: AQUATIC BASELINE SAMPLING LOCATIONS

Lake	Stantec (2010c) Sampling Station	Coordinates	
		Easting	Northing
A	FL-03	413762	6886729
Ball	–	417796	6889038
Blachford	BL-01	415403	6891246
Buck	UN-12	417861	6889261
Cressy	FL-02	416471	6887742
Dinosaur	UN-09	418403	6889795
Drizzle	UN-13	418851	6888823
Egg	UN-11	420050	6888277
Elbow	EL-01 EL-02	416388 415576	6885140 6883908
Fred	FL-01	415751	6887108
Great Slave	GL-01	413845	6882398
Kinnikinnick	UN-08	420757	6885658
Long	LL-02	417273	6885871
Megan	TL-05	418356	6886890
Murky	UN-10	417893	6887973
North Tardiff	NT-01	417128	6886360
Pistol	UN-05	419676	6886500
Porkchop	UN-07	418462	6885389

TABLE 2.6-1: AQUATIC BASELINE SAMPLING LOCATIONS			
Lake	Stantec (2010c) Sampling Station	Coordinates	
		Easting	Northing
Redemption	UN-14	429566	6899312
Ring	TL-04	417267	6888738
South Tardiff	ST-01	417360	6886126
Thor	TL-06 TL-07	415842 416636	6886885 6887520
Thorn	TL-03	417700	6886655
Wasp	UN-04	418521	6886407

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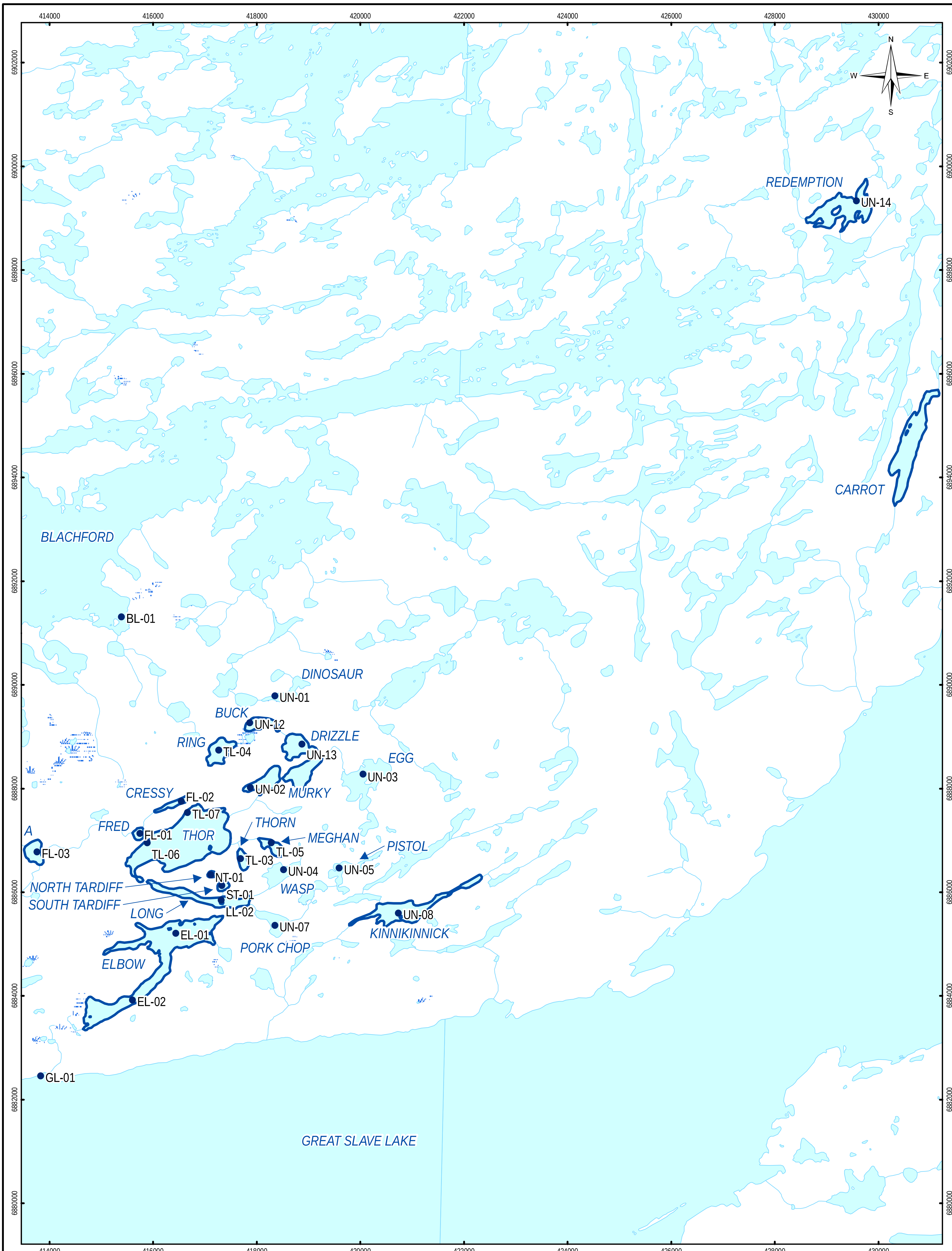

LEGEND

- Aquatic Sample Stations
- Fisheries Lakes
- Watercourse
- Waterbody
- Wetland

NOTES
Figure Source: Appendix A, Figure 3-1. Stantec 2010c.

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THOR LAKE PROJECT

Aquatic Baseline Sampling Locations

PROJECTION UTM Zone 12		DATUM NAD83	
Scale: 1:70,000 (1 0.5 0 1 2 Kilometres)			
FILE NO. V15101007_DAR_Map039_AquaticsBaseline.mxd			
PROJECT NO. V15101007.006	DWN SL	CKD DM	REV 0
OFFICE EBA-VANC	DATE May 9, 2011		

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Figure 2.6-1

2.6.1 Water Quality

2.6.1.1 Methods

Physical Water Quality Parameters

Lake water quality profiles were measured during all Stantec sampling events at each lake, at consistent sample stations. 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.

Water Chemistry

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 habitat requirements for plants, algae, benthos and fish.

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 of the lake at the time of sampling. Water samples were collected at mid-depth if water temperature was relatively stable throughout the water column and there was no evidence of thermal stratification (e.g., at most stations in spring and fall, and all stations in winter). If the lake was thermally stratified, water samples were collected at mid-depth of the epilimnion, above the thermocline.

Chain of custody forms describing sampling times and analytical requirements were submitted to the analytical laboratory.

Laboratory Analysis

Water samples were analyzed at ALS Environmental, Vancouver, BC, for general parameters. These included major anions, alkalinity, total suspended solids (TSS), total dissolved solids (TDS), pH, conductivity, total metals, dissolved metals, total Kjeldahl nitrogen (TKN), nitrate and nitrite nitrogen, 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).

Data Analysis

Summary statistics were generated for all parameters at each site over the entire baseline program to date. These statistics included sample size, 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.

All general chemistry results were compared to available CCME guidelines (maximum levels) for the protection of aquatic life (CCME 2007). The British Columbia Approved and Working Water Quality Guidelines (BC-MOE 2006, 2008, Nagpal et al. 2006, Nordin and Pommen 2009) were used where CCME guidelines did not exist. These guidelines are summarized in Stantec (2010c). In most cases, detection limits were well below CCME guidelines and had no bearing on the water quality assessment.

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 2.6-2.

TABLE 2.6-2: 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

2.6.1.2 Results

Mean water temperature across all lakes in summer was 9.7°C and 2.2°C during winter. Mean pH values in winter were generally lower than in summer (7.5 vs. 8.1). Shallow lakes had very low dissolved oxygen levels in winter (<5 mg/L), and some were anoxic. Temperature and dissolved oxygen profiles of select lakes are provided in Figure 2.6-2 (a and b).

Based on data reported by Stantec (2010c) and Melville et al. (1989), waters within the broad footprint of the proposed Nechalacho Mine and Flotation Plant site area have relatively high alkalinity, hardness, and calcium. These characteristics indicate a high acid buffering capacity. Lakes tend to be relatively clear with low suspended sediment levels, and low nutrient and metals concentrations. It is important to note that no CCME exceedances were noted for Thor Lake, into which discharges from the tailings area would ultimately drain. (No CCME exceedances in Thor Lake were noted except for one result for copper (6.03 μg/L) for March, 2008. All subsequent analyses were an order of magnitude or greater less than that value). Water quality analyses for a wide range of parameters are provided in Stantec (2010c; Section 6.2 and Appendices E and F); minimum, average, and maximum conductivity, pH, hardness, total suspended solids, ammonia, phosphate, total arsenic, and total iron are shown in Figure 2.6-3 (a and b) (sampling stations are identified in Table 2.6-1).

Neutral to basic conditions were documented at all sample stations from 2008 to 2010, with mean pH ranging from 7.58 to 8.35, although Golder (1998a) measured a pH of 8.7 in Thor Lake in early June, 1998. 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 2.6-1).

Within a sampling station, there were large fluctuations seasonally in many general chemistry and metal parameters, as indicated by minimum and maximum values (Figure 2.6-2 a and b). 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.

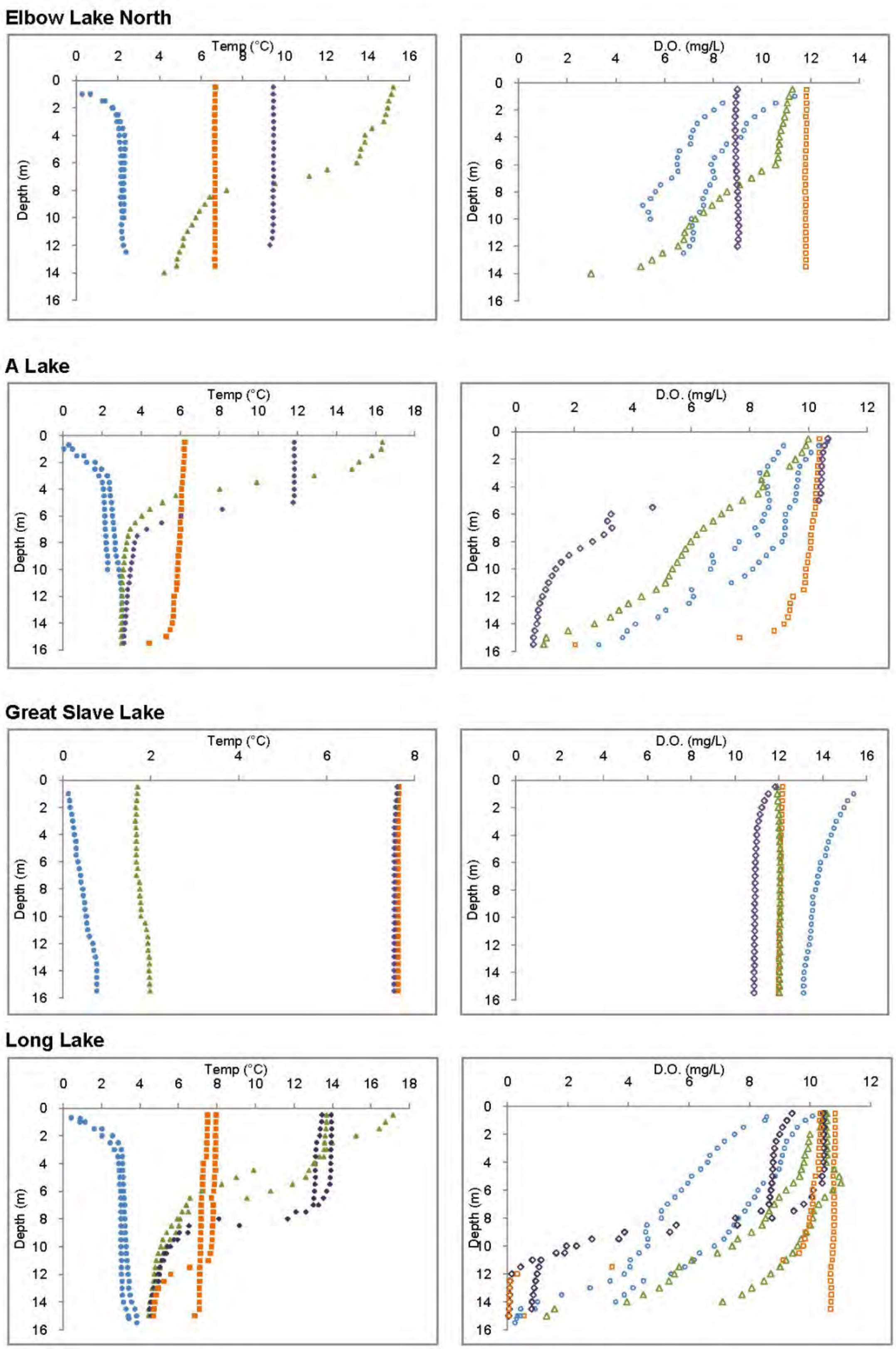
Winter water quality had a large effect on summary statistics for the shallow lakes, as the high values inflated the mean. Mean values for larger, deeper lakes are less affected by omission of winter data, showing less seasonal variation in general chemistry. Megan Lake is one exception to this, though 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).

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).

The Tardiff, Tributary, and Ring Lake groups tended to have higher mean ammonia, phosphate, iron, and arsenic levels than the other groups, probably due to the shallow depths of most of these lakes.

Differences in general chemistry between the lake groups were noted for the Tardiff, Reference, and Great Slave lakes, which had lower mean conductivity and hardness than the other lakes; mean pH was also lower in the Tardiff group. 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.



NOTES

1. Temperature is on the left and Dissolved Oxygen is on the right.
2. Blue circles = winter; green triagles = spring; purple diamonds = late summer/early fall; orange squares = fall.
3. Figure Source: Figure 6-27. Stantec 2010c.

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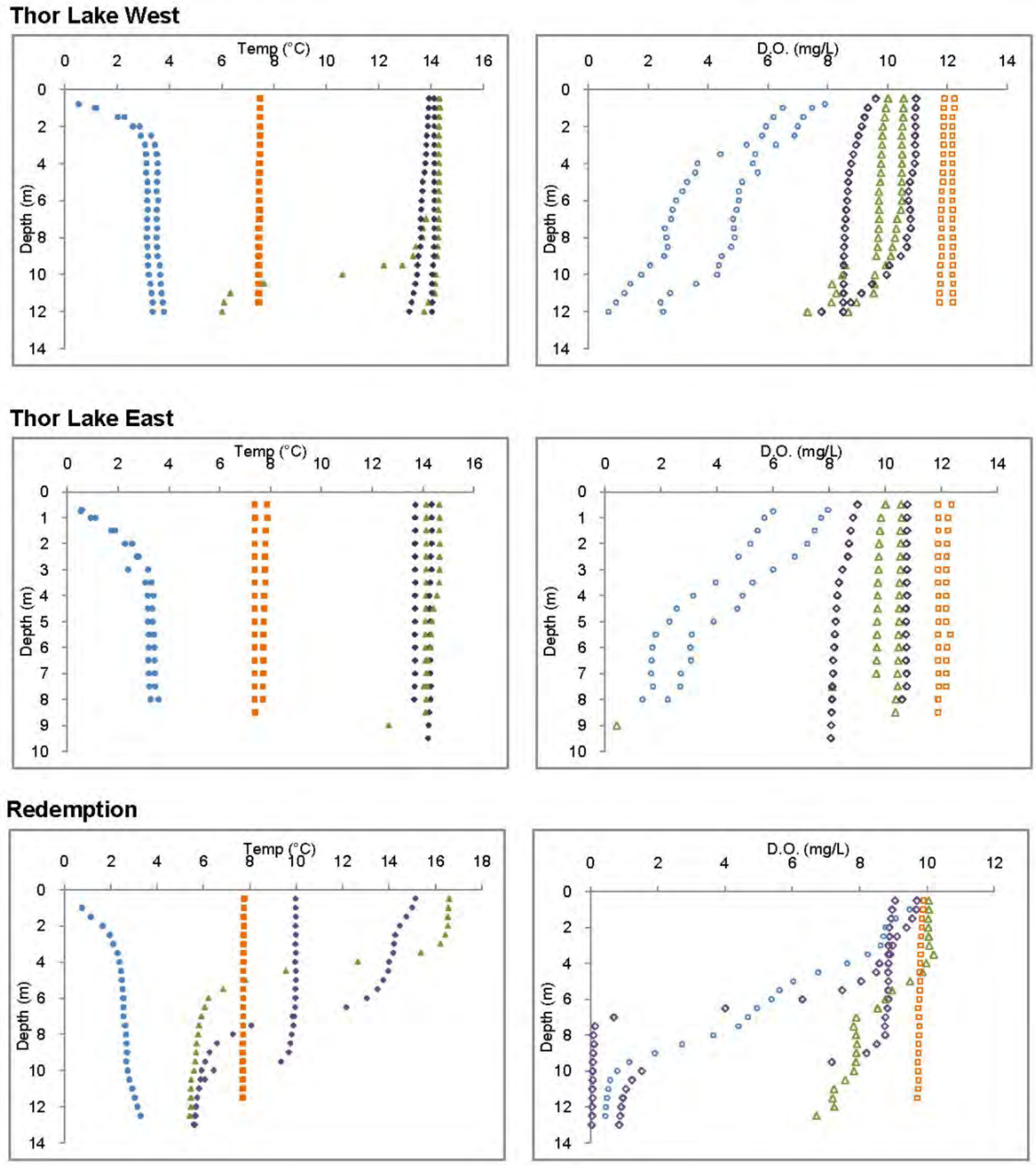
THOR LAKE PROJECT

Temperature and Dissolved Oxygen Profiles of Selected Lakes

PROJECT NO.	DWN	CKD	REV
V15101007.006	SL	DM	0

OFFICE	DATE
EBA-VANC	May 9, 2011

Figure 2.6-2a



NOTES

1. Temperature is on the left and Dissolved Oxygen is on the right.
2. Blue circles = winter; green triagles = spring; purple diamonds = late summer/early fall; orange squares = fall.
3. Figure Source: Figure 6-27. Stantec 2010c.

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THOR LAKE PROJECT

Temperature and Dissolved Oxygen Profiles of Selected Lakes

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Figure 2.6-2b

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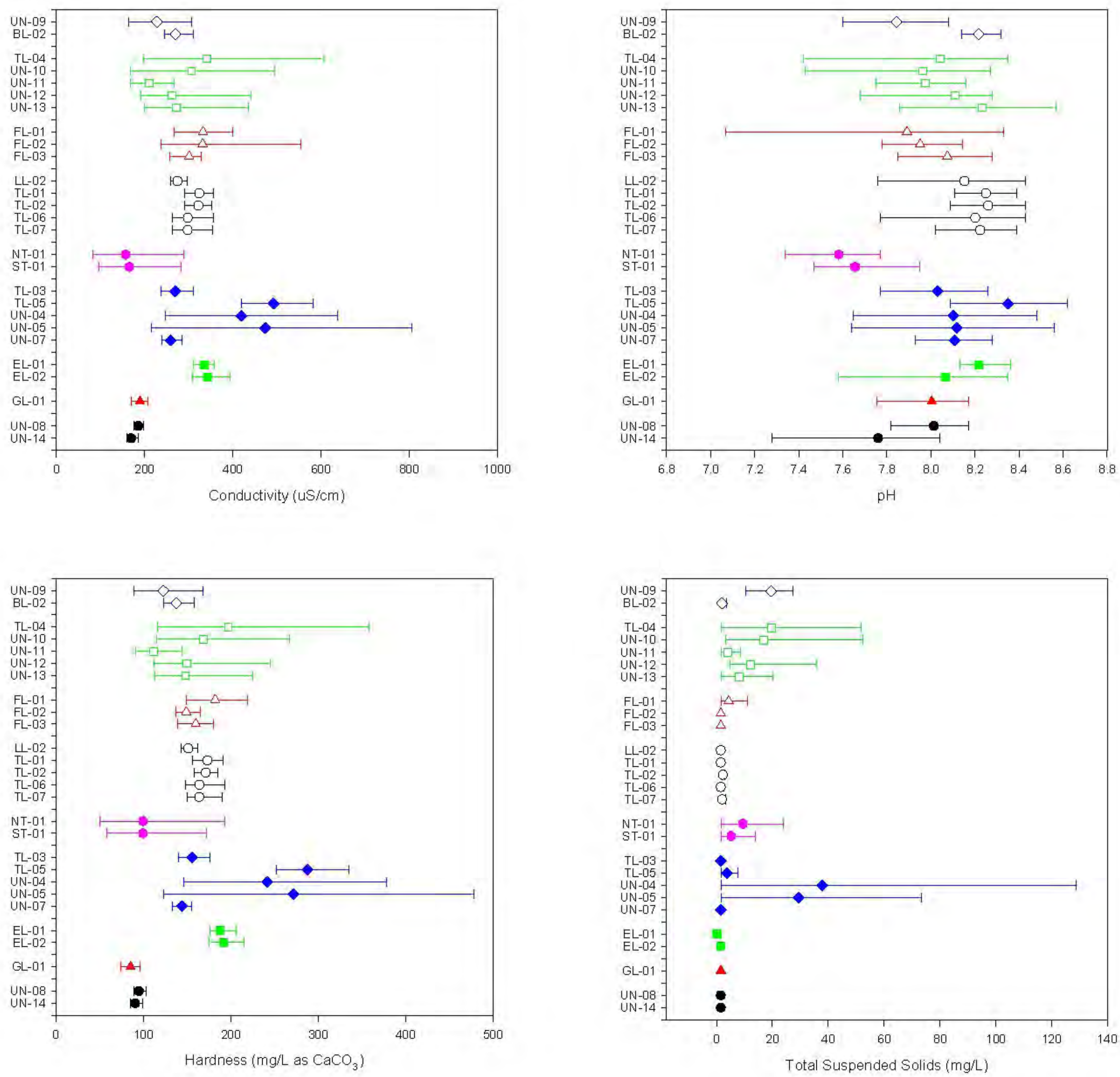

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NOTES

1. 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.
2. Figure Source: Figure 6-28. Stantec 2010c.

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Minimum, Average and Maximum Levels of Several Water Quality Parameters from 2008 to 2010

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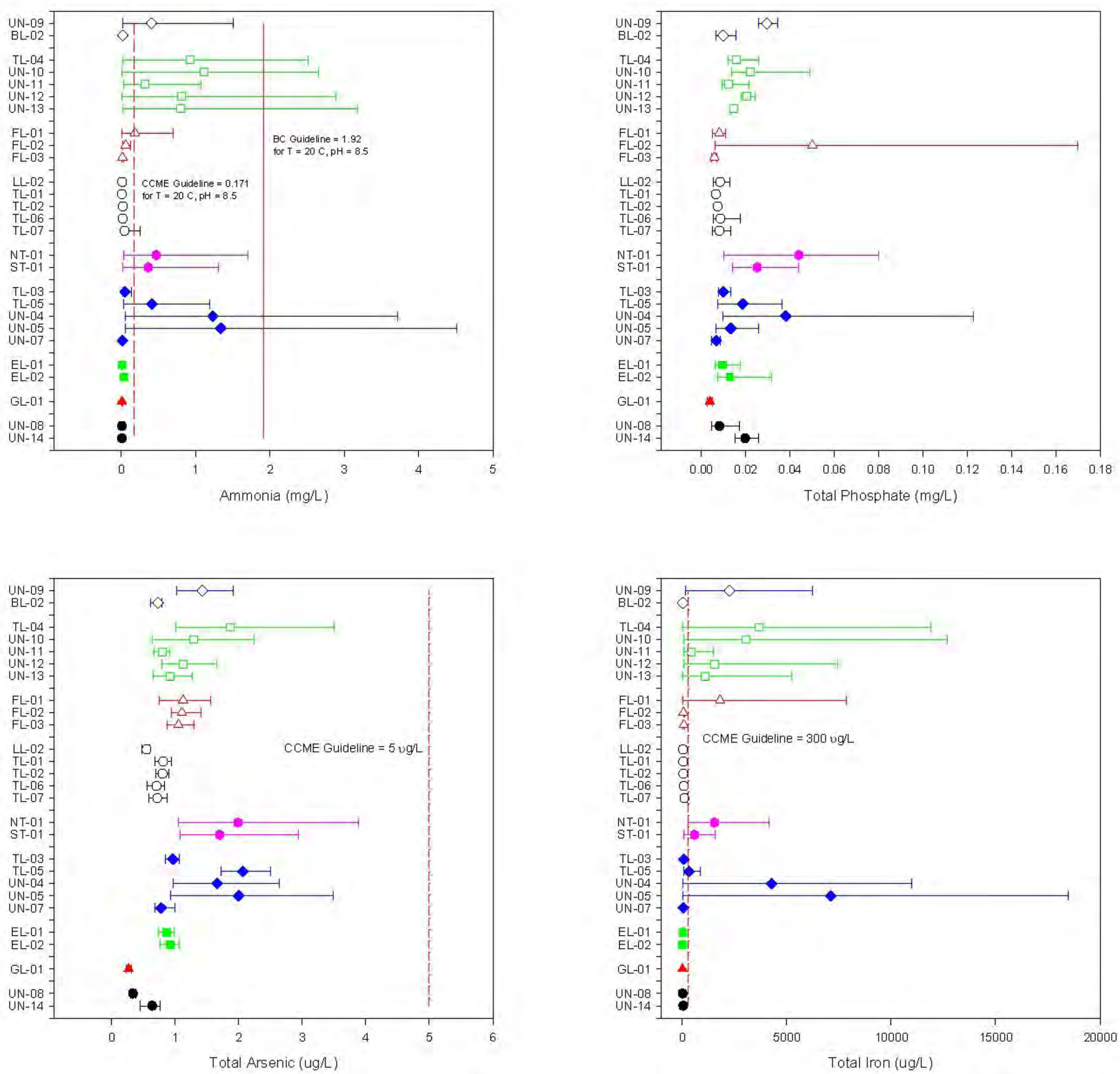
Figure 2.6-3a



NOTES

1. 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.
2. Figure Source: Figure 6-28. Stantec 2010c.

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THOR LAKE PROJECT

Minimum, Average and Maximum Levels of Several Water Quality Parameters from 2008 to 2010

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Figure 2.6-3b

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The following are summaries of baseline water quality characteristics for each lake group. Lake groupings are shown in Figure 2.8-12 (Section 2.8).

