PHASE 2
DRAFT ENVIRONMENTAL IMPACT STATEMENT

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Glossary and Abbreviations

Terminology used in this document is defined where it is first used. The following list will assist readers who may choose to review only portions of the document.

AEMP	Aquatic Effects Monitoring Program
DGPS	Differential Global Positioning System
D_S	Secchi Depth
EIS	Environmental Impact Statement
EZD	Euphotic Zone Depth
LSA	Local Study Area
NIRB	Nunavut Impact Review Board
NTKP	Naonaiyaotit Traditional Knowledge Project
NWB	Nunavut Water Board
RSA	Regional Study Area
VEC	Valued Ecosystem Component

3. Limnology and Bathymetry

Limnology is the study of inland waters as ecological systems and bathymetry is the measurement of depths in aquatic environments. Limnology and bathymetry are considered to be a Subject of Note in this Environmental Impact Statement as they were not identified as potential Valued Ecosystem Components (VECs) in the EIS Guidelines (NIRB 2012) and any Phase 2 activities that could affect these subjects will be addressed as linkages to other VECs. For example, the potential for Phase 2 activities to affect lake water levels will be considered within the VEC Hydrology (Volume 5, Chapter 1).

The objective of this chapter is to describe the physical limnological processes and bathymetries of specific interest to Phase 2 and its brief overlap with the Doris Project (approximately 2 years). This chapter provides the information requested in the EIS Guidelines (NIRB 2012) and supports other freshwater VEC chapters such as hydrology, water quality, sediment quality, and fisheries. Section 3.1 addresses the Inuit Traditional Knowledge relevant to the study site and limnology and bathymetry, while Section 3.2 presents an overview of the physical limnological and bathymetric characteristics associated with Phase 2 activities and the surrounding region. Section 3.3 details how the limnology and bathymetry chapter is treated as a Subject of Note in the EIS.

3.1 INCORPORATION OF TRADITIONAL KNOWLEDGE

3.1.1 Incorporation of Traditional Knowledge for Existing Environment and Baseline Information

The *Inuit Traditional Knowledge for TMAC Resources Inc. Proposed Hope Bay Project, Naonaiyaotit Traditional Knowledge Project* (NTKP) report (Banci and Spicker 2016) was reviewed for information related to limnology and bathymetry. There were no direct references relevant to limnology and bathymetry in the NTKP report.

3.2 EXISTING ENVIRONMENT AND BASELINE INFORMATION

Phase 2 development will occur within the boundaries of the Hope Bay Project, approximately 153 km southwest of Cambridge Bay on the southern shore of Melville Sound in the West Kitikmeot region of Nunavut (Figure 3.2-1). The Hope Bay Project is within a greenstone belt in the Queen Maud Gulf Lowlands that runs 80 km in a north-south direction that varies in width between 7 km and 20 km. Phase 2 development will occur in two mining districts within the belt: Madrid in the north-central area, and Boston at the southern end of the belt (Figure 3.2-1).

Baseline freshwater aquatic information has been collected within the belt since the early 1990s. The proposed infrastructure in each mining district lies within a single defined Local Study Area (LSA) that is bounded by a larger Regional Study Area (RSA; see Volume 5, Chapter 4, Section 4.4; Figure 3.2-2). Regionally, Phase 2 lies entirely within the Southern Arctic Ecozone and is situated in an area of continuous permafrost with flat rolling bedrock covered by thin layers of moraine, lacustrine, and fluvial deposits.

Figure 3.2-1
Hope Bay Project Location and Existing and Proposed Phase 2 Infrastructure

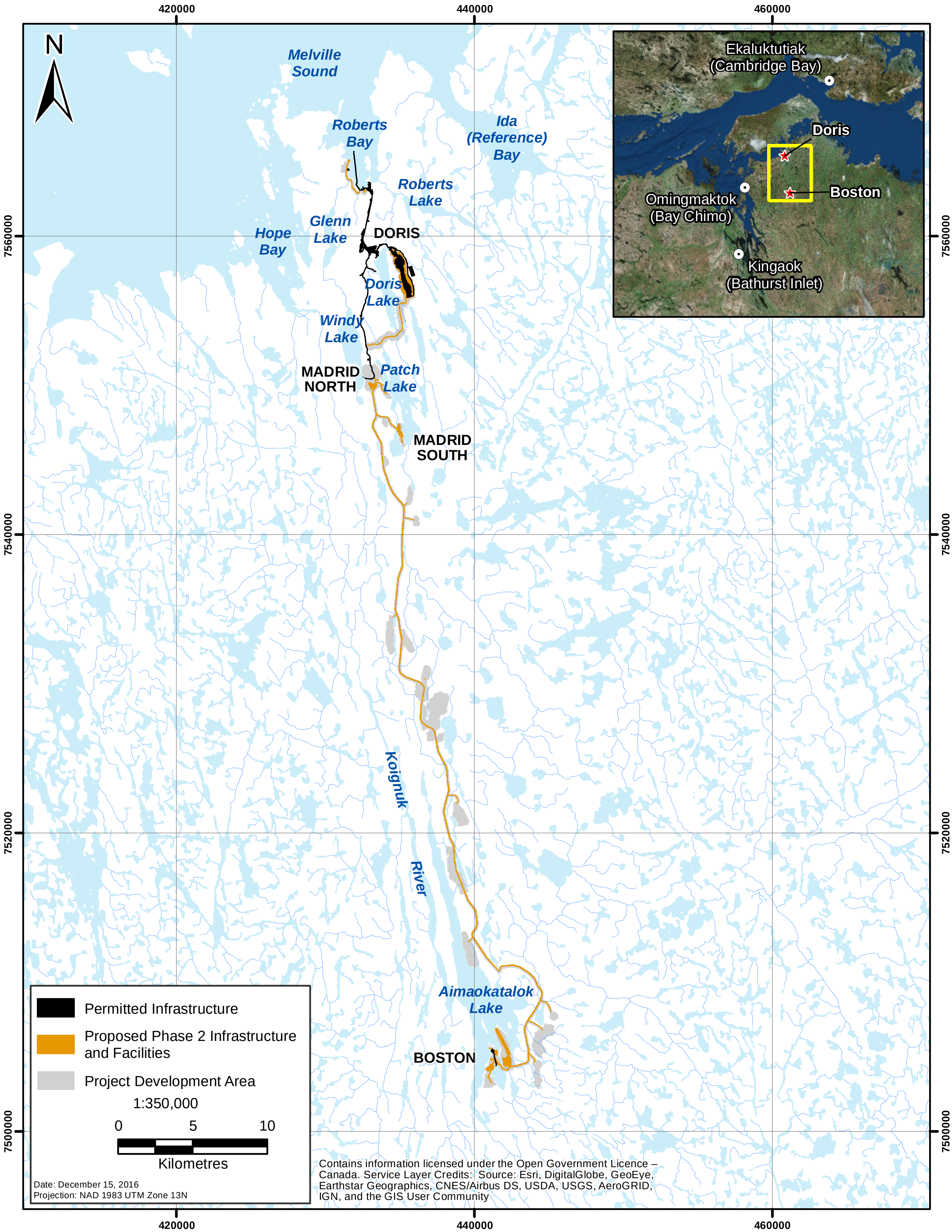