Thor Group

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

The two stations sampled in Thor Lake had only slight differences in maximum and mean values for specific parameters (nitrate, total aluminum and iron, and total and dissolved manganese and zinc). Observed differences may be related to proximity to shore (Thor East is located approximately 5 m from vertical bedrock cliff) and use of different sample depths.

Overall, both Thor and Long lakes are characterized by clear, hard water with low conductivity, 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.

Melville et al. (1998) report that radionuclide levels for Thor Lake (as well as Elbow and Ring) were at or below 0.04 Bq/L and that Radium 226 were uniformly below the limits of detection. Uranium levels were below detection limits except in Cressy Lake, where they were as high as 1.9 µg/L. No explanation was offered for the elevated level in this one lake. In the Stantec (2010c) study, radionuclide results were below detection or less than five times the detection limit and no guideline exceedances were observed for any of the measured radionuclide parameters.

Cressy Group

Water quality has been assessed in the Cressy group lakes (Cressy, Fred, and A lakes) from March 2008 to September 2009. General chemistry parameters tend to be similar among these three lakes; however, Fred and Cressy typically have greater variability in levels. All three lakes appear 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, Kjeldahl nitrogen, barium, manganese and strontium. Guideline exceedances for metals did not occur in Cressy or A Lakes.

Ring Group

Water quality in Ring, Murky and Egg lakes has been investigated from March 2008 to October 2010. Buck and Drizzle were added to the aquatic baseline program in September 2009. Ring, Buck, Drizzle and Murky lakes were found to have similar mean values of conductivity, hardness, total suspended solids, nitrate, ammonia and total phosphate, 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, probably due to the fact that Egg Lake is larger and deeper than the other lakes in this group.

Total and dissolved iron levels in Ring, Buck, Drizzle, and Murky lakes were 17-42 times higher than CCME guidelines in winter. Total iron exceeded the CCME guideline in Egg Lake in March 2009, associated with high total suspended solids and turbidity; dissolved iron levels were low. Anoxic and very hard water conditions in winter existed in Ring, Buck, Drizzle, and Murky Lakes.

Great Slave Lake

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 generally observed. Great Slave Lake has a relatively high mean nitrate concentration however, similar to that of Cressy and South Tardiff. This is likely a characteristic of Great Slave Lake.

Reference Group

Water quality data have been collected at Kinnikinnick Lake from March, 2008 to September, 2009, and in Redemption Lake from September, 2009 to October, 2010. General chemistry is typical of large, deep lakes in the study area and is characterized by clear, moderately hard water with low conductance, nutrients and organic carbon, and a low buffering capacity. No exceedances of WQG for metals occurred in the dataset; most metal concentrations are low and relatively stable throughout the seasons sampled.

Tributary Group

The Tributary Group includes all lakes considered upstream of the Thor Group, with the exception of the Tardiff lakes; it is comprised of Megan, Pistol, Porkchop, Thorn and Wasp lakes (see Figure 2.8-12). Pistol and Wasp lakes are shallow with strong seasonal variation in water chemistry. This contrasts with conditions in Thorn and Porkchop lakes, which have less seasonal variability due to their greater depths. Megan Lake is an exception, having considerable seasonal variation despite being of moderate depth (maximum 6.6 m).

Tardiff Group

The Tardiff Group includes North Tardiff and South Tardiff lakes, two small lakes that are located south of Thor Lake and contained within the Lake Zone ore body.

Generally, North and South Tardiff are highly coloured with high dissolved organic carbon (DOC) levels, though they show lower mean values for conductivity, pH, hardness and alkalinity, and a reduced 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 mean nitrate and phosphate (total and ortho) concentrations. The Tardiff lakes exhibit strong seasonal 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 applicable guidelines during winter in both lakes; dissolved aluminum also exceeded the B.C. dissolved guideline in winter at North Tardiff.

High iron (total and dissolved) levels appear to be relatively consistent through all seasons at North Tardiff Lake (ranging from 232 to 3,110 μg/L dissolved iron). The dissolved iron 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 in spring through fall. The disparity in iron concentrations between the Tardiff lakes may be an indication of differences in iron speciation, phytoplankton community composition and subsequent differences in phytoplankton-iron interactions (Öztürk et. al. 2003). High DOC levels, combined with higher nutrients and iron in the Tardiff lakes may be a result of their surrounding peatland environment, 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).

Elbow Lake

Water quality data have been collected in Elbow Lake at two stations since March 2008. Overall, Elbow Lake shows intermediate values of mean conductivity, hardness and dissolved solids. Mean concentrations of some nutrients (nitrate and total phosphate) are higher in Elbow than other deep lakes of the study area (i.e., Long, Kinnikinnick) and greater variation through the dataset is observed. No metals exceeded CCME or BC guidelines through 2008 and 2009 in Elbow Lake, though one outlier was noted at Elbow South (total zinc at 40.3 μg/L).

Blachford Group

The Blachford group of lakes includes Dinosaur Lake and the sampled bay in Blachford Lake (see Figure 2.8-1). Water quality data were collected in the Blachford group 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 sampled bay reflects this. Generally the Blachford sample station exhibited lower mean conductivity, hardness, and nutrients, with no metal exceedances; higher values for some nutrients and suspended solids shown at this station occurred in March 2008 when the station was located in a shallower area of the bay.

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

2.6.2 Sediment Quality

Sediment sampling and analysis has been carried out in Nechalacho Project area lakes since 2008 to establish a baseline for identification of potential effects following mine development. 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.

The resuspension of metals due to sediment disturbance may result in acute or chronic toxicity in benthic and planktonic organisms (e.g., biochemical and physiological changes), which can lead to altered community structure and to effects on other organisms, including fish, in the aquatic food web (Stantec 2010c). Further discussion of sediment chemistry is available in Stantec (2010c).

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. Importantly, the ISQG are not defined for a particular sediment particle size range. Since only the fine fraction (<63 μm) was analyzed for this Project, a bias toward higher metal levels may have been introduced into the results since this fraction tends to have the highest metals content.

2.6.2.1 Sample Collection Methods

Sediment samples were collected during September 2009 and 2010 using a 2.4 L (152 x 152 mm) petite ponar sediment grab (Stantec 2010c). 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.

Sediment samples were also collected from Thor Lake and Blachford Lake (in addition to other lakes outside the Nechalacho Mine site area) in June, 1998 (Golder 1998a). Sampling was carried out using a two-inch corer; three replicate samples were collected from each lake and were frozen prior to analysis. Sediment samples were analyzed for metals, nutrients, total organic carbon, major ions, and radionuclides.

Sediment samples were not collected as part studies within the Project footprint area carried out in 1988 by Melville et al. (1989).

2.6.2.2 Laboratory Methods

Sediment samples collected in 1998 (Golder 1998a) were submitted to Enviro-Test Laboratories in Edmonton, Alberta, for analysis. However, analysis methods were not described in that report.

Sediment samples collected in 2008-2010 (Stantec 2010c) 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.

2.6.2.3 Data Analysis and QA/QC

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 (Golder 1998a) 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 2.6-3 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 2.6-3: SUMMARY OF CCME ISQ GUIDELINES AND DETECTION LIMITS FOR SEDIMENT PARAMETERS WITH DETECTION LIMITS APPROACHING GUIDELINES (STANTEC 2010C)

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

NOTES:
Silver sediment guideline from BC Working Sediment Quality Guidelines
PAHs includes 17 parent PAHs; individual guideline values are described in Table 2.6-4

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 2.6-4.

TABLE 2.6-4: PARAMETERS ANALYZED AND CANADIAN (CCME) AND BRITISH COLUMBIA WORKING SEDIMENT QUALITY GUIDELINES FOR PROTECTION OF AQUATIC LIFE (STANTEC 2010c)

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	–	–

TABLE 2.6-4: PARAMETERS ANALYZED AND CANADIAN (CCME) AND BRITISH COLUMBIA WORKING SEDIMENT QUALITY GUIDELINES FOR PROTECTION OF AQUATIC LIFE (STANTEC 2010c)

Parameters	Sediment Quality Guidelines (mg/kg)			
	CCME ISQG[1]	CCME PEL[1]	BC LEL[2,3]	BC SEL[2,3]
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	–	–

NOTES:
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 and j) fluoranthene, and total, barium, beryllium, cobalt, molybdenum, antimony, tin, thallium, uranium and vanadium.

QA/QC protocols for the Stantec (2010c) studies 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. Specific QA/QC field and laboratory procedures are provided in Stantec (2010c). No QA/QC procedures were described for the Golder (1998a) studies.

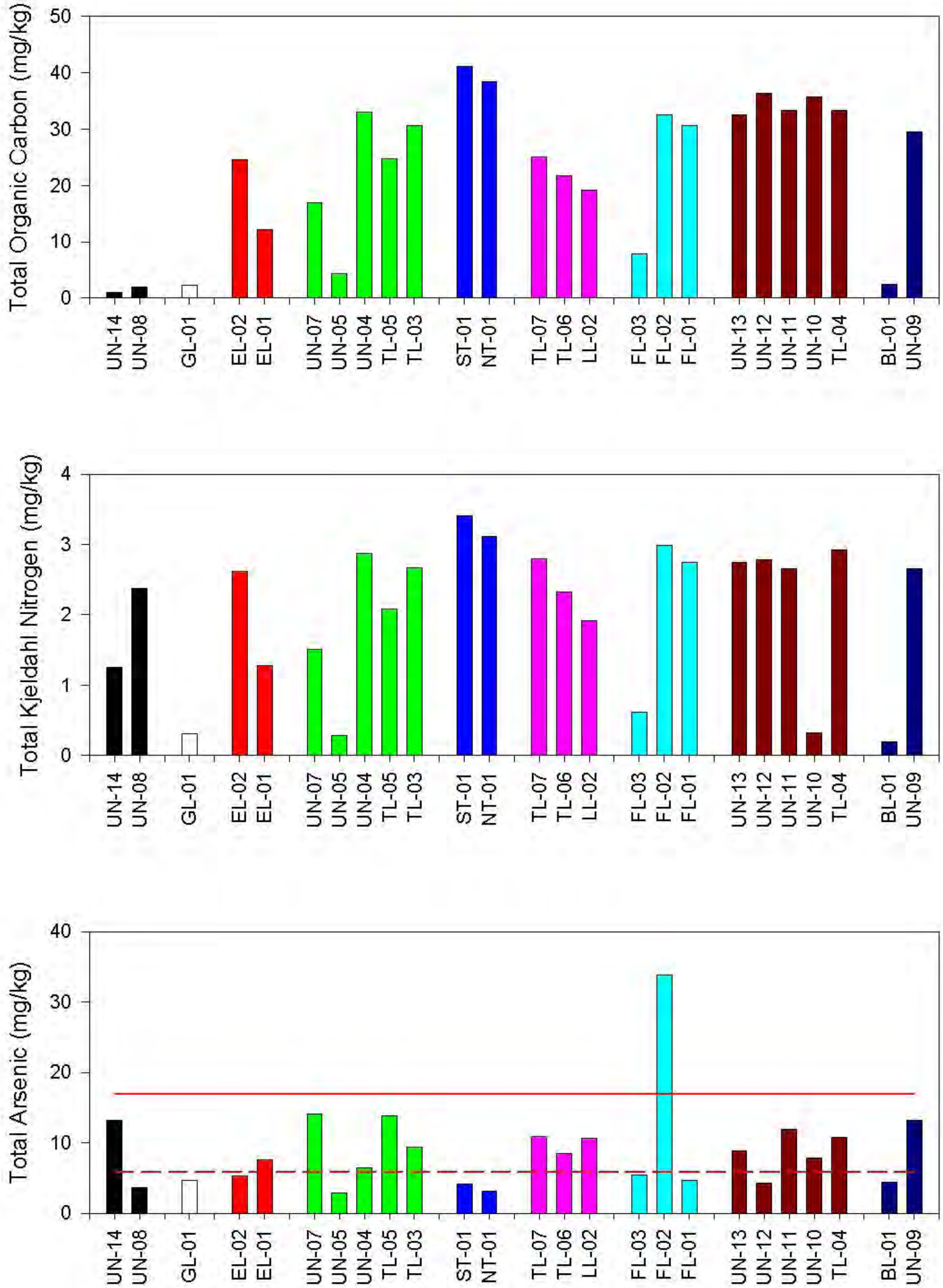
2.6.2.4 Results

Results from the Stantec (2010c) sediment analyses are shown graphically in Figure 2.6-4 a and b for total organic carbon, total Kjeldahl nitrogen, total arsenic, total silver, total nickel, and total copper. The full sediment analyses data set for the 2008-2010 study is available in Stantec (2010c; Appendix A).

Sediment characteristics from the 2008-2010 studies varied across the Project 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 2.6-4a and b). TOC was lowest in the Reference group, while Blachford Lake showed the lowest Total Kjeldahl Nitrogen. Phosphorous, TOC and Kjeldahl nitrogen were not analyzed in the Golder (1998a) samples.

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. Of these metals, only arsenic and copper were analyzed in the Golder (1998a) studies and neither exceeded the CCME ISQG.

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.



NOTES
1. Red dashed line indicates the CCME ISQG, solid red line indicates CCME PEL
2. Figure Source: Figure 6-30. Stantec 2010c.

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Mean Levels of Several Sediment Parameters in September 2009-2010

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Figure 2.6-4a

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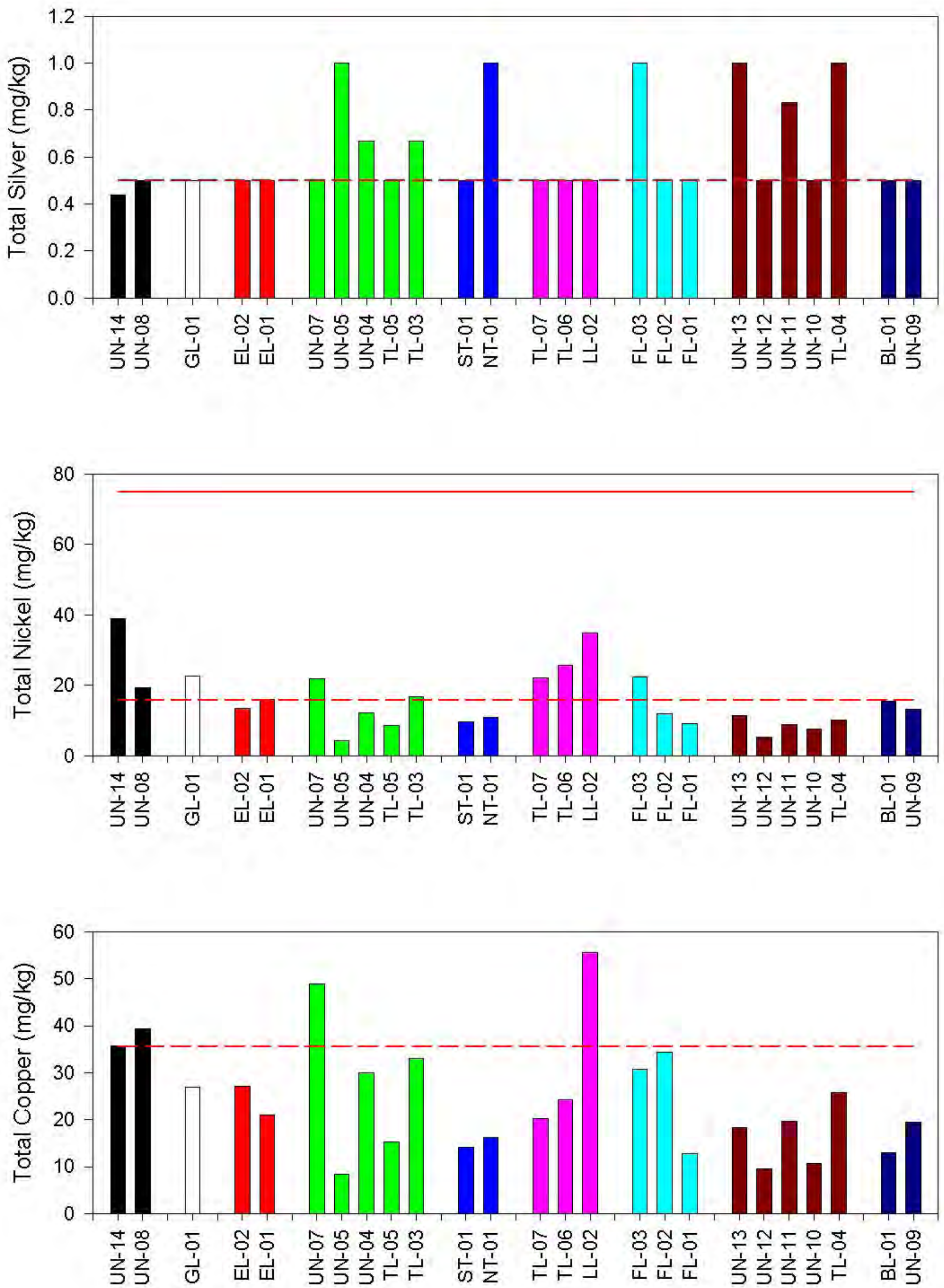

NOTES

1. Red dashed line indicates the CCME ISQG, solid red line indicates CCME PEL
2. Figure Source: Figure 6-30. Stantec 2010c.

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THOR LAKE PROJECT

Mean Levels of Several Sediment Parameters in September 2009-2010

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Figure 2.6-4b

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The following are summaries of baseline sediment quality characteristics for each lake group as reported by Stantec (2010c). Lake groupings are shown in Figure 2.8-12 (Section 2.8).

Thor Group

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.

Cressy Group

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).

Ring Group

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).

Great Slave Lake

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).

Reference Group

Sediment chemistry at Kinnikinnick Lake indicated 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.

Tributary Group

Sediment chemistry 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.

Tardiff Group

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.

Elbow Lake

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).

Blachford Group

Sediment chemistry is dissimilar between Blachford and Dinosaur 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.

2.6.3 Groundwater Quality

Groundwater sampling in the Nechalacho Mine site area has been conducted to establish baseline conditions prior to development in order to characterize existing groundwater quality for future monitoring purposes. A description of the groundwater monitoring wells located within the Project area is contained in Section 2.7; well locations are shown in Figure 2.7-1. Groundwater investigations were carried out by Stantec (2010b). There are no reports of groundwater sample collection prior to those 2008-2010 studies.

2.6.3.1 Sampling Methods

Groundwater samples were collected by Stantec using disposable bailers from existing and new monitoring wells up to three times during the 2008, 2009, and 2010 field programs (August to October 2008, March and June to October 2009, and May to October 2010). Sample bottles were provided by ALS Laboratory Group (ALS). Non-powdered nitrile gloves were worn at all stages of the sampling procedure to prevent sampling contamination (Stantec 2010b)

Samples were analyzed for physical parameters, nutrients, total metals, dissolved metals, and total organic carbon. The samples to be analyzed for dissolved metals were filtered using a 0.45 μm sterilized membrane in the field. The appropriate preservatives were added to the samples, as outlined by ALS. The samples were labeled and stored in a chilled cooler with ice packs while transported to the lab. A chain of custody form detailing the sampling handling information and analysis required was prepared and included with the samples prior to shipping via air cargo to ALS in Vancouver, BC. All samples were received by lab within QA/QC protocol. Field and duplicate samples were also collected based on standard QA/QC protocols.

All groundwater quality data have been compared to federal, Canadian Council of Ministers of Environment (CCME), Canadian Water Quality Guidelines for the protection of Aquatic Life (December 2007). In addition, data have been compared to the British Columbia Contaminated Sites Regulation (CSR), Schedule 6 Generic Numerical Water Standards for the protection of Freshwater Aquatic Life (January, 2009).

These criteria were selected due to the absence of any other existing federal or territorial guidelines for groundwater quality. These criteria serve to provide general guidance only and have been used for comparison to existing background groundwater quality conditions at the study area. It is anticipated that the background concentrations represent ambient levels, which may reflect natural geologic variations in relatively undeveloped areas.

2.6.3.2 Results

The analytical results of all groundwater samples collected during the period 2008 to 2010 are presented in Tables 2.6-5, 2.6-6 and 2.6-7 and reported in Stantec (2010b; Appendix A, Tables 5-7). Results of analysis for wells sampled over multiple events were generally in the same range. Although no seasonal trends were apparent, this may be due to short term and infrequent data collection.

Magnesium was found to be the dominating cation in two of the monitoring wells sampled (L08-124 and MW08-130), while sodium dominated in the other two sample locations (MW08-127 and MW09-152), and both sodium and magnesium dominated MW08-128 depending on the sampling event. Carbonate was the dominating anion in all samples.

All groundwater samples were analyzed for their concentrations of total and dissolved metals. The measured dissolved metal concentrations were compared to CSR and CCME water quality guidelines for the protection of aquatic life. The CSR guideline values apply to both surface and groundwater, whereas the CCME guidelines only apply to surface water. However, as groundwater ultimately discharges to surface water bodies, the CCME guideline values are included here for reference. All exceedances are identified in Tables 2.6-5, 2.6-6 and 2.6-7.

Exceedances of the CSR and/or CCME guidelines are summarized in Table 2.6-8. These exceedances of the CCME and/or CSR guidelines do not imply that the groundwater at the study area is currently contaminated; only that background concentrations of these parameters are higher than typically found in groundwater at other natural sites in Canada. These background groundwater quality results merely reflect the natural geologic and hydrogeologic conditions within these specific areas of the property (Stantec 2010b).

TABLE 2.6-5: GROUNDWATER GENERAL CHEMISTRY

Parameter	Units	D.L.	Sample Stations																					
			MW08-124		MW008-127				MW08-128								MW08-130			MW08-152				
			8-Oct-08	8-Oct-09	20-Sep-08	9-Oct-08	8-Oct-09	14-Oct-10	20-Sep-08	8-Oct-08	8-Oct-09	11-Jun-10	3-Sep-10	Dup 2-Sep-10	14-Oct-10	Dup 14-Oct-10	21-Sep-08	7-Oct-08	14-Oct-10	26-Jun-09	Dup 26-Jun-09	8-Oct-09	Dup 08-Oct-09	14-Oct-10
Physical																								
Hardness (as CaCO3)	mg/L	0.7	469	365	142	72.6	74.5	239.0	261	166	147	253	303	302	301	300	282	304	-	71.4	71.3	96.9	96.5	47.3
Conductivity	µS/cm	2	738	460	878	405	404	414	482	382	367	419	498	502	505	514	557	558	788	717	721	592	587	230
pH	pH	0.01	8.25	8.10	8.15	8.16	6.86	8.10	7.59	7.9	7.41	7.49	8.00	8.00	7.82	7.87	8.1	8.21	7.72	8.52	8.56	8.17	8.24	8.10
Total Dissolved Solids	mg/L	10	422	274	487	291	240	231	335	258	230	333	312	302	299	294	331	335	546	446	464	388	399	135
Total Suspended Solids	mg/L	3	110	28.8	33	213	56.8	692	49.5	29.20	17.8	10.9	38.8	34.3	90.2	40.2	14.5	3.2	7.7	110	116	23.3	35.8	244.0
Turbidity	NTU	0.1	171	70.6	13	1150	42.7	323	79.3	42.2	20.0	13.6	19.8	18.1	41.8	28.5	4.05	2.69	6.05	35.1	34.1	22.6	19.8	41.7
Anions																								
Alkalinity, Total (as CaCO3)	mg/L	2	442	265	287	144	121	232	251	202	173	262	275	276	279	282	266	276	290	287	282	278	289	107
Bromide (Br)	mg/L	0.05	<0.050	<0.050	0.358	<0.25	<0.050	<0.050	<0.25	<0.25	<0.050	<0.50	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.50	0.188	0.193	<0.050	<0.050	<0.050
Chloride (Cl)	mg/L	0.5	1.55	0.84	108	43.2	36.9	1.11	3.6	3.5	11.4	<5.0	1.96	1.50	2.24	2.31	3.48	3.68	66.8	61.8	62	20.8	21.0	7.49
Fluoride (F)	mg/L	0.02	2.41	2.19	2.54	1.37	0.720	0.631	1.29	397	1.16	0.92	1.32	1.39	1.46	1.47	1.05	1.04	0.85	4.37	4.38	2.76	2.79	0.937
Sulphate (SO_4)	mg/L	0.5	24.5	7.80	1	4	25.1	1.76	4.8	7.7	6.88	<5.0	8.08	8.30	7.75	8.13	14.9	14.4	18.7	12.6	12.6	8.40	7.08	3.18
Nutrients																								
Nitrate as N	mg/L	0.005	0.475	0.125	<0.0050	<0.025	0.0063	<0.0050	<0.025	<0.025	<0.0050	<0.050	0.0138	<0.0050	<0.0050	<0.0050	5.07	5.5	0.323	4.37	4.38	<0.0050	<0.0050	<0.0050
Nitrite as N	mg/L	0.001	0.0254	<0.0010	<0.0010	0.0079	<0.0010	<0.0010	0.0137	0.0078	<0.0010	<0.050	<0.0010	<0.0010	<0.0010	<0.0010	0.227	0.237	<0.010	<0.0050	<0.0050	<0.0010	<0.0010	<0.0010
Total Kjeldahl Nitrogen	mg/L	0.05	0.47	0.481	0.477	2.19	0.508	1.12	1.88	1.79	1.14	1.79	0.91	0.92	1.11	1.09	0.813	0.872	0.51	0.705	0.681	0.716	0.769	1.11
Ortho Phosphate as P	mg/L	0.001	<0.0010	<0.0010	<0.0010	0.0087	<0.0010	<0.0010	0.0016	<0.0010	<0.0010	0.012	0.0018	0.0015	0.0010	0.0017	<0.0010	<0.0010	0.0031	-	-	<0.0010	<0.0010	0.0010
Total Phosphate as P	mg/L	0.20	<0.020	0.019	0.024	0.066	0.060	0.270	0.030	0.163	0.041	0.027	0.034	0.447	0.068	0.043	0.0062	0.0044	0.046	-	-	0.0078	0.0148	0.123
Organics																								
Total Organic Carbon (TOC)	mg/L	0.5	7.78	11.9	10.4	28.7	11.8	13.7	30.9	25.5	14.9	30.6	17.4	15.2	14.1	14.5	16	15.8	102	9.32	8.78	19.7	18.5	9.57

TABLE 2.6-6: GROUNDWATER TOTAL METALS

TOTAL METALS	UNITS	D.L.	CCME FAL	BC CSR AW	Sample Stations													
					L08-124	MWL08-127			MWL08-128							MWL08-130		MW08-152
					8-Oct-08	20-Sep-08	9-Oct-08	14-Oct-10	20-Sep-08	8-Oct-08	11-Jul-10	3-Sep-10	Dup 3-Sep-10	14-Oct-10	Dup 14-Oct-10	21-Sep-08	7-Oct-08	14-Oct-10
Aluminum (Al)	mg/L	0.005*	0.1[6]	-	**1.14**	**0.566**	**37.0**	**11.7**	**0.552**	**0.302**	**0.149**	**0.220**	**0.193**	**0.844**	**0.281**	**0.811**	**0.178**	**2.17**
Antimony (Sb)	mg/L	0.0005*	-	0.20	<0.00050	<0.0010	<0.0025	0.00013	<0.00050	<0.00050	<0.00010	<0.00010	<0.00010	0.0001	<0.00010	<0.00050	<0.00050	0.00129
Arsenic (As)	mg/L	0.0005*	0.005	0.05	0.00067	0.0017	0.0067	0.00229	**0.0231**	**0.00512**	0.00478	**0.00829**	**0.00794**	**0.00614**	**0.00649**	0.00102	0.00054	0.00131
Barium (Ba)	mg/L	0.02	-	10	0.160	0.044	0.473	0.278	0.179	0.156	0.208	0.194	0.191	0.196	0.193	0.440	0.407	0.0953
Beryllium (Be)	mg/L	0.001*	-	0.053	<0.0010	<0.0020	<0.0050	0.00064	<0.0010	<0.0010	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.0010	<0.0010	<0.00050
Boron (B)	mg/L	0.1	-	50	<0.10	0.67	0.33	0.026	<0.10	<0.10	0.027	0.020	0.021	0.018	0.018	<0.10	<0.10	0.189
Cadmium (Cd)	mg/L	0.000017*	0.000017	0.00001 -	**0.000254**	**0.000316**	**0.000287**	**0.000088**	**0.000430**	**0.000282**	**0.000038**	**0.000212**	**0.000198**	**0.000179**	**0.00193**	**0.000156**	**0.000060**	**0.000291**
Calcium (Ca)	mg/L	0.1	-	-	30.9	24.3	17.6	45.2	49.1	29.1	44.8	53.7	53.1	50.6	52.0	48.3	50.5	15.3
Chromium (Cr)	mg/L	0.001*	-	-	0.0104	<0.0020	0.0489	0.0124	0.0013	0.0010	0.00151	0.00109	0.00090	0.00184	0.00108	0.0071	<0.0010	0.0101
Cobalt (Co)	mg/L	0.003*	-	0.04	0.00439	<0.00060	0.0143	0.00417	0.00146	0.00138	0.00021	0.00022	0.00020	0.00035	0.00021	0.00316	0.00349	0.00110
Copper (Cu)	mg/L	0.001*	0.002-	0.002 - 0.009[8]	**0.0256**	**0.0276**	**0.0804**	**0.0995**	0.0033	0.0029	0.00063	0.00104	<0.00090	0.00183	0.00094	**0.0402**	**0.0272**	**0.115**
Iron (Fe)	mg/L	0.03	0.3	-	**32.1**	**0.837**	**37.4**	**23.9**	**8.89**	**14.5**	**16.2**	**9.04**	**9.45**	**12.6**	**9.77**	**2.69**	**0.303**	**4.92**
Lead (Pb)	mg/L	0.0005*	0.001 -	0.004 - 0.016[10]	0.00069	<0.0010	**0.0146**	**0.00790**	0.00253	0.00103	0.000266	0.000305	0.000268	0.00129	0.000519	0.00360	<0.00050	0.00286
Lithium (Li)	mg/L	0.005	-	-	0.0208	0.051	0.075	0.0204	0.0161	0.0147	0.0069	0.0077	0.0079	0.0073	0.0083	0.0154	0.0126	0.0224
Magnesium (Mg)	mg/L	0.1	-	-	94.1	19.8	17.2	37.8	33.6	22.1	31.4	39.0	38.3	37.1	38.3	39.1	43.0	5.35
Manganese (Mn)	mg/L	0.0003*	-	-	0.188	0.190	0.619	1.08	0.490	0.552	0.508	0.404	0.400	0.387	0.365	0.123	0.100	0.141
Mercury (Hg)	mg/L	0.00002	-	0.001	<0.000020	<0.000020	<0.00010	0.000049	<0.000020	<0.000020	<0.000010	<0.000010	<0.000010	0.000013	<0.000010	<0.000020	<0.000020	0.000014
Molybdenum (Mo)	mg/L	0.001*	0.073	10	0.0215	0.0286	0.0359	0.00440	0.0241	0.0177	0.00862	0.0164	0.0163	0.0152	0.0161	0.0559	0.0456	0.126
Nickel (Ni)	mg/L	0.001*	0.025 -	0.025 - 0.15[13]	0.0075	0.0020	0.0396	0.0131	0.0035	0.0036	0.00073	0.00073	0.00058	0.00148	0.00080	0.0108	0.0115	0.00516
Potassium (K)	mg/L	2	-	-	3.9	5.9	10.5	8.0	7.8	4.1	3.9	3.5	3.5	4.0	4.0	3.9	3.1	2.9
Selenium (Se)	mg/L	0.001*	0.001	0.01	<0.0010	<0.0020	<0.0050	0.0046	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	**0.0011**	<0.0010	**0.0012**
Silver (Ag)	mg/L	0.00002*	0.0001	0.0005 - 0.015[14]	**0.00470**	**0.000396**	**0.00229**	**0.0191**	**0.000332**	**0.000171**	0.000064	0.000059	0.000050	0.000096	0.000053	**0.00351**	**0.00377**	**0.00132**
Sodium (Na)	mg/L	2	-	-	10.6	131	74.5	7.4	11.8	22.3	5.0	4.3	4.2	4.5	4.8	16.6	13.8	36.6
Thallium(Tl)	mg/L	0.002*	0.0008	0.003	<0.00020	<0.00040	<0.0010	0.00020	<0.00020	<0.00020	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00020	<0.00020	<0.00010
Tin (Sn)	mg/L	0.0005*	-	-	0.00196	<0.0010	<0.0025	0.00107	<0.00050	0.00176	0.00013	0.00012	0.00012	0.00012	0.00013	0.00053	0.00106	0.00180
Titanium (Ti)	mg/L	0.01	-	1	0.018	<0.010	0.696	0.242	0.010	0.010	<0.010	<0.010	<0.010	0.017	<0.010	0.016	<0.010	0.048
Uranium (U)	mg/L	0.0002*	-	0.30	0.0197	0.0132	0.0035	0.0103	0.0266	0.00382	0.00494	0.0115	0.0113	0.00981	0.0116	0.00273	0.00235	0.00350
Vanadium (V)	mg/L	0.001*	-		0.0013	<0.0020	0.0642	0.0145	0.0021	0.0012	0.0026	0.0013	0.0013	0.0019	0.0012	<0.0010	<0.0010	0.0031
Zinc (Zn)	mg/L	0.005	0.03	0.075 - 2.4[15]	0.0188	0.0091	**0.0987**	**0.0412**	0.0140	0.0139	<0.0010	<0.0030	<0.0020	0.0101	0.0062	0.0118	0.0052	**0.132**
Chromium (VI)	mg/L	0.001			--	<0.001	--	--	<0.001	--	--	--	-	--	--	<0.001	--	--

TABLE 2.6-7: GROUNDWATER DISSOLVED METALS

Dissolved Metals	Units	D.L.	CCME FAL	BC CSR AW	Sample Stations																	
					MWL08-124		MWL08-127			MWL08-128							MWL08-130	MWL09-152				
					08-Oct-08	08-Oct-09	09-Oct-08	08-Oct-09		08-Oct-08	08-Oct-09	11-Jul-10	3-Sep-10	Dup	14-Oct-10	Dup	07-Oct-08	26-Jun-09	Dup 26-Jun-09	08-Oct-09	Dup 08-Oct-09	14-Oct-10
Aluminum (Al)	mg/L	0.005*	0.1[6]	-	0.0065	0.0037	**15.3**	0.0108	0.0116	0.0338	0.0084	0.0504	0.0335	0.0344	0.0279	0.0276	0.0077	0.0178	0.0181	0.0066	0.0245	0.0132
Antimony (Sb)	mg/L	0.0005*	-	0.20	<0.00050	<0.00010	<0.0025	0.00013	<0.00010	<0.00050	0.00011	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00050	0.00032	0.00029	0.00011	0.00012	0.00046
Arsenic (As)	mg/L	0.0005*	0.005	0.05	<0.00050	0.00038	0.0027	0.00066	0.00079	0.00233	0.00404	0.00469	0.00944	0.00905	0.00813	0.00856	0.00065	0.0018	0.00174	0.00084	0.00090	0.0003
Barium (Ba)	mg/L	0.02	-	10	0.084	0.0874	0.257	0.0496	0.117	0.143	0.107	0.204	0.195	0.199	0.185	0.187	0.401	0.016	0.0164	0.0212	0.0217	0.0463
Beryllium (Be)	mg/L	0.001*	-	0.053	<0.0010	<0.00050	<0.0050	<0.00050	<0.00050	<0.0010	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.00050	<0.0010	<0.0010	<0.0010	<0.00050	<0.00050	<0.00050
Boron (B)	mg/L	0.1	-	50	<0.10	0.050	0.31	0.067	0.017	<0.10	0.021	0.024	0.017	0.018	0.017	0.017	<0.10	0.806	0.817	0.690	0.725	<0.00050
Cadmium (Cd)	mg/L	0.000017*	0.000017	0.00001 - 0.00006[7]	<0.000017	<0.000080	**0.000206**	<0.000080	<0.000017	**0.000249**	<0.00020	**0.000041**	**0.000208**	**0.000209**	**0.000187**	**0.000193**	0.000018	<0.00020	<0.0020	<0.00010	<0.00020	**0.000018**
Calcium (Ca)	mg/L	0.1	-	-	29.5	26.7	14.9	17.1	44.2	29.3	29.8	46.8	55.2	55.2	54.8	54.0	50.4	15.7	15.6	20.4	20.5	12.8
Chromium (Cr)	mg/L	0.001*	-	-	0.0013	<0.0030	0.0179	<0.0060	<0.00050	<0.0010	<0.0030	<0.0015	<0.0010	<0.0010	<0.0010	<0.0020	<0.0010	<0.003	<0.0030	<0.0020	<0.0030	<0.00050
Cobalt (Co)	mg/L	0.003*	-	0.04	0.00178	0.00138	0.0057	0.00045	0.00025	0.00126	0.00043	0.00017	0.00014	0.00016	0.00017	0.00016	0.00328	<0.00020	<0.00020	0.00017	0.00017	<0.00010
Copper (Cu)	mg/L	0.001*	0.002-0.004[9]	0.002 - 0.009[8]	**0.0046**	**0.00408**	**0.0474**	0.00102	0.00059	<0.0010	**0.00046**	0.00025	0.00024	0.00031	<0.00050	<0.00050	**0.0182**	<0.00020	0.00021	0.00040	0.00062	0.0144
Iron (Fe)	mg/L	0.03	0.3	-	0.133	**0.324**	**8.85**	**1.09**	2.27	**10.8**	**5.96**	15.4	9.00	8.96	10.1	9.15	<0.030	0.083	0.093	0.098	0.094	0.04
Lead (Pb)	mg/L	0.0005*	0.001 - 0.007[11]	0.004 - 0.016[10]	<0.00050	<0.000050	**0.0066**	0.000141	<0.000050	<0.00050	<0.000050	<0.000050	<0.000050	0.000335	<0.000050	<0.000050	<0.00050	<0.00010	<0.00010	<0.000050	0.000052	0.000162
Lithium (Li)	mg/L	0.005	-	-	0.0194	0.0189	0.043	0.0188	0.0057	0.0152	0.0139	0.0070	0.0077	0.0074	0.0078	0.0080	0.0127	0.063	<0.061	0.0580	0.0586	0.0189
Magnesium (Mg)	mg/L	0.1	-	-	96.1	72.6	8.59	7.73	31.2	22.5	17.5	33.0	40.0	39.8	39.8	40.0	43.3	7.79	7.83	10.9	11.0	3.74
Manganese (Mn)	mg/L	0.0003*	-	-	0.0506	0.0508	0.260	0.222	0.797	0.544	0.336	0.485	0.392	0.389	0.368	0.362	0.0888	0.0255	0.0254	0.0294	0.0304	0.00075
Mercury (Hg)	mg/L	0.00002	-	0.001	<0.000020	--	<0.00010	--	<0.000010	<0.000020	--	<0.000010	<0.000010	<0.000010	<0.000010	<0.000010	<0.000020	<0.000050	<0.000050	--	--	<0.000010
Molybdenum (Mo)	mg/L	0.001*	0.073	10	0.0119	0.0281	0.0345	0.0230	0.00388	0.0194	0.0627	0.00663	0.0150	0.0152	0.015	0.0157	0.0466	0.0497	0.0497	0.0382	0.0403	0.0119
Nickel (Ni)	mg/L	0.001*	0.025 - 0.15[13]	0.025 - 0.15[13]	0.0024	0.00208	0.0151	0.00663	0.00102	0.0027	0.00371	<0.00050	<0.00050	<0.00050	0.00057	0.00051	0.0108	<0.0010	<0.0010	0.00054	0.00071	0.00124
Potassium (K)	mg/L	2	-	-	3.4	3.5	6.6	2.7	3.6	4.2	3.0	4.3	<0.30	<0.30	4.2	4.0	3.0	3.2	3.2	3.2	3.2	<2.0
Selenium (Se)	mg/L	0.001*	0.001	0.01	<0.0010	<0.0010	<0.0050	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0020	<0.0020	<0.0010	<0.0010	<0.0010
Silver (Ag)	mg/L	0.00002*	0.0001	0.0005 - 0.015[14]	<0.000020	0.000010	**0.00133**	<0.000010	0.000012	0.000031	0.000013	0.000039	0.000031	0.000037	0.000032	0.000029	<0.000020	<0.000020	<0.000020	<0.000010	<0.000010	<0.000010
Sodium (Na)	mg/L	2	-	-	10.5	8.1	72.9	58.8	6.8	23.3	36.0	0.114	4.4	4.4	4.9	4.9	13.9	147	148	112	112	36
Thallium (Tl)	mg/L	0.002*	0.0008	0.003	<0.00020	<0.00010	<0.0010	<0.00010	<0.00010	<0.00020	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	<0.00020	<0.00020	<0.00020	<0.00010	<0.00010	<0.00010
Tin (Sn)	mg/L	0.0005*	-	-	<0.00050	0.00014	0.0027	0.00036	<0.00010	0.00071	0.00048	<0.00010	<0.00010	<0.00010	<0.00010	<0.00010	0.00333	<0.00020	<0.00020	0.00022	0.00022	0.00023
Titanium (Ti)	mg/L	0.01	-	1	<0.010	<0.010	0.354	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Uranium (U)	mg/L	0.0002*	-	0.30	0.0199	0.0175	0.0027	0.000918	0.00688	0.00324	0.00428	0.00470	0.0114	0.0114	0.01040	0.0113	0.00230	0.00662	0.00658	0.00764	0.00765	0.00258
Vanadium (V)	mg/L	0.001*	-		<0.0010	<0.0010	0.0229	<0.0010	<0.0010	<0.0010	<0.0010	0.0023	0.0011	0.0011	<0.0010	<0.0010	<0.0010	<0.0020	<0.0020	<0.0010	<0.0010	<0.0010
Zinc (Zn)	mg/L	0.005	0.03	0.075 - 2.4[15]	<0.0050	0.0022	**0.0327**	0.0076	<0.0030	0.0090	0.0063	0.0045	<0.0010	0.0014	<0.0030	<0.0030	0.0061	<0.0020	<0.0020	0.0018	0.0031	0.0246
Chromium (VI)	mg/L	0.001	-	-	--	<0.0010	--	<0.0010	-	--	<0.0010	-	-	-	-	-	--	0.0032	0.0015	<0.0010	<0.0010	-

Notes

1. **Bolded** and/or Underlined result implies a guideline exceedance, **Blue** indicates guidelines less than detection limits available
2. D.L. = laboratory detection limit
3. '*' implies detection limit varied - '<' (less than) value implies detection limit
4. **CCME FAL** - Canadian Council of Ministers of the Environment Freshwater Aquatic Life guidelines (December 2007)
5. BC CSR AW - British Columbia Contaminated Sites Regulation Aquatic Life Guidelines; provided for comparison only
6. Aluminum guideline is 100 µg/L when pH > 6.5
7. Cadmium guideline 0.1 µg/L when [CaCO3] is 0 - 30 mg/L
   0.3 µg/L when [CaCO3] is 30 - 90 mg/L
   0.5 µg/L when [CaCO3] is 90 - 150 mg/L
   0.6 µg/L when [CaCO3] is > 150 mg/L

8. Copper guideline
   2 µg/L when [CaCO3] is 0 - 50 mg/L
   3 µg/L when [CaCO3] is 50 - 75 mg/L
   4 µg/L when [CaCO3] is 75 - 100 mg/L
   5 µg/L when [CaCO3] is 100 - 125 mg/L
   6 µg/L when [CaCO3] is 125 - 150 mg/L
   7 µg/L when [CaCO3] is 150 - 175 mg/L
   8 µg/L when [CaCO3] is 175 - 200 mg/L
   9 µg/L when [CaCO3] is > 200 mg/L
9. Copper guideline
   2 µg/L when [CaCO3] is 0 - 120 mg/L
   3 µg/L when [CaCO3] is 120 - 180 mg/L
   4 µg/L when [CaCO3] is > 180 mg/L

10. Lead guideline:
   4 µg/L when [CaCO3] is 0 - 50 mg/L
   5 µg/L when [CaCO3] is 50 - 100 mg/L
   6 µg/L when [CaCO3] is 100 - 200 mg/L
   110 µg/L when [CaCO3] is 200 - 300 mg/L
   160 µg/L when [CaCO3] is > 300 mg/L
11. Lead guideline
   1 µg/L when [CaCO3] is 0 - 60 mg/L
   2 µg/L when [CaCO3] is 60 - 120 mg/L
   4 µg/L when [CaCO3] is 120 - 180 mg/L
   7 µg/L when [CaCO3] is > 180 mg/L
12. Manganese guideline
   1 µg/L when [CaCO3] is 0 - 60 mg/L
   2 µg/L when [CaCO3] is 60 - 120 mg/L
   4 µg/L when [CaCO3] is 120 - 180 mg/L
   7 µg/L when [CaCO3] is > 180 mg/L

13. Nickel guideline:
   25 µg/L when [CaCO3] is 0 - 60 mg/L
   65 µg/L when [CaCO3] is 60 - 120 mg/L
   110 µg/L when [CaCO3] is 120 – 180 mg/L
   150 µg/L when [CaCO3] is > 180 mg/L
14. Silver guideline
   0.5 µg/L when [CaCO3] < 100 mg/L
   15 µg/L when [CaCO3] > 100 mg/L
15. Zinc guideline
   7.5 µg/L when [CaCO3] is 0 - 90 mg/L
   15 µg/L when [CaCO3] is 90 - 100 mg/L
   90 µg/L when [CaCO3] is 100 - 200 mg/L
   165 µg/L when [CaCO3] is 200 - 300 mg/L
   240 µg/L when [CaCO3] is > 300 mg/L

TABLE 2.6-8: SUMMARY OF BASELINE GROUNDWATER GUIDELINE EXCEEDENCES (STANTEC 2010b)				
Monitoring Well	TDS (mg/L)	EC (µS/cm)	pH	Exceeds CSR and/or CCME Guidelines
L08-124	274-422	460-738	8.10-8.25	Aluminum, cadmium, copper, iron, silver
MW08-127	240-487	404-878	6.86-8.16	Aluminum, cadmium, copper, iron, silver, lead
MW08-128	230-335	367-482	7.41-7.90	Aluminum, arsenic, cadmium, iron, silver
MW08-130	331-335	557-558	8.10-8.21	Aluminum, cadmium, copper, iron, silver
MW09-152	388-464	587-721	8.17-8.56	n.a.

Notes:
TDS-total dissolved solids
EC-Electrical activity
mg/L-milligrams per litre
µS/cm-microsiemen per centimetre
n.a.-total metals not collected

2.7 HYDROGEOLOGY

2.7.1 Nechalacho Mine Site

The Nechalacho Mine study area is relatively flat with a maximum elevation change of approximately 50 m. Lowlands in the area tend to have poor drainage and are commonly wet for prolonged periods. Permafrost is discontinuous but widespread.

In areas of widespread permafrost, the permafrost typically acts as an aquitard for groundwater, with flow being limited to the areas where permafrost is not present. Most commonly, the flows occur either above the permafrost table through the active layer in the summer months, below the bottom of the permafrost (year round) or within thawed zones through the permafrost (taliks).

For the Nechalacho Mine site area, it is expected that the presence of shallow, competent bedrock across the area, will have the most significant control of the groundwater flows. Project designs will rely less on permafrost as an aquitard and more on the underlying competent bedrock.

The property is located approximately 230 masl, approximately 80 m in elevation above Great Slave Lake. Drainage in the area appears to flow in a variety of directions but is expected to eventually reach Great Slave Lake.

To gain an understanding of the hydrogeological conditions of the Nechalacho Mine site area, Stantec (2010b) was retained commencing in 2008 to:

- Describe hydrogeologic and hydrostratigraphic units and their spatial variability;
- Measure occurrence of groundwater;
- Quantify hydraulic properties of the hydrostratigraphic units;
- Sample, analyze and summarize groundwater chemistry.

In addition, in the late summer of 2010, Knight Piésold was retained to conduct a more site specific hydrogeological investigation program as part of the geomechanical site program to determine the hydraulic characteristics of the Nechalacho Deposit rock mass. The results of this program are described in Section 2.7.1.6.

No seepage meters have been installed at the Nechalacho Mine site to date. Seepage can be checked and monitored using the monitoring wells that will be installed around the perimeter of the Tailings Management Facility (TMF) during future Phase 2 site investigations. Seepage from the TMF is expected to be minimal.

2.7.1.1 Monitoring Well Drilling and Installation

The 2008, 2009 and 2010 field programs consisted of: drilling and installing wells, developing, hydraulic testing, measuring groundwater levels, and sampling monitoring wells for select analytical parameters.

During the Summer 2008 and Winter 2009 exploration programs, eight coreholes were drilled as multipurpose holes; five were installed as monitoring wells (MW08-127, MW08-128, MW08-130, MW09-151, and MW09-152), two were left as open coreholes (L08-123 and L08-124), and a thermistor was installed in one (L08-134). All 2008 coreholes were cored by Peak Drilling of Yellowknife, NWT, using a diamond drill and NW-sized drilling tools. The borehole diameter was 89 mm and the core diameter 76 mm. The 2009 boreholes were drilled by Foraco Drilling Ltd. (Foraco) of Yellowknife, NWT, using a diamond drill and NQ-sized drilling tools. The borehole diameter was 78 mm and the core diameter 48 mm.

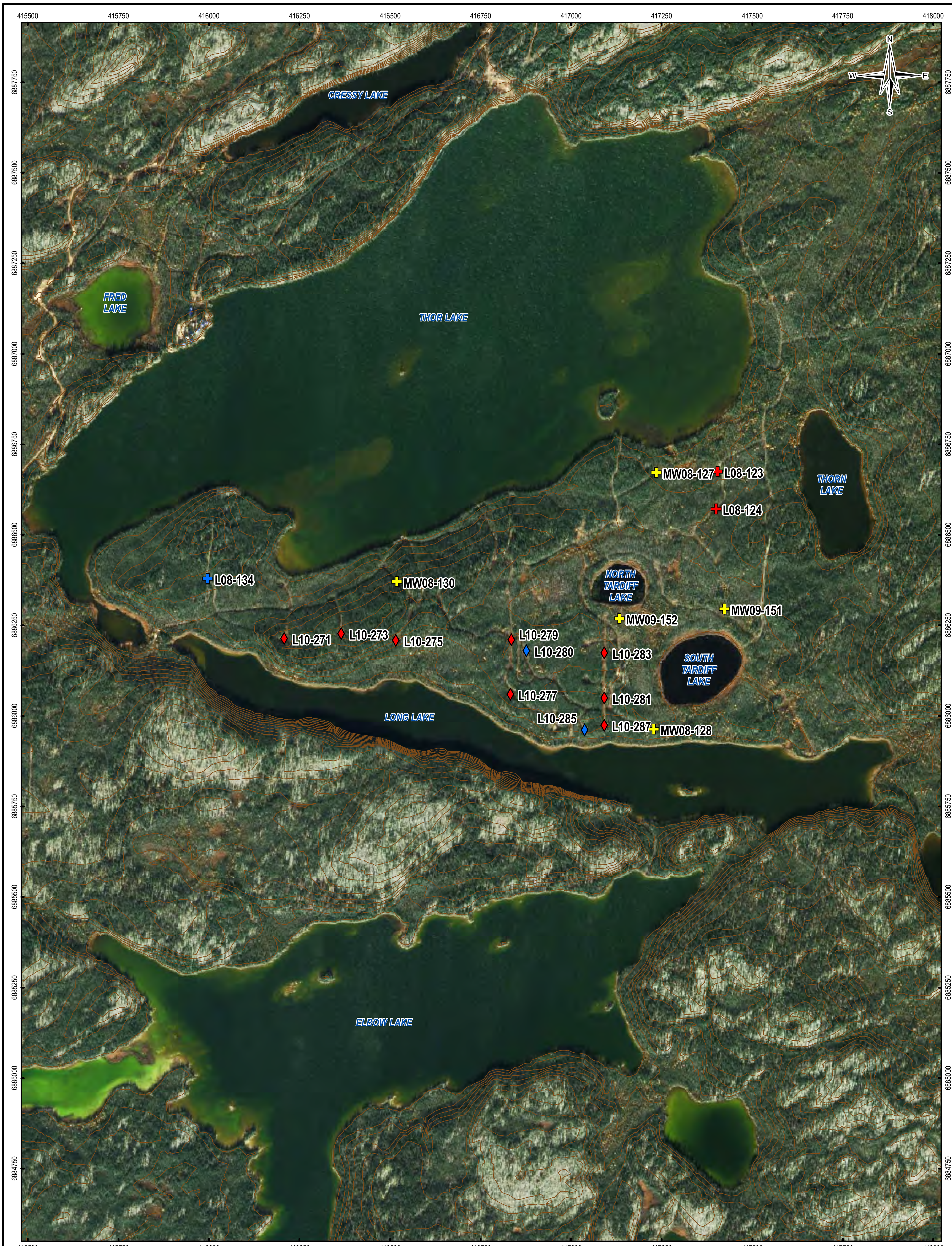
All core logging was completed by Avalon, after the coreholes were drilled. Stantec later reviewed the core and borehole logs to evaluate hydrostratigraphy and help design the monitoring wells. Figure 2.7-1 shows the locations of each of the monitoring wells. Monitoring well completion details are provided in Stantec (2010b) provided in Appendix A.

The 2008 boreholes were completed as monitoring wells using 51 mm diameter schedule 40 PVC well materials. The 2009 boreholes were completed as monitoring wells using 25 mm diameter schedule 40 PVC well materials. The screen sections for both diameter monitoring wells had slot openings of 0.25 mm (0.010 inch or 10 slot). The lengths of the screened intervals ranged from 2.3 m to 15.0 m depending on well depth, water levels and hydrostratigraphic variations.

A silica sand pack (#10-20, grain size 1 mm) was placed around the screen, 0.5 m to 5.0 m above the screen section of each well. The annulus was then sealed with bentonite chips. Caution was exercised to install proper seals to prevent bridging of the bentonite chips, borehole instability and collapse, and/or to prevent surface water from entering the borehole. The seal was achieved by pouring the bentonite chips very slowly and regularly checking the depth to the bentonite seal using a downhole measuring tape.

One thermistor string was installed in one of the boreholes (L08-134) during the 2009 field program. The thermistor was installed inside 51 mm diameter schedule 40 PVC and backfilled with sand to hold it in place. Ground temperature readings were collected with a TH2016 (RST Instruments Inc.) portable thermistor readout unit.

Q:\Vancouver\GIS\ENGINEERING\V151\V15101007_ThorLake\Maps\006_DAR\V15101007_DAR_Map028_Groundwater.mxd



LEGEND

Source	Type	
Knight Piesold	Borehole	Contours (2 m)
Stantec	Monitoring Well	
	Thermistor	

NOTES
Base data source: Imagery provided by Avalon (October, 2010).

ISSUED FOR USE

THOR LAKE PROJECT

Groundwater Monitoring Well Locations

PROJECTION	DATUM
UTM Zone 12	NAD83

Scale: 1:10,000
200 100 0 200
Metres

AVALON RARE METALS INC

EBA Engineering Consultants Ltd.

FILE NO.			
V15101007_DAR_Map028_Groundwater.mxd			
PROJECT NO.	**DWN**	**CKD**	**REV**
V15101007.006.004	SL	TP	0
OFFICE	**DATE**		
EBA-VANC	February 8, 2011		

Figure 2.7-1

2.7.1.2 Groundwater Level Measurements

Instantaneous groundwater levels were recorded at monitoring wells using a Solinst water level meter. Groundwater levels were measured at various dates during August – October 2008, March and June – October 2009, and May – October 2010.

Groundwater elevations at the 2008 well locations were surveyed using ground-based differential GPS methods. The casing stick-up and ground elevation was measured at each monitoring well location and groundwater elevation was calculated.

Groundwater level measurements were collected in the seven monitoring wells from seven to ten separate times, depending on well conditions (presence of ice), during 2008 (September and October), 2009 (March, June and October), and 2010 (May, June, September, and October). Groundwater levels in the seven wells have fluctuated from 0.24 m (MW08-127) to 3.67 m (MW09-152). The presence of ice in the wells has affected water level fluctuations in L08-123, MW08-130 and MW09-152, and may have affected water levels in MW08-128 and MW09-151. Ice did not seem to have affected water levels in L08-124 and MW08-127.

In March 2009 ice was encountered in the five 2008 wells at ~1.0 to 3.0 m below the previous autumn water-level measurement. Subsequent groundwater levels measured in June and/or October 2009 were similar to those measured in the previous autumn, but in some cases these water levels were measured on top of ice in the well.

During the 2010 field program, ice measurements collected in June were in some cases approximately 1.0 to 3.0 m below the March 2009 measurements. By September and October the depth to ice was in some cases approximately 8 to 10 m deeper. The presence of shallow ice in the wells was likely due primarily to seasonal freezing, whereas the presence of ice deeper in the wells is likely due to permafrost. The variable depth of thaw in each well was likely a combination of seasonal thaw, the area of disturbed ground around the well, and the relatively higher thermal conductance of the well (or open borehole) compared to the surrounding ground.

Generally groundwater elevation was measured to be near the ground surface (0.7 m bgs to 4.5 m bgs) in all the wells. Although the monitoring wells have not been measured frequently enough to observe seasonal effects or responses to extended wet or dry periods, groundwater levels are expected to have some seasonal response so that higher groundwater levels would be expected during the spring freshet, and lower groundwater levels related to late summer.

Due to the general shallow depths to groundwater in all the wells, the relatively long distance between wells and the small overall difference in depths to groundwater levels, horizontal gradients (and as a result flow directions) are expected to follow the general topographic surface.

2.7.1.3 Ground Temperature

Near surface ground temperatures can vary substantially and are subject to seasonal temperature variations. Below the level of zero annual amplitude (i.e., below the depth of penetration of seasonal temperature variations), ground temperatures and permafrost thickness generally reflect the mean annual air temperature and local physical conditions.

The depth of zero annual amplitude and thickness of permafrost also varies depending on local environmental conditions (soil properties, land cover, vegetation, insulation, proximity to large water bodies, and other factors). At some depth, the effect of the geothermal gradient is greater than the effect of surface effects, and ground temperatures steadily increase with further increasing depth.

Thermistor readings were collected in L08-134 during the 2009 and 2010 field programs. The thermistor reading in October 2009 had a minimum temperature of -0.75°C at 14 mbg which was at the end of the string. The minimum temperature (also at 14 mbg) was slightly warmer in October 2010. The temperature-depth data from both years data indicated that the permafrost temperature was rather warm (<1°C), and appeared to approach isothermal character with depth (below approximately 7.0 mbg).

A minimum permafrost thickness of 44 to 59 m at this location was estimated by assuming ground temperatures increase from -0.75ºC at -14.0 mbgs based on a geothermal gradient of 1ºC per 30 to 60 m (Lachenbruch 1968). Further, two of the deeper monitoring wells (i.e., MW09-151 and MW09-152) obtained groundwater from the 80 to 100 mbg range, indicating that in those locations permafrost thickness was no deeper than approximately 80 m. Thus, it is reasonable to assume an approximately 60 to 80 m permafrost thickness at these well locations.

The active layer is defined as the shallow soil zone that freezes and thaws with the changing seasons. The 2009 readings and the majority of the 2010 readings indicated that subzero ground temperatures were reached at approximately 2 to 3 mbg, perhaps indicative of the thickness of the active layer. Readings in September and October of 2010, however, indicated that subzero ground temperatures were reached between 4 – 6 mbg. By comparing the 2009 October reading with the 2010 October reading, there is an apparent warming trend, which may reflect a deeper thaw attributed to the extent of disturbed ground in the vicinity of the well.

2.7.1.4 Hydraulic Testing

Hydraulic tests were conducted in all new monitoring wells to determine the hydraulic conductivity of the hydrogeologic units. Two types of hydraulic tests were performed: hydraulic recovery tests and packer tests.

Recovery Tests

Hydraulic recovery tests were performed during the 2008 field program in the 2008 monitoring wells to determine the hydraulic conductivity of hydrogeological units. All wells were developed prior to testing to remove suspended sediments, develop the sand pack, and remove possible drill water that had been lost into the formation during drilling. Tests were performed once the wells had been developed and recovered to static water levels. For this Project the slug was a one meter, single use bailer. A minimum of three rising head tests were performed on each well.

The hydraulic recovery test results were interpreted using methods within the Aquifer Test version 3.0 software by Waterloo Hydrogeologic (now Schlumberger Water Services). Hydraulic conductivity was estimated using an analytical relation between the instantaneous displacement of water in a well bore and the resulting rate of head change. These analyses were based on Bouwer and Rice (1976) for fully or partially penetrating wells in unconfined aquifers. Both methods of analysis used a modified version of the Thein equation (Freeze and Cherry 1979) to estimate hydraulic conductivity.

Recovery tests were performed in the three shallow monitoring wells (MW08-127, MW08-128, and MW08-130) and two open boreholes (L08-123, and L08-124) during the 2008 field program. All three shallow monitoring wells were completed in bedrock. The data were analyzed with methods applicable to fully penetrating and partially penetrating wells in unconfined aquifers.

Although it is likely that the assumptions regarding isotropic, homogenous, and fully penetrating conditions are not likely met, the curves generated by the analytical methods employed match fairly well to the observed conditions, so that the calculated hydraulic conductivities are reasonable as bulk (or average) conductivities over the screen length.

In the area of study, estimated hydraulic conductivity values in bedrock varied over three orders of magnitude from 6.06×10^{-8} m/s to 3.08×10^{-5} m/s.

Packer Tests

Packer tests were performed in March 2009 to determine in-situ hydraulic conductivity of a rock mass over a specific interval under constant pressure head conditions. Packer tests were performed in one of the 2009 boreholes (MW09-152) over selected and representative intervals. The packer test intervals were selected after an inspection of the drill core to determine representative depth intervals for lithology, fracture frequency, and fault zones over the entire depth of the borehole.

The packer test system was composed of the following three main components:

- A downhole assembly of two or three inflatable packer glands used to seal the tested interval within the borehole
- A packer inflation system that used nitrogen to inflate the packer glands and seal the test section
- A water pressure system that facilitated water injection at a constant pressure (head) into the tested interval and provided a measurement of the flow rate.

The tests were conducted after the borehole was completed. The drill rods were pulled back to allow water levels to stabilize. The water level was used to determine the maximum (Pmax) and minimum (Pmin) inflation pressure to be applied over the tested interval.

The packer inflation pressures ensure that the tested interval is properly sealed, prevents slippage, and avoids damage to the packer gland. The borehole was thoroughly flushed with water until clear, prior to testing to ensure the hole was free of any cuttings. The downhole assembly was lowered through the drill rods into the open borehole.

The packer glands were slowly inflated using nitrogen gas; once inflated the water pressure system was connected to the system. Water was injected down the rods into the tested interval under staged but a constant pressure. The injected rate was measured using a flow meter and recorded for selected pressures. The packer tests were conducted in stages where the maximum injection pressure increased from 25%, 50%, 75%, to 100%. The data collected from these stages were then used to calculate the hydraulic properties of the rock mass within the test interval.

One borehole was tested over five depth intervals in the local study area, during the 2009 winter field program. The test intervals ranged from 3.3 m to 139.4 m in length, and the depth of the test intervals ranged from 20.0 m bgs to 208.6 m bgs.

In general, hydraulic conductivity decreased with depth; this was expected due to the higher density of vugs in bedrock near surface, and the decreasing fractures and joints with depth. . Based on the method of analyses employed, the hydraulic conductivities were estimated to range from to 1.66 x 10^{-6} m/s in tests performed near surface and 2.90 x 10^{-8} m/s at depth.

In summary, the results of the hydraulic testing of the wells conducted by Stantec (2010c) suggest a range of hydraulic conductivity from 2.90 x 10^{-8} to 3.08 x 10^{-5} m/s. The variable hydraulic conductivity seen in the bedrock is typical of vuggy crystalline rock (Freeze and Cherry 1979), which also showed decreasing hydraulic conductivity with depth.

2.7.1.5 Conceptual Hydrogeological Model

Based on analyses and interpretation of the information gathered during the 2008, 2009, and 2010 field programs, the local hydrogeological conceptual model of the area between Thor Lake and Long Lake consists of shallow (perched) and deep aquifers separated by permafrost. The shallow aquifer is composed of unconsolidated surficial material and, in some places the bedrock is porous and vuggy, perched on the permafrost.

The deep aquifer likely occurs below permafrost and is comprised of different bedrock lithologies in which groundwater flow mainly occurs along fractures and other rock discontinuities. Although this conceptual model can likely be extrapolated to other places in the proposed Project footprint, more data (i.e., greater spatial – both vertically and horizontally - coverage of groundwater elevations and hydraulic properties) and information (i.e., surficial and bedrock maps, distribution of permafrost map) would be required to develop a more detailed concept. The following summarizes our understanding of the hydrogeology based on the data gathered to date.

Shallow Aquifer

The shallow aquifer is composed of unconsolidated surficial material and, where spatially present, porous and vuggy bedrock within the active zone, which has been interpreted to be perched on the permafrost. The unconsolidated surficial material mainly consists of till and organic deposits in topographically low areas. The till varies throughout the study area but generally consists of a poorly compact, stony, matrix supported diamicton. The organic deposits are poorly drained fine materials.

Recovery tests performed in shallow monitoring wells showed a hydraulic conductivity range over several orders of magnitude, from 7.56 x 10^{-7} m/s to 3.08 x 10^{-5} m/s. Groundwater flow within the shallow aquifer occurs in the active layer (i.e., in the layer of seasonal thawing and freezing). The highest groundwater levels are expected to occur during the snowmelt in late spring after thawing the shallow sediments. Groundwater flow is expected to be characterized by local, small-scale flow, and the flow direction is assumed to follow the local topography.

Deep Aquifer

A deeper bedrock aquifer underlies the permafrost. The bedrock lithology mainly consists of intrusive zoned syenite and granite, with dykes and sills throughout the pluton. Groundwater flow in the bedrock aquifer is expected to occur, predominantly, in fractures and fault zones. Groundwater flow in fractured media is complex, depending on the local hydrogeological and structural geological conditions. Transmissivity values can differ over several orders of magnitude within the same rock mass, and groundwater flow may be largely controlled by a few conductive fractures or other rock mass discontinuities.

Groundwater within the bedrock aquifer is thought to occur beneath the permafrost, which may or may not be in hydraulic connection with some of the taliks surrounding the larger and deeper lakes. In general, though it is expected that there is very little connection between the shallow and deep aquifers. Due to the limited number of groundwater monitoring wells there is little information to estimate flow direction of water in the bedrock. From a conceptual perspective, it is likely that the deep aquifer flows southward and is ultimately in hydraulic connection with deeper sections of Great Slave Lake.

Packer tests performed in the deep aquifer suggest a hydraulic conductivity that ranges over several orders of magnitude (4.1 x 10^{-8} m/s to 1.7 x 10^{-6} m/s). The range of hydraulic conductivity is within the expected range for fractured crystalline rock, (Freeze and Cherry 1979). Hydraulic conductivity generally decreased with depth, which is expected due to the increasing competence of the bedrock with depth. Although the hydraulic conductivity data are consistent with fractured crystalline rock, the spatial variability across the study area is not well known at this time.

2.7.1.6 Nechalacho Mine Site 2010 Hydrogeological Site Investigation

During the period August 21 to September 30, 2010, a more site-specific hydrogeological site investigation program was completed by Knight Piésold for Avalon as part of the geomechanical site program to determine hydraulic characteristics of the Nechalacho Deposit rock mass.

The hydrogeological program consisted of packer testing in seven drillholes, the installation of thermistor strings in two drillholes and the collection of information regarding geological descriptions from eight (8) diamond drillholes. Figure 2.7-1 shows the locations of both the Stantec monitoring wells and the Knight Piésold hydrogeological drillholes.

The dominant groundwater flow pathways within bedrock typically occur within fractures or faults. As part of the geomechanical site investigation, RQD and RMR were logged for each drillhole. The RQD and RMR range that was recorded along each of the tested intervals is reported in Knight Piésold (2010d) (Appendix C). The RQD and RMR values are characteristic of good to very good quality rock indicating that there are limited pathways for groundwater flow.

Packer testing was conducted from August 22 to September 10, 2010. A total of 14 packer tests were conducted in seven drillholes. All tests were conducted using a single HQ nitrogen packer system. In general, drillholes were advanced using a synthetic polymer and packer tests were conducted after the drillholes were flushed. The packer tests included measurements of flow during five pressure stages. The packer system was checked for leaks and inadequate seals during each test.

The majority of the packer tests were conducted within the lower portion of the drillholes to target the rock mass where underground openings will be developed. The tests were conducted within drillholes that were inclined at a dip of either 65 degrees or 55 degrees. Test interval lengths ranged from 16.5 m to 73.5 m. The depth of the test intervals ranged from 86 m below ground surface (bgs) to 119 m bgs and from 256 m bgs to 271 m bgs.

The packer test program determined that the hydraulic conductivity in the Nechalacho Deposit rock mass ranges from 3×10^{-9} m/s to 2×10^{-7} m/s. Results of the hydrogeological testing program will be used to estimate mine water inflows associated with the proposed underground mine.

2.7.2 Hydrometallurgical Plant Site

The hydrogeology for the Pine Point region has been previously studied and reported on by Geologic Testing Consultants (GTC 1983) and Stevenson International Groundwater Consultants (Stevenson 1983, 1984). The following hydrogeology description for the Pine Point region is largely based on this work.

2.7.2.1 Regional Hydrogeology

On a regional scale, groundwater flow is believed to originate in topographic highs (recharge area) such as the Caribou Mountains located 200 km south of the Pine Point area as shown in Figure 2.7-2. The Caribou Mountains rise approximately 600 m above the surrounding land surface and groundwater flow is more or less radially distributed. Stevenson (1984) has postulated that a perched groundwater flow system exists within the Caribou Mountain uplands which re-charges the lower Slave Point formation. Due to geologic conditions, most of the groundwater is thought to discharge to the Hay River valley to the northwest and the Little Buffalo River and Slave River valleys to the northeast. A smaller portion is thought to flow north to Great Slave Lake.

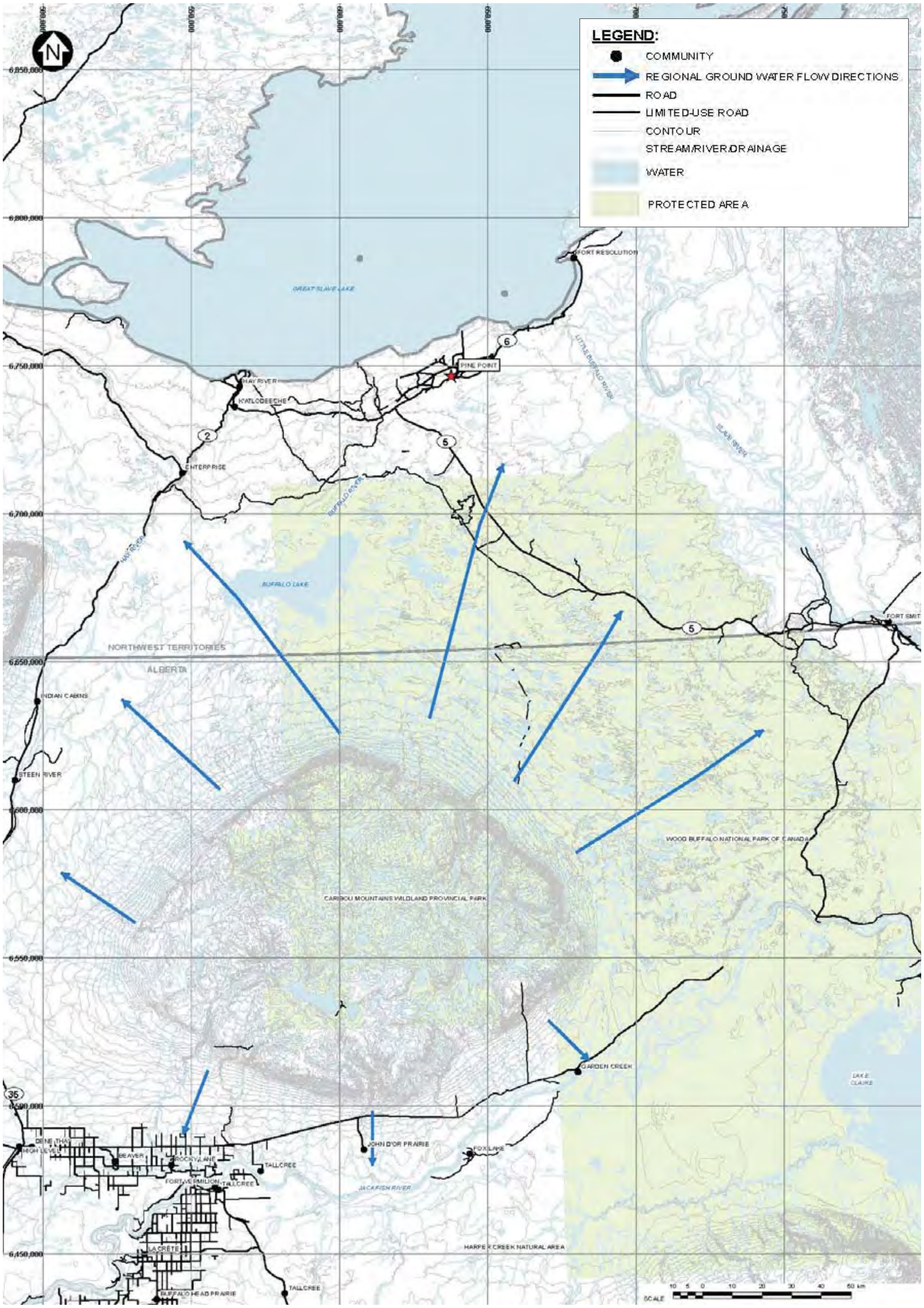
The south side of Great Slave Lake comprises a lowland area and is considered a major groundwater discharge area. Other areas of regional discharge are the Hay River, Buffalo River, Little Buffalo River and Slave River. Groundwater discharge is evident as sulphurous springs and as areas of high specific conductance in rivers. Springs discharging mineralized groundwater have been observed along the south shore of Great Slave Lake at High Point, Sulphur Point and Windy Point. Springs have also been observed at the mouth of Salt River and at the base of the Little Buffalo River Formation escarpment.

High specific conductance readings have also been observed along Slave River, Salt River, Little Buffalo River, Buffalo River and along Great Slave Lake between Fish Point and Presqu'ile Pont. Groundwater discharge is also evident through the presence of swampy areas and sulphurous springs throughout the northern sections of the Pine Point area. Sulphurous springs documented along tributaries of the Buffalo River within the Pine Point Area by EBA in 2005 are shown Photos 2.7-1 and 2.7-2.

2.7.2.2 Site Hydrogeology

Local groundwater recharge to the bedrock aquifer at the Pine Point site is likely to be variable and largely controlled by the overburden geology. High rates of recharge are expected in areas where sinkholes are present, but in general recharge will be limited by the presence of till overburden. Several small ponds were observed in boggy areas that were several meters above the regional water table, indicating that recharge is relatively slow through the till.

Local surface water/groundwater flows through the till, then downwards through fractured bedrock towards the water table. Several seepage points observed in pit walls indicate that there is some lateral flow within the unsaturated bedrock. Photos 2.7-3 and 2.7-4 show stains along the north wall of the L-37 Pit due to groundwater seepage occurring along bedding planes within the dolomite. This seepage is thought to be due to local infiltration being directed horizontally along bedding planes. The staining indicates that the local seepage is highly mineralised and sulphurous.



NOTES
1. Base map 1:250,000 © Her Majesty the Queen in Rights of Canada Department of Natural Resources (2009). All Rights Reserved.
2. Co-ordinate grid is in metres. Datum: NAD83. Projection: UTM Zone 11
3. Contour interval is 20 metres.
4. Figure Source: Knight Piesold Consulting, November 2010 (Ref No. NB10-00488, Figure 9).

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THOR LAKE PROJECT

Pine Point Area Regional Plan Hydrogeology

PROJECT NO.	DWN	CKD	REV
V15101007.006	SL	RH	0

OFFICE: EBA-VANC
DATE: March 7, 2011

Figure 2.7-2

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Photo 2.7-1
View of Sulphurous spring discharge at Buffalo River tributary.

Photo 2.7-2
View of Buffalo River tributary with mineralized water from aquifer.

Photo 2.7-3
View showing L-37 Pit wall seepage from bedding plane.

Photo 2.7-4
L-37 Pit wall seepage discharge.

The bedrock units that represent the most productive aquifers are the Presqu'ile formation and the Pine Point formation. A simplified stratigraphy relating geology to hydrogeology (for the A-70 Pit area to the northwest portion Pine Point area) developed by Vogwill (1976) is shown on Figure 2.7-3.

As shown, the Presqu'ile and Pine Point formations form the main aquifer consisting of highly porous, well fractured dolomite, and groundwater within the saturated bedrock is expected to flow along solution channels, bedding planes and fractured zones. According to Stevenson (1984), the aquifer is laterally confined by the Buffalo River shales to the north and the Muskeg evaporites to the south.

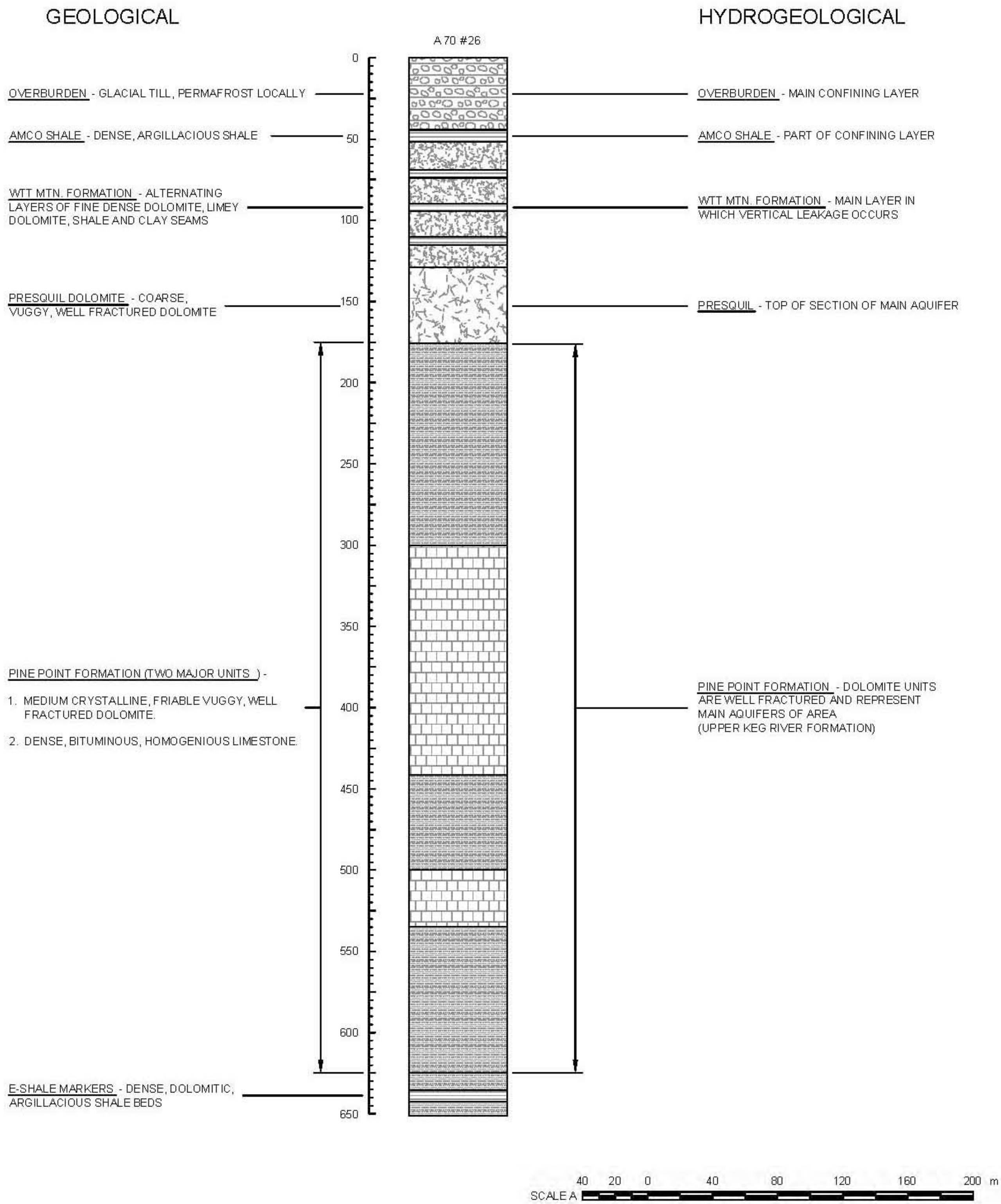
Overlying clay till overburden and Watt Mountain limestones of generally low permeability act to confine the aquifer on top while the Chinchaca formation evaporites underlying the Pine Point and Keg River formations form an effective vertical barrier below the aquifer. The hydraulic continuity is thought to be more predominant along the northeast-southwest trend of the barrier reef complex due to karstification, solution channelling and jointing characteristics (GTC 1983).

The permeability of the Presqu'ile aquifer formation is very high with transmissivities in the order of $1x10^{-2}$ m^2/s (GTC 1983). Based on work completed by Stevenson (1983), the groundwater gradient in the Pine Point area is generally northwards towards Great Slave Lake while to the south of the Pine Point area, the groundwater gradient trends from west to east as shown in Figure 2.7-4. Local gradients range from about 0.4% northwards along the north part of the area and about 0.25% westward along the south portion.

Interpretation of the groundwater gradient contours in relation to the topography indicates that the groundwater level is up to 30 m below the surface along the northeastward trending ridge in the east-central part of the site. In the northwest portion of the site, the piezometric surface is higher than the ground surface. High piezometric levels have resulted in groundwater discharge as springs along the incised Buffalo River channel and other small tributary channels in the area.

Although the Presqu'ile aquifer has a high permeability, the flow through it is thought to be slow due to the low gradient in the Pine Point area. Based on a preliminary calculation taking into account the documented transmissivity values, gradients and geological sections, the flow velocity is estimated to be less than 1 m per day. Due to the high porosity, the storativity of the aquifer is quite high. It is estimated that about 1 billion m^3 of water was removed during mining activities from 1968 to 1984. According to Stevenson (1984), this water came from water stored within the aquifer (16%), recharge from local precipitation (76%), with the remainder from the regional groundwater flow.

Over the period between 1968 and 1982, the yearly average dewatering rate from the Presqu'ile aquifer, due to mining activities, was as high as 269,000 m^3/day (GTC 1983). GTC (1983) also estimated that the maximum drawdown of the water table in response to this dewatering was approximately 20 metres; and that the source of the pumped water was the Presqu'ile aquifer and associated local and regional recharge, with none of the pumped water coming from Great Slave Lake.



NOTES

1. Figure based from Vogwill, 1976. Some practical aspects of open pit dewatering at Pine Point.
2. Figure Source: Knight Piesold Consulting, November 2010 (Ref No. NB10-00488, Figure 10).

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Pine Point Area - Geologic and Hydrogeologic Stratigraphy of the Presqu'ile Barrier Reef Complex at the A-70 Pit Area

PROJECT NO.	DWN	CKD	REV
V15101007.006	SL	RH	0
OFFICE	DATE		
EBA-VANC	March 7, 2011		

Figure 2.7-3

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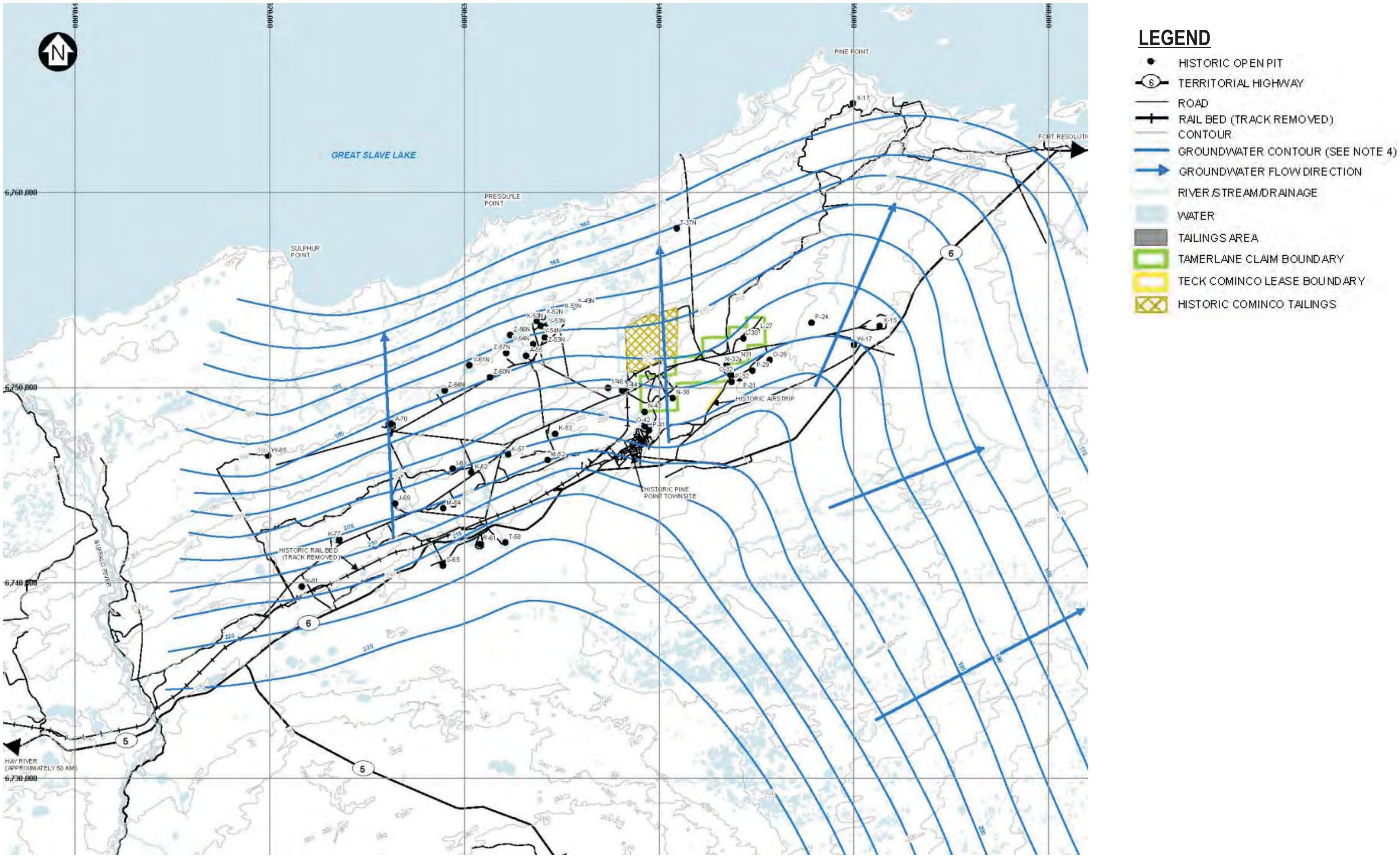

NOTES

1. Base map 1:50,000 © Her Majesty the Queen in Rights of Canada Department of Natural Resources (2009). All Rights Reserved.
2. Co-ordinate grid is in metres. Datum: NAD83. Projection: UTM Zone 11 N.
3. Contour interval is 10 metres.
4. Groundwater contours from Stevenson, 1984. "Figure 3 Contours of Natural Piezometric Levels in the Main Aquifer (Presquile) in Pine Point Mines Property."
5. Figure Source: Knight Piesold Consulting, November 2010 (Ref No. NB10-00488, Figure 11).

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THOR LAKE PROJECT

Pine Point Area Groundwater Gradient Plan

PROJECT NO.	DWN	CKD	REV
V15101007.006	SL	RH	0
OFFICE	DATE		
EBA-VANC	March 7, 2011		

Figure 2.7-4

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2.8 FISH AND AQUATIC HABITAT

2.8.1 Study Objectives and Scope

Multi-year aquatic biophysical studies in the Nechalacho Mine site area (the Project) have been conducted to assemble sufficient background information to describe, characterize, and quantify existing conditions for the purpose of assessing potential mine development effects, identifying impact avoidance and mitigation strategies, and establishing a baseline for future monitoring studies.

This section presents a description of the existing aquatic environmental conditions in the Nechalacho Mine site area, which is shown in Figure 2.8-1. Data included were drawn from a review of the existing literature, and from fieldwork conducted during 2008-2010.

Baseline aquatic studies were carried out in waterbodies within the area potentially affected by the Project and in specific reference (i.e. control) waterbodies outside the area of Project influence. Biophysical characteristics that have been sampled, measured or observed (not necessarily in every waterbody), that are summarized in this section include:

- Lake bathymetry;
- Water and sediment quality;
- Aquatic community: phytoplankton, zooplankton, benthic invertebrates;
- Fish and fish habitat; and,
- Fish biometrics and fish health.

2.8.2 Background Aquatic Studies

The following baseline studies provide the framework for characterization of the aquatic environment within the effect footprint of the Project, and assessment of potential Project effects. In particular, the aquatic descriptions, characterization, and assessments presented are based on data and observations provided by Stantec (2010c), and supplemented by information collected during previous field studies. The Stantec data are the most recent and comprehensive, and focussed directly on waterbodies that have the potential to be affected by the proposed Project.

2.8.2.1 Saskatchewan Research Council Study

An environmental baseline study in the present Nechalacho Mine site area was carried out in 1988 by the Saskatchewan Research Council (SRC; Melville et al. 1989) regarding the potential mining of an ore body for beryllium.

Aquatic studies at that time were designed to characterize existing water quality and large-fish lake populations in close proximity to the mine development site, and focussed on four watersheds:

- Cressy Lake, which was identified as the prospective tailings disposal area, and included Fred Lake, Fred stream, and Lake A;

- The watershed downstream of Den Lake, which flows north to Blachford Lake;
- Thor Lake and its tributary lakes, including Ring Lake, which was the proposed alternate tailings disposal lake; and,
- Elbow Lake, which was the reference lake to which Thor Lake was compared.

Aquatic field studies included lake morphometry, water quality, stream flow, phytoplankton, zooplankton, fish population, and fish tissue analysis.

2.8.2.2 Highwood Resources Ltd. (Golder Associates Report)

Highwood Resources Ltd. commissioned an environmental baseline study by Golder Associates Ltd. (1998b) to obtain fisheries and wildlife information for the Thor Lake Bulk Sample Project, in support of potential beryllium mining. Eight lakes in the Thor Lake area were sampled as part of the aquatic survey, which documented water and sediment quality, fish health, and fish habitat. The sampled lakes included: Thor, Den, B, C, D, Elbow, and Blachford lakes, and the Great Slave Lake docking area (Figure 2.8-1).

This study was designed to supplement baseline data and information collected previously, primarily as part of the SRC 1988 field study (Melville et al. 1989). As a result, fish were not sampled in Thor, Elbow, and Great Slave lakes because they had been sampled previously. Further, fish sampling was not carried out in Den, B, C, and D lakes because their shallow depths prohibited the setting of gill nets and the soft sediments prevented walking into the lake to conduct seine netting.

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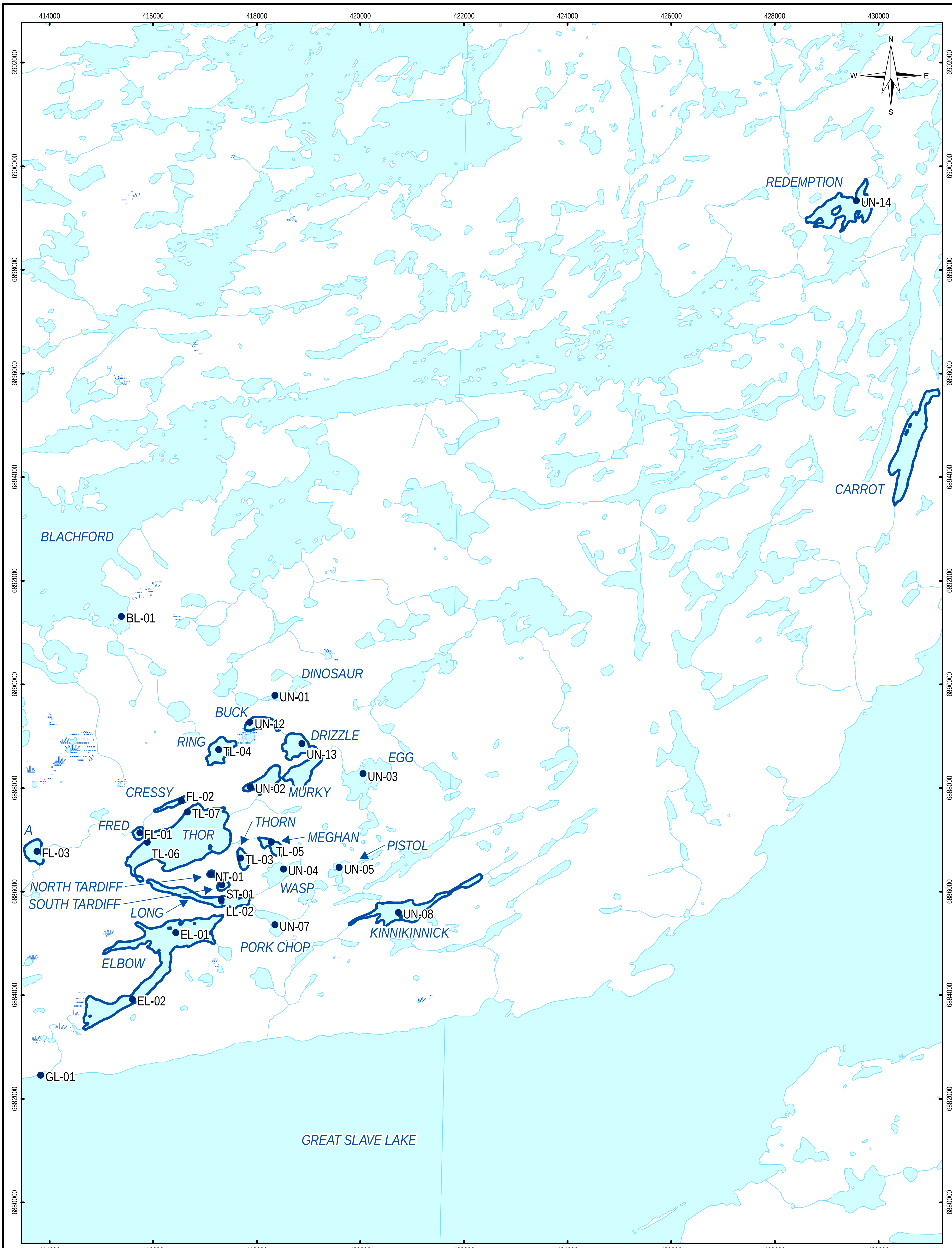

LEGEND

- Aquatic Sample Stations
- Fisheries Lakes
- Watercourse
- Waterbody
- Wetland

NOTES

Figure Source: Appendix A, Figure 3-1. Stantec 2010c.

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THOR LAKE PROJECT

Nechalacho Mine Site Study Area

PROJECTION	DATUM
UTM Zone 12	NAD83

Scale: 1:70,000

1 0.5 0 1 2

Kilometres

AVALON RARE METALS INC.

EBA Engineering Consultants Ltd. eba

FILE NO.
V15101007_DAR_Map040_ThorSA.mxd

PROJECT NO.	DWN	CKD	REV
V15101007.006	SL	DM	0

OFFICE	DATE
EBA-VANC	May 9, 2011

Figure 2.8-1

2.8.2.3 Avalon Rare Metals Inc. (Stantec Reports)

As part of exploration for, and potential development of, a rare earth metals mine in the Nechalacho Project area, Avalon retained Stantec to carry out further baseline studies, which were conducted between 2008 and 2010. These water quality, aquatic ecology, and fish and fish habitat studies were carried out in 26 lakes and 13 watercourses, which were selected as water bodies:

- potentially affected by the Project;
- representing local aquatic conditions; and,
- potentially suitable as reference lakes.

Aquatic and fisheries sampling locations were selected based on the direct Project footprint, potential future expansion, and known information about the surface water drainage in the Nechalacho Mine site area. All lakes and streams that would potentially directly interact with the mine footprint and operations (i.e., lakes above the underground excavations, and lakes and streams affected by water extraction and/or discharge), tailings storage areas, and concentrate transport routes were selected, as was the first lake downstream of the mine area. Sampled lakes are shown on Figure 2.8-1 and listed on Table 2.8-1. Two lakes, Carrot and U, were originally selected as potential reference lakes but were deemed to be unsuitable and will not be discussed further. Kinnikinnick Lake was selected as a suitable near-field reference lake, while Redemption Lake, located approximately 18 km northeast of the Nechalacho Mine site camp, was chosen as an appropriate far-field reference lake.

In addition, the field program included fish and fish habitat investigations in stream channels between lakes in the footprint area.

TABLE 2.8-1: AQUATIC AND FISHERIES BASELINE STUDY LAKES AND STREAMS, 2008 – 2010 AFTER STANTEC 2010C)

Name	Activity[1]	Coordinates[2]	
		Easting	Northing
A	A/F	413762	6886729
Ball	F	417796	6889038
Blachford	A	415403	6891246
Buck	A/F	417861	6889261
Cressy	A/F	416471	6887742
Dinosaur	A	418403	6889795
Drizzle	A/F	418851	6888823
Egg	A	420050	6888277
Elbow	A/F	416388 415576	6885140 6883908
Fred	A/F	415751	6887108
Great Slave	A/F	413845	6882398
Kinnikinnick	A/F	420757	6885658
Long	A/F	417273	6885871
Megan	A/F	418356	6886890
Murky	A/F	417893	6887973
North Tardiff	A/F	417128	6886360
Pistol	A	419676	6886500
Porkchop	A	418462	6885389
Redemption	A/F	429566	6899312
Ring	A/F	417267	6888738
South Tardiff	A/F	417360	6886126
Thor	A/F	415842 416636	6886885 6887520
Thorn	A/F	417700	6886655
Wasp	A	418521	6886407
Watercourses			
Buck Out	F	418466	6889122
Cressy Out	F	415870	6887352
Drizzle Out	F	418542	6888176
Egg Out	F		
Elbow Out	F	414615	6883369
Fred Out	F	415542	6887115
Long Out	F	415851	6886222
Megan Out	F	417976	6887031
Murky Out	F	417946	6887824
Ring Out	F	417603	6888871
S. Tardiff Out	F	417333	6885995
Thor Out	F	415868	6887009
Thorn Out	F	417658	6886921

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

2.8.3 Methods and QA/QC

The Stantec aquatics and fisheries field programs were conducted in March and September-October 2008, March, June and September 2009, and April, June, September, and October, 2010. Water and sediment chemistry and biophysical data were collected in 23 of the 24 lakes included in the study program (Ball Lake was not sampled for these variables); however, not all parameters were investigated at all lakes. Tables 2.8-2 to 2.8-4 provide sampling locations and dates for the field investigations of aquatic physical environment parameters; water and sediment chemistry, and aquatic organism components; and, fisheries parameters, respectively.

Sampling methods and the quality assurance/quality control (QA/QC) program employed in the Stantec baseline studies are detailed in Stantec (2010c). The 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. All water, sediment, fish tissue, and aquatic organism analyses and enumeration were carried out at recognized analytical laboratories, which followed internal QA/QC procedures to maximize data reliability.

The following sections briefly summarize the methods used during the 2008-2010 baseline field programs.

TABLE 2.8-2: STUDY DATES AND LOCATIONS FOR THE PHYSICAL ENVIRONMENT PARAMETERS OF THE THOR LAKE BASELINE STUDY (AFTER STANTEC 2010C)

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										✓	✓	✓	✓	✓		✓		✓
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					✓	✓	✓	✓	✓		✓	✓						
Wasp	UN-04					✓		✓	✓	✓	✓	✓							

NOTE:

[a] Saskatchewan Research Council (SRC). 1989.

[b] Golder Associates Ltd. 1998a. Profile data not collected in 1998 aquatic survey

[1] Bath = bathymetric survey; Prof = water chemistry profile; Hab = littoral and riparian survey.

TABLE 2.8-3: 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												✓			✓	✓	✓	✓	✓	✓	✓	✓	✓			✓
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						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓										
Wasp	UN-04						✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓										

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

TABLE 2.8-4: 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								✓		✓	
Cressy	✓				✓			✓			
Drizzle								✓		✓	
Elbow	✓				✓	✓		✓	✓		
Fred					✓	✓	✓	✓	✓		
Great Slave					✓	✓		✓	✓		
Kinnikinnick								✓	✓		
Long					✓	✓		✓	✓		
Megan					✓			✓			
Murky								✓		✓	
North Tardiff					✓			✓			
Redemption								✓	✓	✓	✓
Ring	✓							✓		✓	
South Tardiff					✓			✓			
Thor	✓	✓			✓	✓		✓	✓		
Thorn					✓			✓			

NOTE:

[1] FP = Fish Presence

[2] FH = Fish Health

2.8.3.1 Bathymetry

Bathymetric surveys were conducted in 24 lakes, including the bay on Great Slave Lake in which seasonal barging will occur. Depths were measured using a depth sounder and location waypoints were recorded on a hand held GPS unit. The waypoints, depth readings, and lake boundaries were loaded into ArcGIS 9.2, and the lake surface elevations were determined from the waypoint elevations.

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.

2.8.3.2 Littoral and Riparian Area Survey

The littoral area – the shallow area where light penetrates to the lake bottom – is critical habitat for many fish species, including the species known to inhabit lakes and streams in the Nechalacho Mine site area (northern pike, lake whitefish, lake cisco, slimy sculpin, and ninespine stickleback). 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) using a boat that was driven near the shoreline of each lake to collect georeferenced data on littoral and riparian habitats. A GPS waypoint was recorded at locations where there were changes in littoral or riparian habitat, and all habitat types were photographed.

The littoral survey, which included areas with a depth up to 2 m, 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;
- Bedrock with lichen and sparse trees;
- Lowland wetland habitat.

Since a fringe of shrubs, such as dwarf birch, or grasses frequently grew along the shoreline, the shoreline vegetation was characterized separately if it differed from the dominant riparian vegetation.

2.8.3.3 Water and Sediment Quality

Physical and chemical water and sediment quality parameters were collected with the objective of identifying baseline characteristics to monitor, assess, and manage changes that may occur due to mining related activities, and to identify parameters that may be present at elevated levels in order to propose site-specific water quality objectives. Water and sediment quality sampling methods and results are discussed in Section 2.6, and are therefore not repeated here.

2.8.3.4 Aquatic Organisms

Phytoplankton

Sample Collection

Phytoplankton were collected from 20 lakes (see Table 2.8-3) during the ice-free season in 2009 (June and September), and in three additional lakes in June and September, 2010, using a Van Dorn sampler, which was deployed to one metre depth. Collected water was divided into samples for chlorophyll *a* (chl *a*) analyses, a measure of phytoplankton biomass, and taxonomic determination. Chlorophyll *a* samples were filtered through 0.45 μm filters and stabilized with magnesium carbonate. Filters were folded, wrapped with aluminum foil, labelled, and then frozen until arrival at the analytical laboratory.

Taxonomic samples were collected in 250 ml labeled plastic bottles and preserved with Lugol's solution (1 ml per 100 ml).

Laboratory Methods

Chlorophyll *a* samples were analyzed at ALS Laboratories in Vancouver, BC for chlorophyll *a* and pheopigment (an indicator of natural degradation of chlorophyll). ALS analyzed samples using fluorometry based on procedures adapted from the USEPA Method 445.0. Chlorophyll *a* and pheopigment results were reported as μg/L.

Taxonomy

Taxonomy samples were examined at Fraser Environmental Services in Surrey, B.C. Samples were settled in 25 ml Utermohl-type 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.

Data Analysis

Phytoplankton statistical data analysis methods are detailed in Stantec (2010c). In summary, phytoplankton diversity was calculated using Simpson's Diversity Index (Environment Canada 2002), and abundance values for each taxonomic group was reported as a percentage of the total number of cells of all taxa.

Zooplankton

The zooplankton community is composed of primary consumers, which eat phytoplankton, and the larger secondary consumers, which feed on other zooplankton and are important as food for forage fish and the larval stages of all fish. As such, zooplankton are a critical component of the aquatic biotic community serving as both recyclers of nutrients and an important link in the food web. The three main taxonomic groups of zooplankton are the rotifers, cladocerans, and copepods (the last two being subclasses of the Crustacea). Other organisms, including protozoans, coelenterates, larval trematode flatworms, gastrotrichs, mites and the larvae of some insects can also be considered to be zooplankton, due to the ecological role that they fulfill within the lake environment.

Sample Collection

Zooplankton samples were collected from 15 lakes in June, 2009, 20 lakes in September, 2009, and an additional three lakes in June and September 2010 (see Table 2.8-3), using a 12 cm diameter zooplankton net (64 µm mesh size). 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. Zooplankton samples were collected in 500 ml labeled plastic bottles and preserved with 10% buffered formalin (25 ml per 250 ml sample).

Laboratory Methods

Zooplankton samples for taxonomic analysis were examined at Fraser Environmental Services in Surrey, B.C. 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, then 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).

Data Analysis

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). 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.

Benthic Invertebrates

Benthos (benthic invertebrates) are commonly used for biomonitoring purposes. Their ubiquity, diversity, 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.

Sample Collection

Lake benthos samples were collected during September, 2009 from 23 lakes and repeated in September, 2010 in Long, Redemption, and Thor lakes (see Table 2.8-3). A 2.4 L (152 mm x 152 mm) petite ponar sediment grab was used to collect samples. 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. 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 labelled 500 ml plastic jars. Benthos sample 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.

Laboratory Methods

Benthos samples were analyzed by Cordillera Consulting through Fraser Environmental Services in Surrey, BC. Samples were rinsed through 0.5 and one millimetre 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).

Data analysis included calculations of density, and summary statistics including minimum, maximum, median, standard deviation, standard error, and percent composition of dominant/indicator taxa. Community diversity was calculated using Simpson's Diversity Index and evenness was calculated using Simpson's Evenness Index to provide an indication of community structure.

2.8.3.5 Fish

Fish species presence was investigated in 12 lakes in September-October 2008, 18 lakes in September 2009 (11 of which were common to the two years) and six lakes in September 2010 (five of which had previously been sampled; see Table 2.8-4). Fred Lake is suspected to be a 'sink' habitat, in which many or all fish die in 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 possible winter fish presence.

Multiple methods were used to target as many of the different species as possible that potentially inhabit the lakes. Two fishing methods, gill netting and minnow trapping, were used in 2008. These two methods, combined with 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 2.8-5. A description of the gear used during the 2008-2010 field surveys is provided in Stantec (2010c).

Two years of fishing effort are recommended by DFO for baseline investigations of fish presence, so all lakes were visited twice, except for Ball and Kinnikinnick lakes.

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).

The catch per unit effort (CPUE) for the gill net sampling was calculated for each species in each lake based on 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.

TABLE 2.8-5: 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) (AFTER STANTEC 2010C)

Lake	Sept – Oct 2008		Mar 2009		Sept 2009				Sept 2010		
	GN[1]	MT	GN	MT[2]	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
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	–	–	–

NOTE:

[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

CPUE data can be used qualitatively to describe relative fish density in the different years and for comparison with future capture rates following mine activation. However, comparisons must be made with caution since differences in gear, set location, and time of year may significantly affect the numbers, life stages, and species of fish captured.

2.8.3.6 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; and,
- The winter water quality data indicate that dissolved oxygen concentration is below the acute minimum value for the protection of aquatic life (5 mg/L; CCME 1999).

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

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.

2.8.3.7 Fish Biometrics and Health

The lakes in which fish morphometric and fish health measurements and inspections were carried out in 2008-2010 are shown in Table 2.8-5. Details of the methods used to determine individual fish weights, lengths, condition, and health during the 2008-2010 field studies, the calculation of indices used in assessing fish growth, maturation, and health, and QA/QC procedures are provided in Stantec (2010c). However, the following sections summarize the field data and sample collection methods used during the Stantec (2010c) studies.

Fish Processing

Fork length of all captured fish was measured in the field using a fish measuring board with millimetre markings. Wet weight of each fish was also measured; in 2008 fish were weighed with a spring scale with 10 g precision due to difficulties with the electronic scale; in 2009-10 fish were weighed with an electronic scale with 0.1 g precision. Each fish was examined for external parasites when its length and weight were measured.

Tissue Sampling and Fish Dissection

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

Age structures were removed from each dissected fish. In 2008, scales were removed from lake whitefish and northern pike. In 2009-10 otoliths were removed from lake whitefish and lake cisco, and cleithra were removed from northern pike. Scales and otoliths were sent to Hamaguchi Fish Aging Services for aging in 2008-09; otoliths collected in 2010 and cleithra collected in 2009 and 2010 were sent to North/South Consultants Inc.

Using standard methods to avoid contamination between samples, a block of muscle tissue, without skin or bones, was removed from each northern pike and lake whitefish. The muscle blocks were frozen promptly and sent to ALS Laboratory Group for analysis.

The body cavity of each fish was opened and the internal organs examined for visible 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 one gram was removed from each female, weighed, and stored in 10% formalin. These samples will be used to determine the proportion of eggs that were mature and immature.

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 Saskatchewan Research Council (SRC) and in 2009-10 samples were sent to ALS Laboratory Group. 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).

2.8.4 Results and Discussion

Results of the 2008-2010 field studies, including raw data and the calculation of population metrics, where appropriate, are provided in Stantec (2010c). The next sections include general summaries of the field study results for the Project area based on those studies, supplemented by data and information reported from previous studies by Melville et al. (1989) and Golder (1998a). These are followed by a more detailed characterization of each lake or lake system that may be affected by the Project.

2.8.4.1 Bathymetry

Bathymetric maps were prepared for 24 lakes; morphometric measurements were calculated for 22 of these since the Great Slave Lake and Blachford Lake sites are open bays with no defined edge. These maps are provided within the Lake Group Results and Discussion section (Section 2.8.5). A summary of the morphometric characteristics of each lake is shown in Table 2.8-6.

TABLE 2.8-6: MORPHOMETRIC CHARACTERISTICS OF STUDY LAKES (STANTEC 2010c)

Lake	Surface Area (m^2)	Littoral Area (m^2)	Deep Area (>8 m) (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
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
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

Thor Lake is the largest of the lakes within the Project area by area, but has slightly less volume than Elbow Lake, which is deeper. Seven of the lakes are very shallow (≤2 m), while an additional seven lakes are less than eight metres.

2.8.4.2 Water and Sediment Quality

As previously discussed in Section 2.6, waters within the broad footprint of the proposed Nechalacho Mine site area have high alkalinity, hardness, and calcium. These characteristics indicate a high acid buffering capacity. Lakes tend to be relatively clear with low suspended sediment levels, and low nutrient and metals concentrations. However, these levels typically rise in shallow lakes (<3 m; identified in (Table 2.8-6) during the winter due to highly reducing, anoxic conditions that develop under the ice, which result in reduced pH and a corresponding increase in the solubility of metals. In particular, levels of iron were many times higher in winter than Canadian Council of Ministers of the Environment (CCME) guidelines. It is important to note that no CCME exceedances were noted for Thor Lake, into which discharges from the tailings area would ultimately drain.

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).

The Tardiff, Tributary, and ring lake groups tended to have higher mean ammonia, phosphate, iron, and arsenic levels than the other groups, probably due to the shallow depths of most of these lakes.

Mean water temperature across all lakes in summer was 9.7°C and 2.2°C during winter. Mean pH values in winter were generally lower than in summer (7.5 vs. 8.1). Shallow lakes had very low dissolved oxygen levels in winter (<5 mg/L), and some were anoxic. Temperature and dissolved oxygen profiles of select lakes are provided in Figure 2.6-2 (a and b).

Winter ice did not vary substantially over the three winter periods sampled, with an overall mean depth of about 0.7 m. Ice thickness (measured in March 2008-09 and early April 2010) in all lakes ranged from 0.54 m to 1.14 m. However, measured ice thickness was consistently less than 0.75 m except at Elbow, Thor Lake west station, Kinnikinnick, and Redemption lakes. Ice thickness was greatest in the sampled bay in Great Slave Lake (1.14 m).

Sediments in many of the lakes within the Nechalacho Mine and Flotation Plant site footprint area were characterized by elevated levels of phosphorous, as well as some metals, in particular arsenic, copper, nickel, and zinc. In some locations, sediment mercury concentrations approached, but did not exceed CCME guidelines.

Sediment 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. Rare earth elements (REE) varied among sediments sampled within study area lakes. Tantalum and hafnium were analyzed at less than detection at all (24) and 19 sample stations, respectively.

2.8.4.3 Littoral and Riparian Areas

Predominant littoral substrates and aquatic vegetation in 18 of the study lakes are provided in Table 2.8-7. Shallow lakes had a substrate predominantly consisting of organic muck. In all lakes, 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.

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 plants were not identified. Large woody debris and large boulders were often absent or not abundant (Stantec 2010c).

Black spruce (*Picea mariana*) was the dominant or co-dominant riparian vegetation of most of the lakes in the study area Species associated with black spruce included paper birch (*Betula* sp.), tamarack (*Larix laricina*), dwarf birch (*Betula* sp.), and Labrador tea (*Ledum* sp.). Grasses or shrubs grew along the shoreline where black spruce forests grew to the lake boundaries. Wetland and bedrock bluff were present or predominant at several lakes. Wetland was dominant at Buck, North Tardiff and South Tardiff lakes. At least one small area of bedrock bluff was present at almost every lake, and also was co-dominant (with black spruce) at Cressy, Kinnikinnick, and Long lakes.

Littoral substrates, aquatic vegetation, habitat features, and riparian communities of the lakes shown in Table 2.8-7 are shown on the bathymetric maps included in Section 2.8.5.

TABLE 2.8-7: LITTORAL SUBSTRATES AND AQUATIC LITTORAL VEGETATION IN LAKES STUDIED IN THE NECHALACHO MINE SITE AREA (STANTEC 2010c).

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
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

2.8.4.4 Aquatic Organisms

Phytoplankton

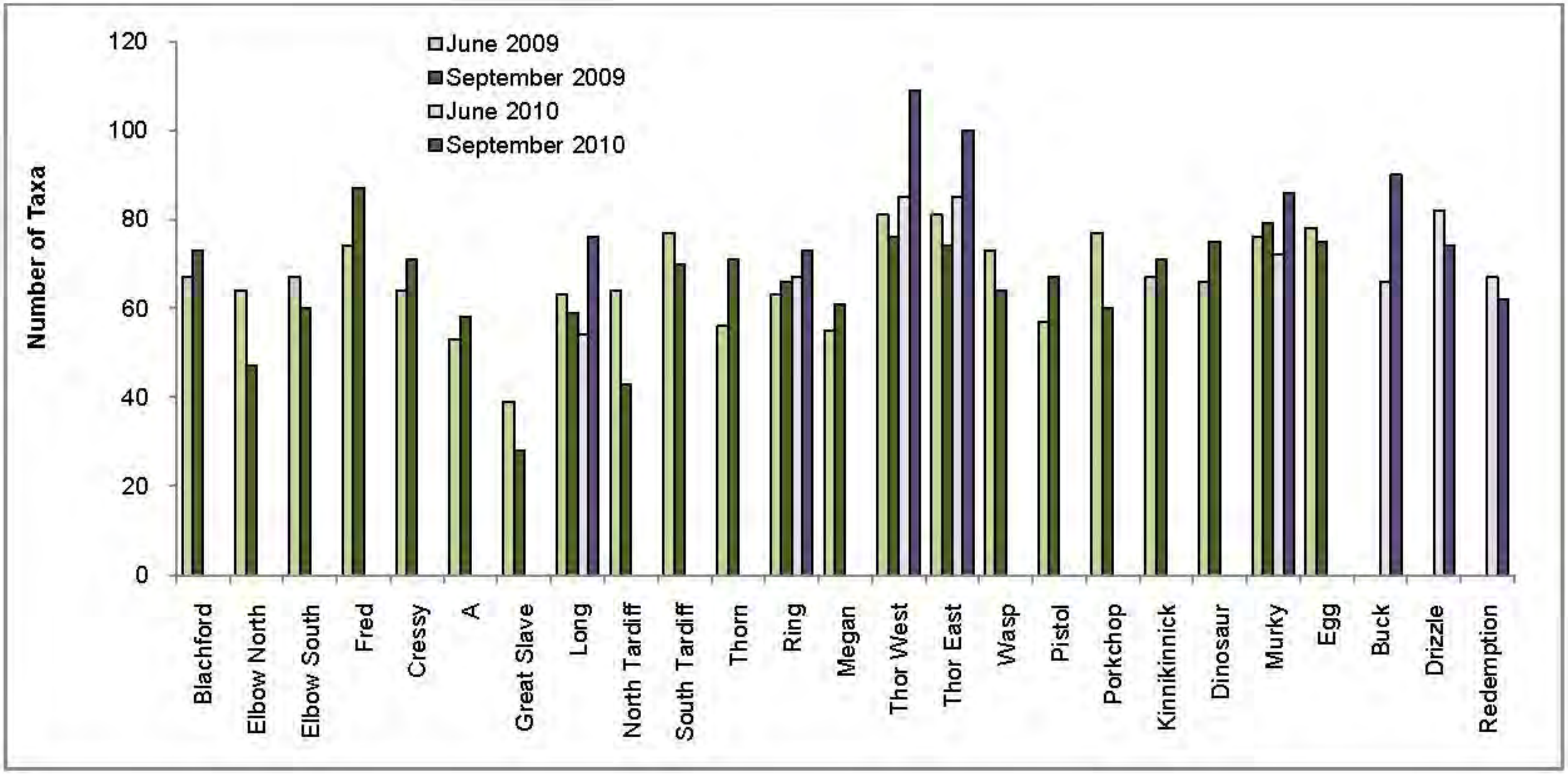
Phytoplankton are algae that grow suspended in the water column, and provide the primary source of energy in lakes (Wetzel 2001). They convert inorganic carbon, nitrogen and phosphorus into organic matter, making it available for secondary consumers such as zooplankton and benthic invertebrates. Phytoplankton are sensitive to changes in nutrient, sediment (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.

With only a few exceptions, lakes included in the Stantec (2010c) study were found to have low levels of chlorophyll *a*, which is an indicator of primary production, and were therefore generally classified (using the classification system adopted by Environment Canada) as ultra-oligotrophic to oligotrophic (Melville et al. (1989) classified Thor Lake as mesotrophic based on chlorophyll *a* results that were 78% higher during September sampling than levels found by Stantec (2010c). Buck, Dinosaur, Drizzle, Murky, Redemption, and Ring lakes had seasonally higher concentrations of chlorophyll *a*, and have therefore been classified as mesotrophic, although there is sufficient inter-seasonal variation to put these classifications in doubt.

Values for phytoplankton abundance, richness (number of taxa per site), and diversity (index that incorporates the number of species in an area with their relative abundance) have been calculated for the study lakes. In total 186 and 180 phytoplankton taxa were identified across the study area in 2009 and 2010, respectively. Only the diatom *Fragilaria crotonensis* and the yellow-brown alga *Dinobryon* sp. were present within all the study lakes (in 2009). Predominant species included filamentous blue-green algae, coccoid blue-green algae, colonial yellow-brown algae, and small cryptoflagellates.

Taxon richness varied from 34 species (in Great Slave Lake) to 81 species (in Fred Lake) in 2009, and 65 to 97 in Long Lake and Thor West, respectively, in 2010. Stations sampled in 2010 generally had higher numbers of taxa than the same locations sampled in 2009, which may be attributed to differences in weather, time of sampling, or both. Species richness was higher in June than September in some lakes, and the reverse in others. A comparison of species richness among lakes between 2009 and 2010 is shown in Figure 2.8-2.

Phytoplankton species diversity ranged from 0.47 (Elbow North) to 0.87 (Fred) in 2009, and 0.50 (Redemption) to 0.89 (Murky) in 2010. Figure 2.8-3 provides a graphical comparison of species diversity in all sampled lakes in June and September 2009-10.



NOTES

Figure Source: Figure 6-36. Stantec 2010c.

CLIENT

AVALON RARE METALS INC.

EBA Engineering Consultants Ltd.

ISSUED FOR USE

THOR LAKE PROJECT

Phytoplankton Richness in Sampled Lakes June and September, 2009-2010

PROJECT NO.	DWN	CKD	REV
V15101007.006	SL	DM	0

OFFICE	DATE
EBA-VANC	May 9, 2011

Figure 2.8-2

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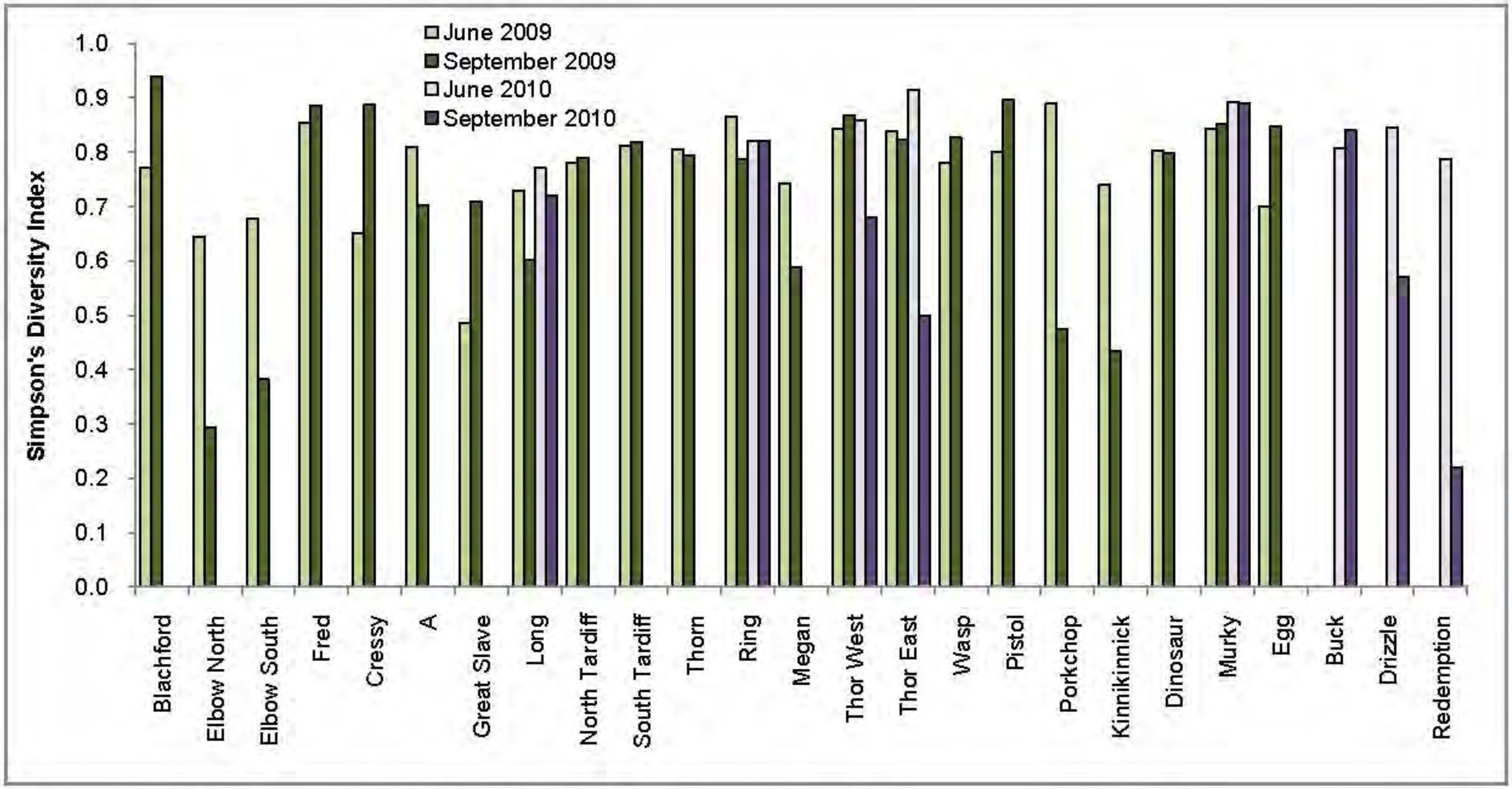

NOTES

Figure Source: Figure 6-38. Stantec 2010c.

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THOR LAKE PROJECT

Phytoplankton Diversity in Sampled Lakes June and September, 2009-2010

PROJECT NO.	DWN	CKD	REV
V15101007.006	SL	DM	0

OFFICE	DATE
EBA-VANC	May 9, 2011

Figure 2.8-3

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).

Zooplankton in freshwater systems are recognized as an essential energy resource for fish of small body size, which then provide energy for larger, piscivorous fish (Medeiros and Arthington 2008). As such, they provide a link between primary producers and fish production, as well as, being important in the recycling of nutrients within an aquatic system.

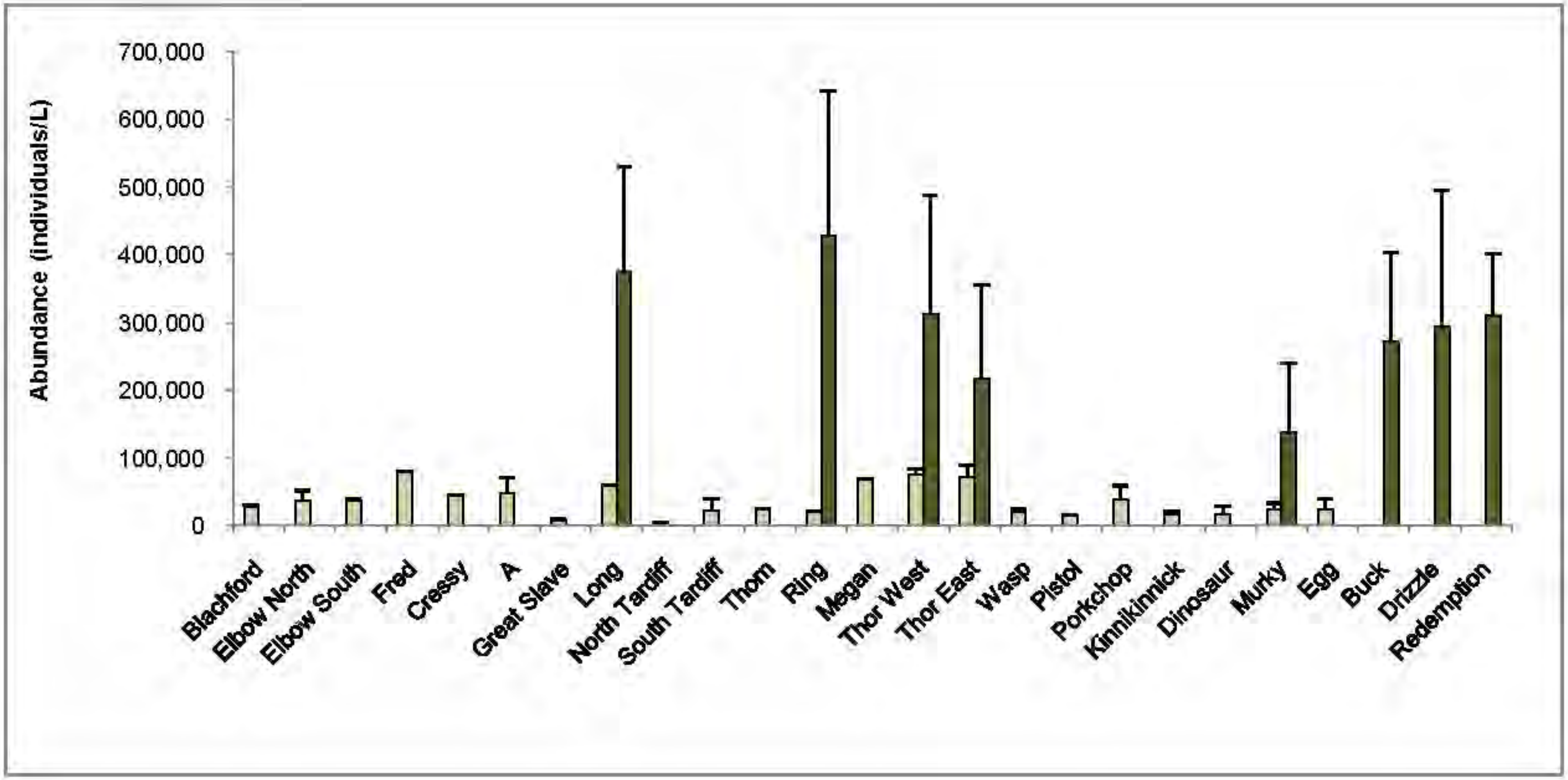
Zooplankton species assemblages can provide an indication of fish presence and abundance in a lake. For example, the phantom midge, *Chaoborus*, is a voracious predator of zooplankton, and is in turn, prey for fish. As such, the presence of large zooplankton such as *Chaoborus* or the copepod, *Heterocope*, particularly in high numbers, may indicate the absence, or low numbers of predatory fish, and may significantly affect zooplankton community structure (Riessen et al. 1984; Vanni 1988).

The data reported by Stantec (2010c) were inconclusive in this regard, since fish were found in three of the nine lakes in which large zooplankton were sampled, and were absent in two of the eight lakes devoid of these zooplankton (Stantec 2010c), although the absence of fish or large zooplankton from some lakes may be due to a variety of factors. Large zooplankton species were not found in Thor Lake during any field studies (Melville et al. 1998; Stantec 2010c).

Zooplankton abundance varied considerably among lakes and between years (Stantec 2010c), as shown in Figure 2.8-4. However, comparison between years is complicated by the change to a larger diameter zooplankton net in 2010, as well as slight differences in the timing of sampling. Variability also likely reflects variability in water chemistry, primary productivity, and predation.

Zooplankton abundance was higher in June than September in both years, except in Great Slave, A, and Pistol lakes in 2009, and Redemption Lake in 2010. This trend was opposite of that for phytoplankton abundance for several lakes in 2009, and for all lakes (except Buck Lake) in 2010.

Forty-four zooplankton taxa were identified in 2009; 38 were counted in 2010. Richness values for 2009 and 2010 in all sampled lakes are shown in Figure 2.8-5; diversity values are provided graphically in Figure 2.8-6.



NOTES

1. Light bars represent 2009 and dark bars represent 2010.
2. Different diameter nets were used in 2009 and 2010.
3. Figure Source: Figure 6-39. Stantec 2010c.

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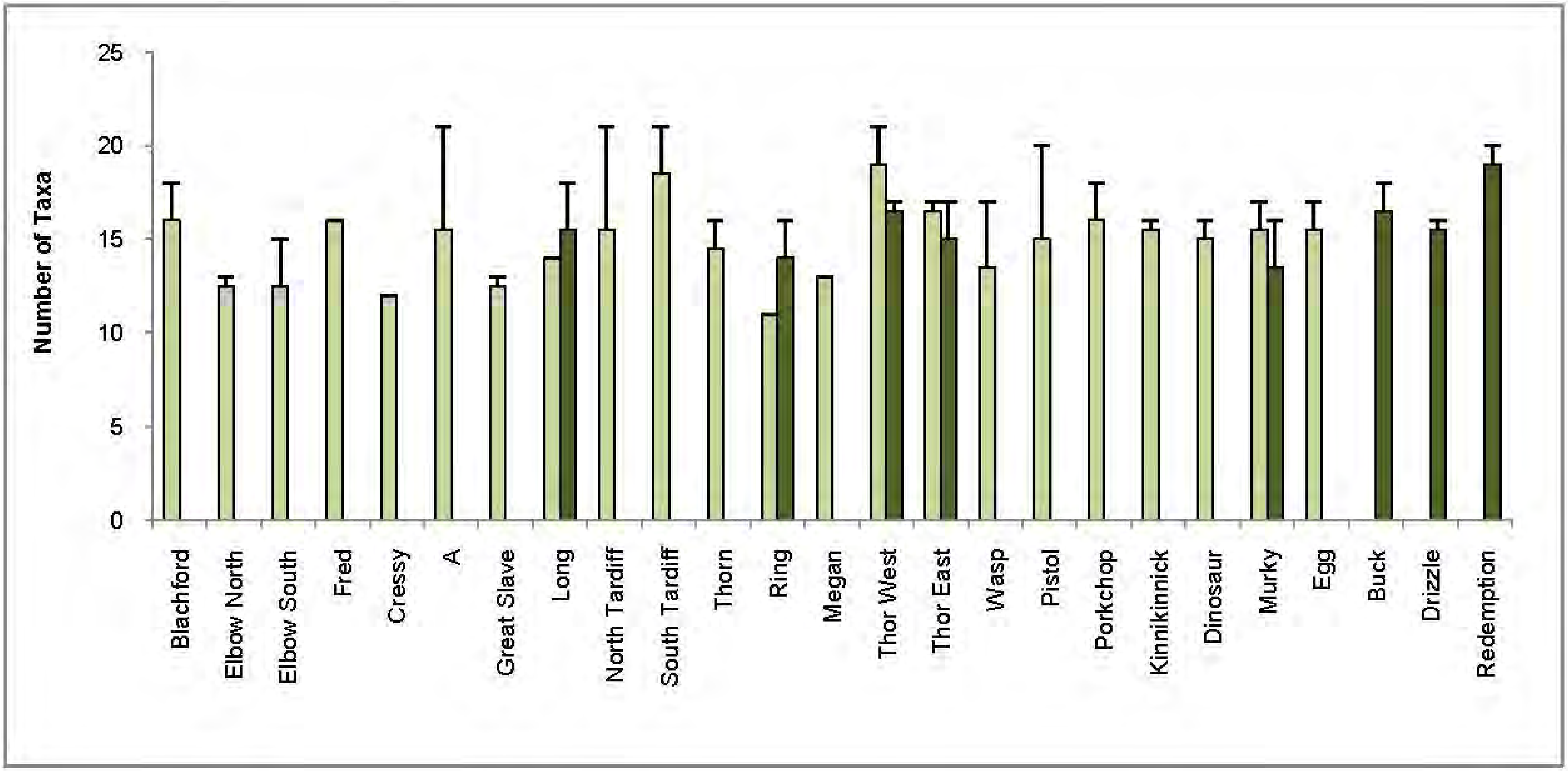
THOR LAKE PROJECT

Mean and Maximum Zooplankton Abundance in Sampled Lakes, 2009-2010

PROJECT NO.	DWN	CKD	REV
V15101007.006	SL	DM	0
OFFICE	DATE		
EBA-VANC	May 9, 2011		

Figure 2.8-4

Q:\Vancouver\Graphics\ENGINEERING\V151\V15101007_ThorLake\006_DAR\V15101007_DAR_CDR021.cdr



NOTES

1. Light bars represent 2009 and dark bars represent 2010.
2. Figure Source: Figure 6-41. Stantec 2010c.

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THOR LAKE PROJECT

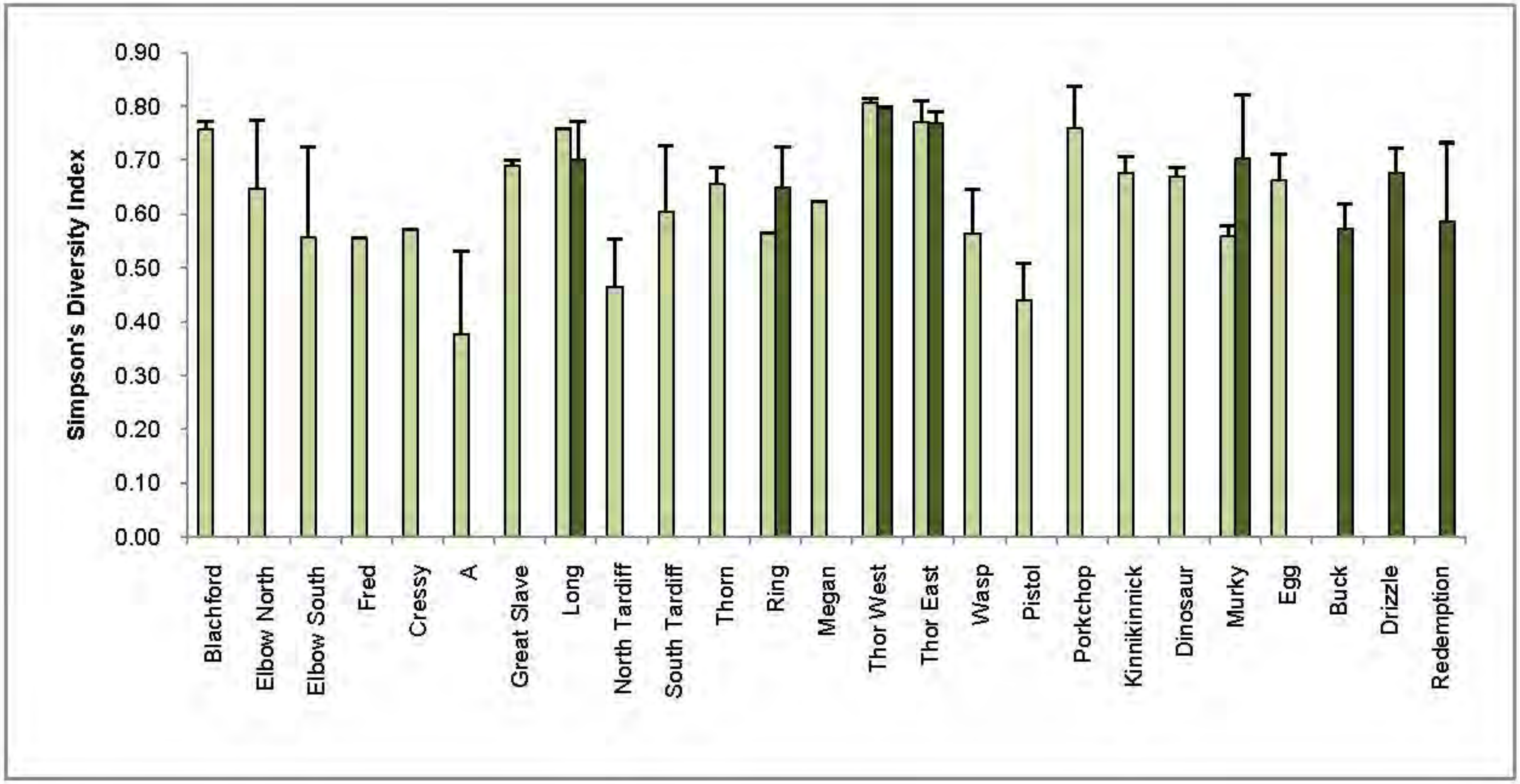
Mean and Maximum Zooplankton Richness in Sampled Lakes, 2009-2010

PROJECT NO.	DWN	CKD	REV
V15101007.006	SL	DM	0

OFFICE	DATE
EBA-VANC	May 9, 2011

Figure 2.8-5

Q:\Vancouver\Graphics\ENGINEERING\V151\V15101007_ThorLake\006_DAR\V15101007_DAR_CDR022.cdr



NOTES

1. Light bars represent 2009 and dark bars represent 2010.
2. Figure Source: Figure 6-43. Stantec 2010c.

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THOR LAKE PROJECT

Mean and Maximum Zooplankton Diversity in Sampled Lakes, 2009-2010

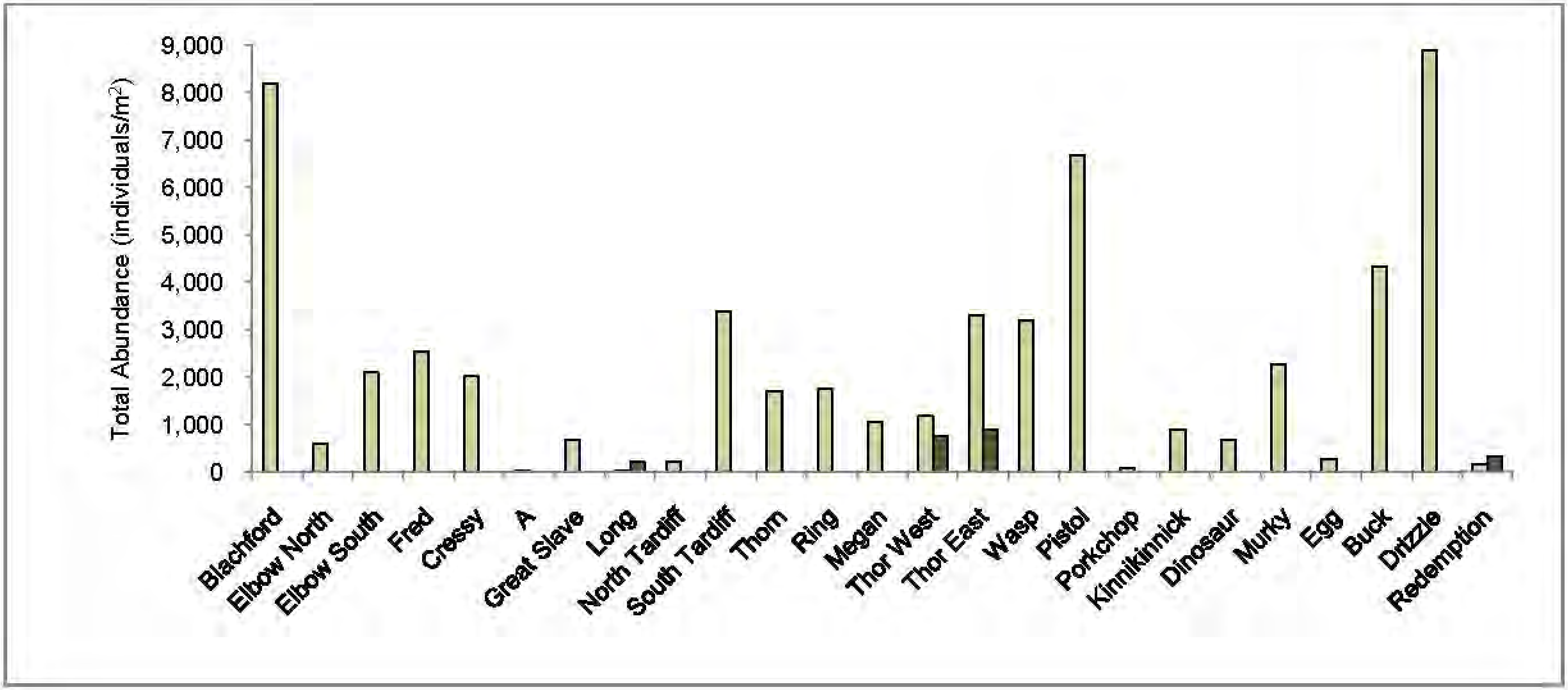
PROJECT NO.	DWN	CKD	REV
V15101007.006	SL	DM	0
OFFICE	DATE		
EBA-VANC	May 9, 2011		

Figure 2.8-6

Benthic Invertebrates

The most common benthic invertebrate taxa were the chironomidae (non-biting midges) and sphaeriidae (small bivalve freshwater molluscs). Predominant and common taxa included three diptera (true fly) families, two copepod orders, two crustacean families, one clam family, two snail taxa, one aquatic earthworm, and one nematode taxon.

Abundance, richness, and diversity of benthic invertebrates varied considerably among the sampled lakes (Figures 2.8-7, 2.8-8, 2.8-9, respectively). Abundance ranged from 34 organisms/m^2 in Long and A lakes, to 8,892 organisms/m^2 in Drizzle Lake. Richness ranged from two (number of taxa) in Long and A lakes, to 18 in Drizzle Lake, while in 2009 diversity ranged from a low of 0.15 in Thor Lake (west sampling location) to 0.84 in Blachford Lake. Diversity in Thor Lake West was considerably higher in 2010 than in 2009, although no substantial difference was noted for Thor Lake East. Between 2009 and 2010 diversity declined in both Long and redemption lakes.



NOTES

1. Light bars represent 2009 and dark bars represent 2010.
2. Figure Source: Figure 6-45. Stantec 2010c.

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THOR LAKE PROJECT

Benthic Invertebrate Abundance in Sampled Lakes in September, 2009-2010

PROJECT NO.	DWN	CKD	REV	
V15101007.006	SL	DM	0	**Figure 2.8-7**
OFFICE	DATE			
EBA-VANC	May 9, 2011			

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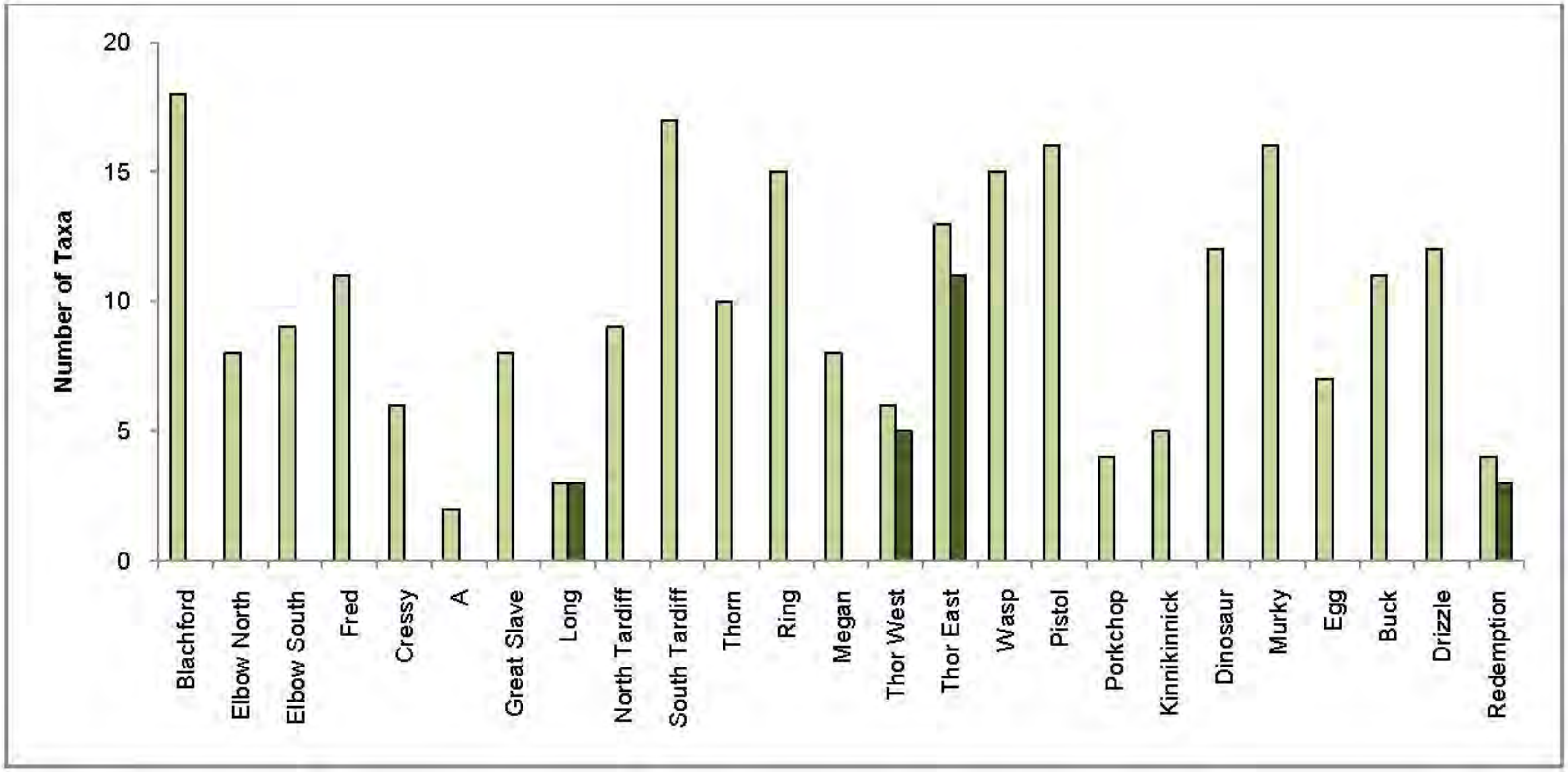

NOTES

1. Light bars represent 2009 and dark bars represent 2010.
2. Figure Source: Figure 6-46. Stantec 2010c.

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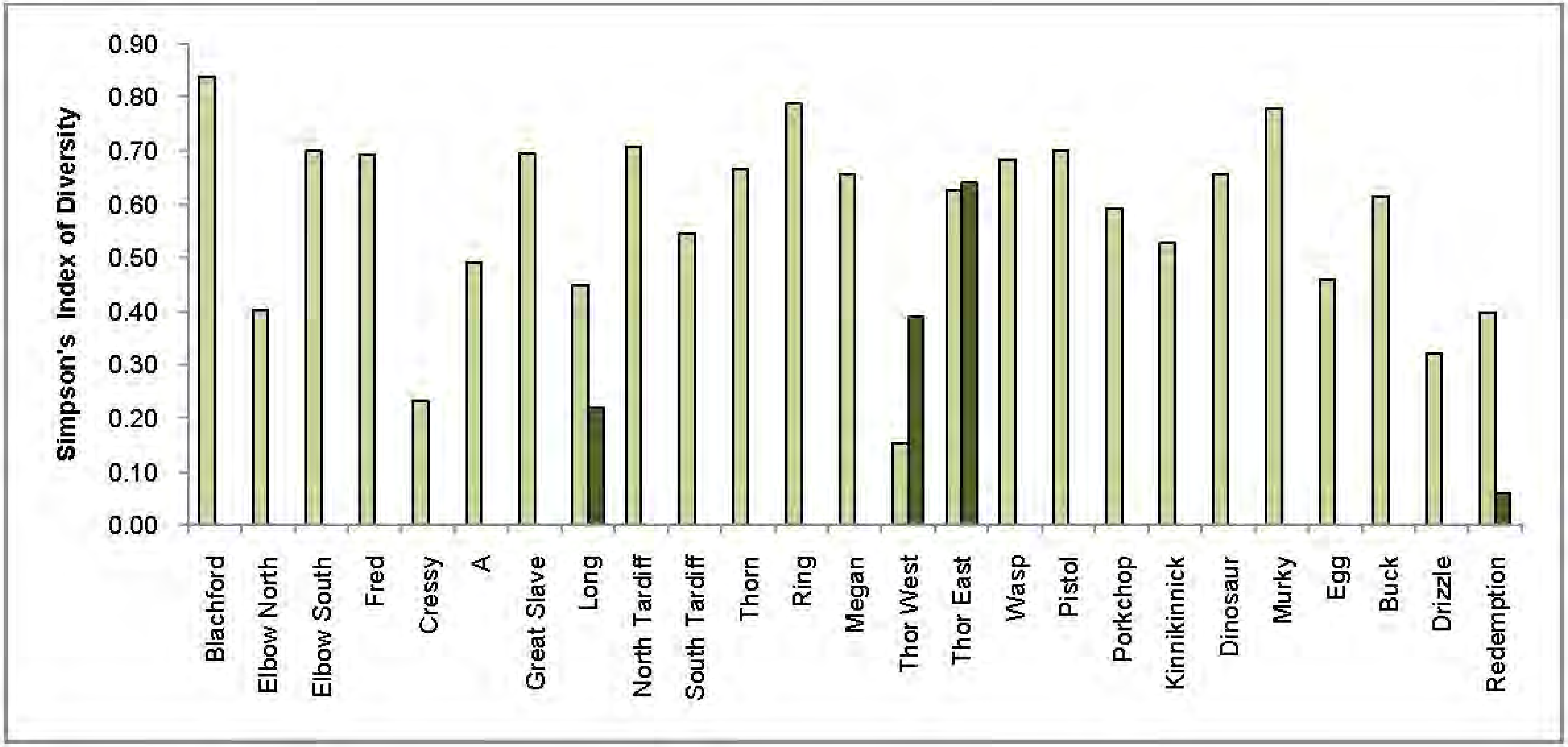
THOR LAKE PROJECT

Benthic Invertebrate Richness in Sampled Lakes in September, 2009-2010

PROJECT NO.	DWN	CKD	REV
V15101007.006	SL	DM	0
OFFICE	DATE		
EBA-VANC	May 9, 2011		

Figure 2.8-8

Q:\Vancouver\Graphics\ENGINEERING\V151\V15101007_ThorLake\006_DAR\V15101007_DAR_CDR025.cdr



NOTES

1. Light bars represent 2009 and dark bars represent 2010.
2. Figure Source: Figure 6-47. Stantec 2010c.

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THOR LAKE PROJECT

Benthic Invertebrate Diversity in Sampled Lakes in September, 2009-2010

PROJECT NO.	DWN	CKD	REV
V15101007.006	SL	DM	0
OFFICE	DATE		
EBA-VANC	May 9, 2011		

Figure 2.8-9

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2.8.4.5 Fish

Fish Abundance

Five fish species were sampled during baseline studies (Stantec 2010c) in lakes within the effect footprint of the proposed Nechalacho Mine: lake whitefish (*Coregonus clupeaformis*), lake cisco (*Coregonus artedii*), northern pike (*Esox lucius*), ninespine stickleback (*Pungitius pungitius*), and slimy sculpin (*Cottus cognatus*). In addition to these species, Melville et al. (1989) also reported catching troutperch (*Percopsis omyscomaycus*) in Thor Lake (Melville et al. 1989), however, these fish were not captured during two seasons of sampling by Stantec (2010c). Trout-perch typically inhabit deeper waters during the day and move into shallow areas at night and are therefore mainly caught by seining at night (Scott and Crossman 1973). 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. Further, no trout perch were identified in the stomach contents of lake whitefish or northern pike, despite its importance as a forage fish for a wide range of predator species (Scott and Crossman 1973).

In addition to the fish species captured in lakes within the immediate Nechalacho Mine site area, fish sampling in the gravel bay on Great Slave Lake in the vicinity of the proposed dock also revealed Arctic grayling (*Thymallus arcticus*), burbot (*Lota lota*), longnose sucker (*Catostomus catostomus*), lake trout (*Salvelinus namaycush*), and round whitefish (*Prosopium cylindraceum*) (Stantec 2010c). However, it is likely that several other fish species could be found within this area at various times of the year due to the diversity and abundance of fish in Great Slave Lake.

Fish were captured or observed in 9 of the 18 fished lakes (Table 2.8-8). (Carrot and U lakes were also fished but were discarded as potential reference lakes, and are therefore not included in the list of sampled lakes). 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 A, Elbow, Long, Redemption, and Thor lakes. Lake trout were captured in Great Slave Lake, and lake chub were captured in Kinnikinnick. Only northern pike were caught in Murky. No fish were caught in Ball, Buck, Cressy, Drizzle, Megan, North Tardiff, Ring, South Tardiff, or Thorn lakes. All of these are shallow with five of them having maximum depths of two metres or less. Blachford, Dinosaur, Egg, Pistol, Porkchop and Wasp lakes were not fished, as they are not expected to be directly affected by the Project and are not being considered as fisheries reference lakes. No fish species at risk, listed in the *Species at Risk Act* or by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), were found within the study area.

Winter sampling in Fred Lake was conducted with two daytime gill nets set under the ice in March 2009, with no success. The results of this sampling provides evidence in support of the hypothesis that Fred Lake is a sink habitat.

TABLE 2.8-8: SUMMARIZED CATCH AND CPUE RESULTS FOR LARGE BODIED FISH SPECIES IN LAKES WITHIN THE NECHALACHO MINE SITE AREA IN 2008 – 2010[3] (STANTEC 2010c)

Lake	Species[1]	# of Fish[2]			Total Effort (hrs)	CPUE
		2008	2009	2010		
A	LC	6	26	-	40.0	0.8
	LWF	28	6	-		0.9
	NP	8	2	-		0.3
Ball	LC	-	-	0	21.4	0
	LWF	-	-	0		0
	NP	-	-	0		0
Buck	LC	-	0	0	35.9	0
	LWF	-	0	0		0
	NP	-	0	0		0
Cressy	LC	0	0	-	48.4	0
	LWF	0	0	-		0
	NP	0	0	-		0
Drizzle	LC	-	0	0	39.3	0
	LWF	-	0	0		0
	NP	-	0	0		0
Elbow	LC	21	6	-	69.7	0.4
	LWF	71	72	-		2.1
	NP	16	16	-		0.5
Fred	LC	1	0	-	30.6	<0.1
	LWF	31	18	-		1.6
	NP	7	8	-		0.5
Great Slave	LC	150	304	-	73.3	6.2
	LWF	17	27	-		0.6
	NP	3	0	-		0.04
Kinnikinnik	LC	-	4	-	33.1	0.1
	LWF	-	0	-		0
	NP	-	18	-		0.5
Long	LC	10	31	-	104.0	0.4
	LWF	72	36	-		1.0
	NP	24	4	-		0.3
Megan	LC	0	0	-	37.7	0
	LWF	0	0	-		0
	NP	0	0	-		0
Murky	LC	-	0	0	34.7	0
	LWF	-	0	0		0

TABLE 2.8-8: SUMMARIZED CATCH AND CPUE RESULTS FOR LARGE BODIED FISH SPECIES IN LAKES WITHIN THE NECHALACHO MINE SITE AREA IN 2008 – 2010[3] (STANTEC 2010c)						
Lake	**Species[1]**	**# of Fish[2]**			**Total Effort (hrs)**	**CPUE**
	NP	-	1	0		<0.1
Redemption	LC	-	25	41	71.3	0.9
	LWF	-	18	38		0.8
	NP	-	9	6		0.2
Ring	LC	-	0	0	33.5	0
	LWF	-	0	0		0
	NP	-	0	0		0
South Tardiff	LC	0	0	-	22.1	0
	LWF	0	0	-		0
	NP	0	0	-		0
North Tardiff	LC	0	0	-	nr[3]	0
	LWF	0	0	-		0
	NP	0	0	-		0
Thor	LC	3	29	-	69.4	0.5
	LWF	84	64	-		2.1
	NP	18	11	-		0.4
Thorn	LC	0	0	-	37.2	0
	LWF	0	0	-		0
	NP	0	0	-		0

[1] LC=lake cisco; LWF=lake whitefish; NP=northern pike
[2] A "-" indicates that no nets were set
[3] nr=not reported
[3]"-" indicates that the lake was not sampled.

Table 2.8-8 summarizes the fishing effort, total catch, and catch per unit effort (CPUE) for lake cisco, lake whitefish, and northern pike in lakes where sampling was conducted using gill nets (after Stantec 2010c).

Lake whitefish tend to be the most abundant large bodied fish species in the Project area, although the catch statistics must be read with caution due to the possibility of varying gear selectivity among species, and the likelihood that fish are not equally distributed within a lake. For example, northern pike will often inhabit shallow, weedy areas where they are not particularly susceptible to gill net capture.

Sampling results from Melville et al. (1989) and Stantec (2010c) indicated that lake whitefish made up about 70% of all large bodied fish in Thor Lake, although catch per unit effort (CPUE) was considerably higher during the 1988 field studies (10.7 vs. 2.2, respectively), although this could be accounted for by differences in gill net mesh sizes used. Any substantial differences noted in catches between years during the Stantec (2010c) study are attributed to differences in the gill net positioning within the lakes.

The following sections provide brief life history descriptions of the fish species known to inhabit the Nechalacho Mine site area, with an emphasis on life history and habitat selection in lakes, due to the predominance of lake habitat in this area. The potential anthropogenic effects identified in these sections are those that may occur due to mining related activities.

Lake Whitefish

Lake whitefish, also called Humpbacks or Crooked Backs, are primarily a freshwater fish, inhabiting lakes, larger rivers, and occasionally, brackish waters (Scott and Crossman 1973). They represent a taxonomically complex group of closely related fish with anatomical characteristics that are variable, and which are influenced by geography, latitude, and life history (Scott and Crossman 1973; Birtwell et al. 2005). They are an important commercial and sport fish in the north.

Spawning and Egg Development

Generally, spawning takes place in October or November at night along shallow beaches in waters less than five metres in depth. Water flow is not a requirement for spawning. Adhesive eggs are broadcast over rock, sandy, or gravelly substrates where they attach to the substrate or settle into crevices. Temperatures must be greater than 0°C for egg survival and optimal temperature has been found to be 4-6°C. An oxygen level greater than 8 mg/L is required for normal egg development (Birtwell et al. 2005). Eggs normally hatch in April or May depending particularly on water temperatures. Lake whitefish eggs are subject to predation by other fish species, in particular burbot and suckers. Eggs deposited over cobble or irregular surfaces will filter down into crevices and have a better chance of survival than those attached to exposed surfaces.

Larvae and Juveniles

The very small larvae (1.1 to 1.4 cm) remain in the vicinity of their spawning grounds for about two months, generally in water less than one metre and in association with emergent vegetation and woody debris. After about three weeks, the yolk sac is absorbed and juvenile whitefish begin to feed on zooplankton. Growth in the first year is rapid as their food supply changes from plankton to aquatic insect larvae. After about 8 weeks, juveniles move into deeper, cooler waters and adopt a benthic mode of life. By October, these fish are about 12 cm long (Richardson et al. 2001; Birtwell et al. 2005).

Adults

Adult lake whitefish are primarily a benthic, lake dwelling fish that prefer cool water. They move from shallow to deep water during the summer months, and then into shallower water as the temperature cools. Lake whitefish feed on aquatic insects, molluscs, amphipods and a variety of small fish and fish eggs, and will feed on planktonic organisms if there is a shortage of benthic food supply. In the Nechalacho Mine site area, Melville et al. (1989) noted that ninespine sticklebacks made up a high proportion of the food items consumed by whitefish in both Thor and Elbow lakes. The age of sexual maturity is partially dependent on temperature and growth rates. In the north, this can range from eight to 13 years, depending on latitude (Richardson et al. 2001; Birtwell et al. 2005).

Anthropogenic Factors Influencing Survival

The selection by adult lake whitefish of deep lake habitats likely reduces the potential of mining effects on this stage of their life history. In addition, because their spawning habitat is variable, slight changes in lake level due to water diversion or withdrawal, unless sudden, are not likely to have a significant impact on spawning success. Egg survival can be adversely affected by the settling of suspended sediment, which may result from land disturbance activities (Fudge and Bodaly 1984). Altered water temperature regimes interfere with maturation as well as spawning migrations within a lake system. It has also been observed that lake whitefish avoid waters contaminated by such heavy metals as copper, lead, and zinc (Birtwell et al. 2005).

Lake Cisco

Lake cisco, also called lake herring, is a salmonid species that encompasses many variants (collectively called a species complex), which are widely distributed in North America, ranging from north-central and eastern United States and throughout much of Canada, including as far north as Great Bear Lake (Scott and Crossman 1973).

These fish are predominantly found in lakes, although the anadromous form does exist, particularly in the James Bay Region (Scott and Crossman 1973).

Spawning and Egg Development

Spawning takes place in shallow, 1-5 m deep water in late September and through October, depending on water temperature and ice conditions, and often as ice begins to form around lake margins. Spawning habitat has been reported to include a very wide range of substrates, including clay, mud, vegetation, sand, gravel, rubble, and boulders. Eggs are deposited on these substrates and develop slowly over the winter, likely not hatching until ice breakup (Scott and Crossman 1973).

Larvae and Juveniles

Larval lake ciscoes begin to feed before the yolk sac has been fully absorbed, but can likely survive a period of about 20 days of starvation after hatching (Scott and Crossman 1973). While little is known about the habitat requirements of young lake ciscoes, it is surmised that they prefer shallow water areas of protected bays in association with rocky substrates and vegetation until they are about one month (Richardson et al. 2001). They then move into deeper water and assume a pelagic existence. Young lake ciscoes feed on zooplankton, algae, copepods and cladocera (e.g. daphnia).

Adults

Adult lake cisco are schooling, pelagic fish that can be found in both shallow and deep waters. Seasonally, these fish tend to move into deeper water as summer progresses, and then into shallower areas as surface waters cool. They also may migrate toward shore at sunrise and away from shore at sunset (Richardson et al. 2001). Adults typically feed on plankton, as well as crustaceans, chironomid larvae, young fish, and fish eggs.

Being opportunistic feeders, however, their diet is likely dependent on food availability. In Lake Superior, for example, crustaceans make up most of their diet (Dryer and Biel 1964). In other areas, lake cisco are prey for a variety of predatory fish species. However, predation on lake cisco in the Nechalacho Project footprint area is likely limited to northern pike due to the absence of such species as lake trout and burbot. The age at maturity is likely dependent on latitude, ranging from age 2 in southern regions to 5 or 6 at the northern limit of their range (Scott and Crossman 1973). Their life span is reported to be 13 years.

Anthropogenic Factors Influencing Survival

As with lake whitefish, the almost exclusive preference of lake cisco for a lacustrine existence and the nonspecific nature of their spawning habitats reduces the likelihood of impacts due to mining activities that may affect lake level. Small changes in lake water levels would not be expected to affect spawning success or larval survival due to the highly varied depths and substrates chosen for spawning. Changes in water quality that affect the composition and abundance of prey organisms (e.g., nutrients) could potentially affect lake cisco populations within lakes of the Nechalacho Mine site area. Increased erosion and sediment discharges to lakes due to land disturbances could also contribute to adverse effects due to the settling of suspended sediment and subsequent smothering of lake cisco eggs.

Northern Pike

The northern pike is a highly piscivorous fish with a preference for weedy bays of lakes and slow moving weedy areas of large rivers (Richardson et al. 2001; Evans et al. 2002). Across their range, which covers much of Canada and the northern United States, pike exhibits lacustrine, riverine, and adfluvial strategies, which explains its wide distribution in the northern hemisphere.

Spawning and Egg Development

Spawning occurs in spring immediately following ice-out, which in northern latitudes can extend from mid-May into June. Northern pike spawn in heavily vegetated shallows of lakes, marshes, and backwaters of rivers (Scott and Crossman 1973; Richardson et al. 2001; Evans et al. 2002) in waters generally less than two metres in depth, and over a variety of substrates. Semi-buoyant, transparent strings of gelatinous eggs adhere to vegetation, and occasionally the substrate. Eggs normally hatch within 10-21 days, but this period may be longer depending on ambient water temperature.

Larvae and Juveniles

Northern pike larvae are inactive and remain associated with vegetation until their yolk sacs are exhausted, usually within 10 days. They then remain in shallow, vegetated areas for several weeks before moving into deeper waters, although still in areas of submergent vegetation, which provides both protection and shelter for potential prey species of fish (Richardson et al 2001). After absorption of the yolk sac, young pike feed on zooplankton and small invertebrates for up to about 10 days, before seeking out prey fish. Their growth is rapid, with fish attaining lengths of up to 12 cm in the first year at northern latitudes (Scott and Crossman 1973).

Adults

Adult northern pike remain in relatively shallow waters except during winter when they seek deeper areas. Within the Nechalacho Mine site area, fish inhabiting shallow weedy areas at the mouths of small lakes, would likely descend to larger, deeper lakes, such as Thor Lake, for overwintering. During the open water period, adults are normally found in moderately vegetated shallows with almost no water velocity, over mud, silt, or occasionally, gravel bottoms. They are ambush predators, lurking in vegetation in wait for any living vertebrate that is of a suitable size range (between one-third and one-half of their size). Northern populations of pike reach sexual maturity at ages 5-6 (Richardson et al. 2001).

Anthropogenic Factors Influencing Survival

The selection of shallow vegetated areas by northern pike for all open water life stages make this habitat potentially vulnerable within the Nechalacho Mine site area. Reductions in water levels a with suitable habitats at their outlets or in outlet streams could reduce or eliminate available spawning, rearing, and feeding areas. Adult pike must descend to deep lakes for overwintering, which therefore requires adequate connector stream flows during the fall to permit migration.

Ninespine Stickleback

The ninespine stickleback is ubiquitous in the Northwest Territories and is also found throughout rivers and lakes in north central Canada and in portions of the Arctic Islands (Richardson et al. 2001; Evans et al 2002). It is found in a variety of habitats and includes lacustrine, riverine, and anadromous life histories.

Spawning and Egg Development

Ninespine stickleback spawn in lakes or streams from May to mid-July in nests built by the males in shallow, weedy waters. Nests are built from vegetation and debris, which is glued together using kidney secretions. Nests can also be made in burrows in muddy substrates and between or under rocks along lake shores. Males guard the nests and tend fertilized eggs by fanning the nest entrance to create a current of oxygenated water.

Larvae and Juveniles

Eggs hatch in about one week, after which the male guards the fry a further two weeks in a nursery area constructed above the nest, until they are free swimming and disperse into shallow, vegetated waters (Richardson et al. 2001). (However, the construction of a specific nursery area by male ninespine sticklebacks is disputed by Evans et al. (2002)). The young move into deeper water to overwinter.

Adults

In streams, ninespine sticklebacks are usually found in shallow, slow flowing areas over sand or mud substrates (Evans et al. 2002). Their food consists of aquatic insects and crustaceans, and occasionally small fish fry and fish eggs (Scott and Crossman 1973). These sticklebacks generally mature within the first year of life (Scott and Crossman 1973; Richardson et al. 2001) and have a life span of about three years. These fish are common prey for other fish species.

Anthropogenic Factors Influencing Survival

The selection of shallow, weedy habitats in streams and at lake margins suggests that the habitat of the ninespine stickleback may be affected by either increasing or decreasing water levels. Increasing water velocities could result in displacement of juveniles and adults, which are adapted to slow flowing waters. In addition, excessive erosion and sedimentation due to construction activities have the potential to affect spawning success and prey availability.

Slimy Sculpin

The slimy sculpin is found in cold, well oxygenated waters throughout the Northwest Territories and Nunavut, in addition to its wide distribution elsewhere in northern North America. It is typically found in flowing waters, from rivers to small creeks, and also in lakes (Richardson et al. 2001; Evans et al. 2002; Birtwell et al. 2005).

Spawning and Egg Development

Spawning sites are selected by sculpin males in May, usually under a rock, ledge, or submerged woody debris; over sand, gravel, or rock substrates. Deposited eggs adhere to the ceiling of the nest and are subsequently guarded and tended by territorial males, sometimes up to the time that fry begin to feed (Scott and Crossman 1973). Egg incubation takes approximately one month, after which fry fall to the bottom of the nest and exist on absorbed yolk for 3-6 days (Evans et al. 2002).

Larvae and Juveniles

Free swimming sculpin fry remain in shallow water over sand or gravel substrates, and where velocities are generally less than 0.5 m/s. (Evans et al. 2002). As the fish grow, they may move into faster water over coarser substrates where they reside in contact with the stream bottom. In lakes, juveniles shift to deep water as they grow (Richardson et al. 2001; Birtwell et al. 2005).

Adults

Adult slimy sculpin in streams are found in moderate to fast areas of streams, in contact with gravel or cobble substrates, which they use as refugia, although they also select sand and silt bottoms (Evans et al. 2002). In lakes, adults occupy a wide range of depths, but tend to choose depths of less than 10 m in small northern lakes. They consume a variety of prey items, but particularly benthic invertebrates and crustaceans (Scott and Crossman 1973; Birtwell et al. 2005). Adults tend to be relatively immobile in streams, choosing spawning areas near feeding habitats.

In lakes, spawning migrations to inshore areas occur in spring. In addition, a diurnal pattern has been observed during summer, with fish moving upwards into warmer metalimnetic waters during the day, and into deeper metalimnetic waters at night. Maturity of sculpin in the north usually occurs at ages 3-4. Slimy sculpin are eaten by predaceous fish species. In the Nechalacho Project area, this would include northern pike and to some extent, lake whitefish and lake cisco.

Anthropogenic Factors Influencing Survival

The most likely factors that could affect slimy sculpin due to the Nechalacho Project include lake drawdowns and significant changes in water flow.

2.8.4.6 Fish Habitat

Of the 18 lakes included in the fisheries study, nine are known from field studies to be fish-bearing and one (Drizzle Lake) may be fish-bearing only due to its limited connection to Murky Lake (Table 2.8-9). No fish were captured in Drizzle Lake in two seasons of sampling. In addition, it is very shallow and anoxic in winter, and the stream connecting Drizzle to Murky is only passable during spring high flows. As such, it is unlikely to sustain fish populations or can be considered to be a sink habitat.

All lakes that are considered non-fish-bearing, including Ring and Buck lakes, 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.*

Northern pike were caught in Murky Lake, 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 the Murky outlet stream 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.

TABLE 2.8-9: FISH BEARING STATUS AND DESIGNATION CRITERA (STANTEC 2010c)

Lake	Fish Caught	Isolated	Winter DO[1]	Years of Fishing[2]	Large Plankton[3]	Fish Bearing	Confidence[4]
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
Cressy	N	Y	0.07 – 4.15	2	N	N	High
Drizzle	N	N	0.39 – 0.60	2	Y	Y	Moderate
Elbow	Y	Y	3.63 – 11.3	2	N	Y	High
Fred	Y	N	0.24 – 4.98	2	N	Y[5]	High
Great Slave	Y	N	13.1 – 15.4	2	N	Y	High
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[6]	High

TABLE 2.8-9: FISH BEARING STATUS AND DESIGNATION CRITERA (STANTEC 2010c)

Lake	Fish Caught	Isolated	Winter DO[1]	Years of Fishing[2]	Large Plankton[3]	Fish Bearing	Confidence[4]
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

Notes:

'-' indicates that no data were collected

[1] Values less than 5 mg/L are below the minimum guideline for the Protection of Aquatic Life (CCME, 1999).

[2] Years of fishing includes only fishing conducted as part of the 2008-2010 baseline study.

[3] Large plankton include *Daphnia galeata* and species in the genera *Chaoborus* and *Heterocope*.

[4] 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.

[5] 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. No fish were caught during winter sampling.

[6] 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.

2.8.4.7 Fish Biometrics and Fish Health

Morphometric, age, condition, and health related data for large bodied fish captured during 2008 and 2009 field studies are provided in Stantec (2010c). The following sections summarize these results.

Fish Length

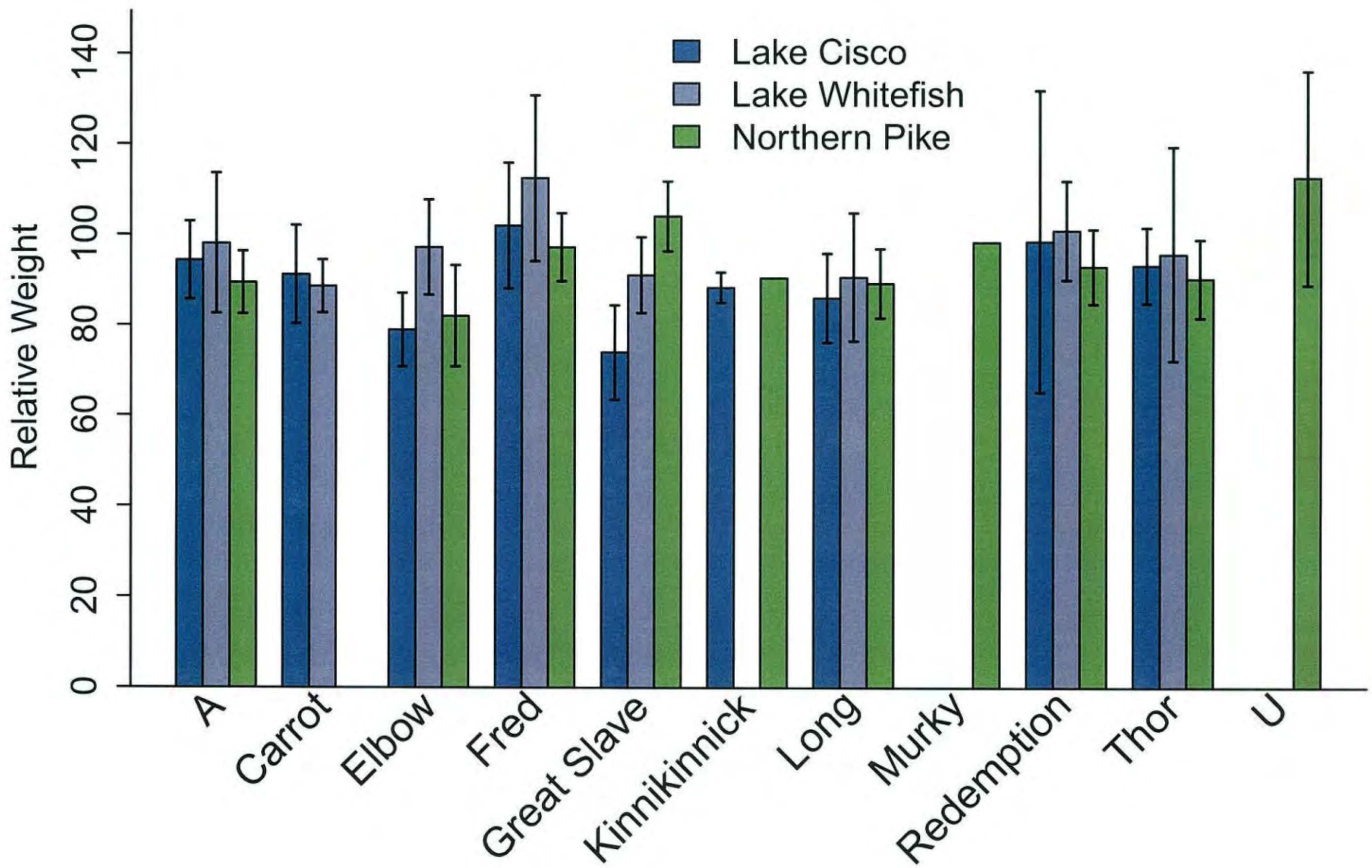
The average lengths of northern pike, lake whitefish, and lake cisco caught in the study lakes were 447 mm, 364 mm and 168 mm. Very few small northern pike and lake whitefish were caught; lake whitefish smaller than 100 mm were only caught in Redemption and Thor lakes, while northern pike smaller than 200 mm were only caught in four lakes (A, Kinnikinnick, Long and Murky). 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.

As indicated earlier, fish capture is heavily influenced by gear selectivity as well as fish distribution relative to sample site selection. In addition, the size of fish of each species 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 tend 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. Although various factors influence fish capture results, the data assembled to date provide a good baseline for future monitoring study comparisons.

Condition – Relative Weight

As an indication of fish condition, the relative weight of individual fish was calculated for the three large bodied species that were present in most of the fish bearing study lakes: northern pike, lake whitefish, and least cisco (Figure 2.8-10). The relative weight compares the weight of each fish with its expected weight based on its length and a standard length-weight relationship developed using data from at least 50 populations. The standard weight equations provide a benchmark for comparison between populations; a fish whose measured weight exactly matches its expected weight has a relative weight of 100.

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. 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 Long Lake (90), while the lowest relative weight for lake cisco was in Great Slave Lake (74). The mean relative weight of northern pike was highest in Great Slave Lake (104), and lowest in Elbow Lake (82).



NOTES

1. Light bars represent 2009 and dark bars represent 2010.
2. Figure Source: Figure 6-52. Stantec 2010c.

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THOR LAKE PROJECT

Mean Relative Weights and Standard Deviations of Large Bodied Fish Species

PROJECT NO.	DWN	CKD	REV
V15101007.006	SL	DM	0

OFFICE	DATE
EBA-VANC	May 9, 2011

Figure 2.8-10

The sample timing for this study (September and early October) may explain why northern pike tended to have lower relative weights in this study than 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.

Lake cisco are known to be morphologically plastic, with more highly variable body form than is usual for other fish species (Scott and Crossman, 1998). This confounds comparisons of health among lakes based on condition factor by masking differences related to health with differences related to natural selection or random genetic drift. Lake cisco relative weights calculated for this study are most useful for comparison with future data, and have limited use for comparison between lakes.

Age

Scales were used to age a subsample of the northern pike and lake whitefish collected in 2008, otoliths were used to age subsamples of lake whitefish and lake cisco caught in 2009 and 2010, and cleithra were used to age a subsample of the northern pike collected in 2009 and 2010. The aging results are presented in Table 2.8-10.

TABLE 2.8-10: AGE RANGES OF NORTHERN PIKE SAMPLED IN 2008 AND 2009 AND LAKE WHITEFISH SAMPLED IN 2008 – 2010 (STANTEC 2010c).

Lake	Northern Pike	Lake Whitefish	Lake Cisco
A	2 – 5	6 – 10	1 – 11
Elbow	4 – 10	4 – 9	–
Fred	1 – 4	1 – 5	–
Great Slave	–	6 – 13	1 – 13
Kinnikinnick	2 – 10	–	–
Long	2 – 7	3 – 8	–
Murky	2	–	–
Redemption	3 – 18	–	1 – 8
Thor	2 – 7	3 – 9	–

Notes:

A (–) indicates that no fish were caught, no age structures were collected, or that the data are not yet available.

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, possibly due to gear selectivity: 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.

Organosomatic Indices

Hepatosomatic and gonadosomatic indices were calculated for fish captured in 2008-2010 and are provided in Stantec (2010c) as baseline data to track possible changes in fish health following mine development. The hepatosomatic (HSI) index compares the liver weight to body weight, while the gonadosomatic (GSI) index compares the gonad (ovary) weight to body weight. Increases in relative liver weight can be an indication of poor health. A summary of HSI indices from sampled lakes is shown in Table 2.8-11.

HSI indices are uniformly higher for northern pike than lake whitefish, which in turn, are higher than those for lake cisco. The HSI index for northern pike in Fred Lake and Long Lake (in 2009) is relatively high. However, it is uncertain whether this is an indication of stressful conditions or if it is due to limited sample sizes. Increases in hepatosomatic indices could be indicative of poor health.

TABLE 2.8-11: HEPATOSOMATIC INDEX VALUES (%) CALCULATED FOR LARGE BODIED FISH SPECIES, 2008 – 2010 (STANTEC 2010c)

Lake	Northern Pike		Lake Whitefish		Lake Cisco	
	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
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	–	–

Notes:
A (–) indicates that no fish of that species were dissected. Mean values are presented ± standard deviations; sample sizes are reported in parentheses.

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. Melville et al. (1989) found that only two-thirds of mature female lake whitefish in Thor and Elbow lakes were "green" (i.e. almost ready to spawn) at the time of sampling. Most of the remaining females carried eggs that were very small and not likely to be viable. This observation is consistent with evidence from elsewhere in the north that not all mature whitefish fish spawn every year (Scott and Crossman 1973). All the ciscoes examined during the same study were observed to be green.

Parasites

The investigation of internal and external parasitic infections provides baseline information for future monitoring purposes.

Stantec (2010c) observed large, easily visible external parasites, primarily leeches, on fish in four of the lakes: Elbow, Long, Redemption and Thor. 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. The cysts were 1-2 mm across and were light coloured and shiny, with a metallic appearance. It is assumed at this time that these cysts were caused by a parasite (Stantec 2010c). Fish with large numbers of the 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 Thor lake whitefish (16 of 24).

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. Data and statistical analyses for these parameters are provided in Stantec (2010c) and are summarized below.

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 for northern pike, and Great Slave Lake for lake whitefish. 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.

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. 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.

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. 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.

The following trends were noted from the data:

- 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.

Melville et al. (1989) found radionuclide activity to be below the level of detection in almost all cases in whitefish and northern pike flesh and bone samples, although sampling and analyses only involved three specimens from each species. Variation in these results was noted due to the elevated level of Pb^{210} in a whitefish flesh sample from one fish.

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).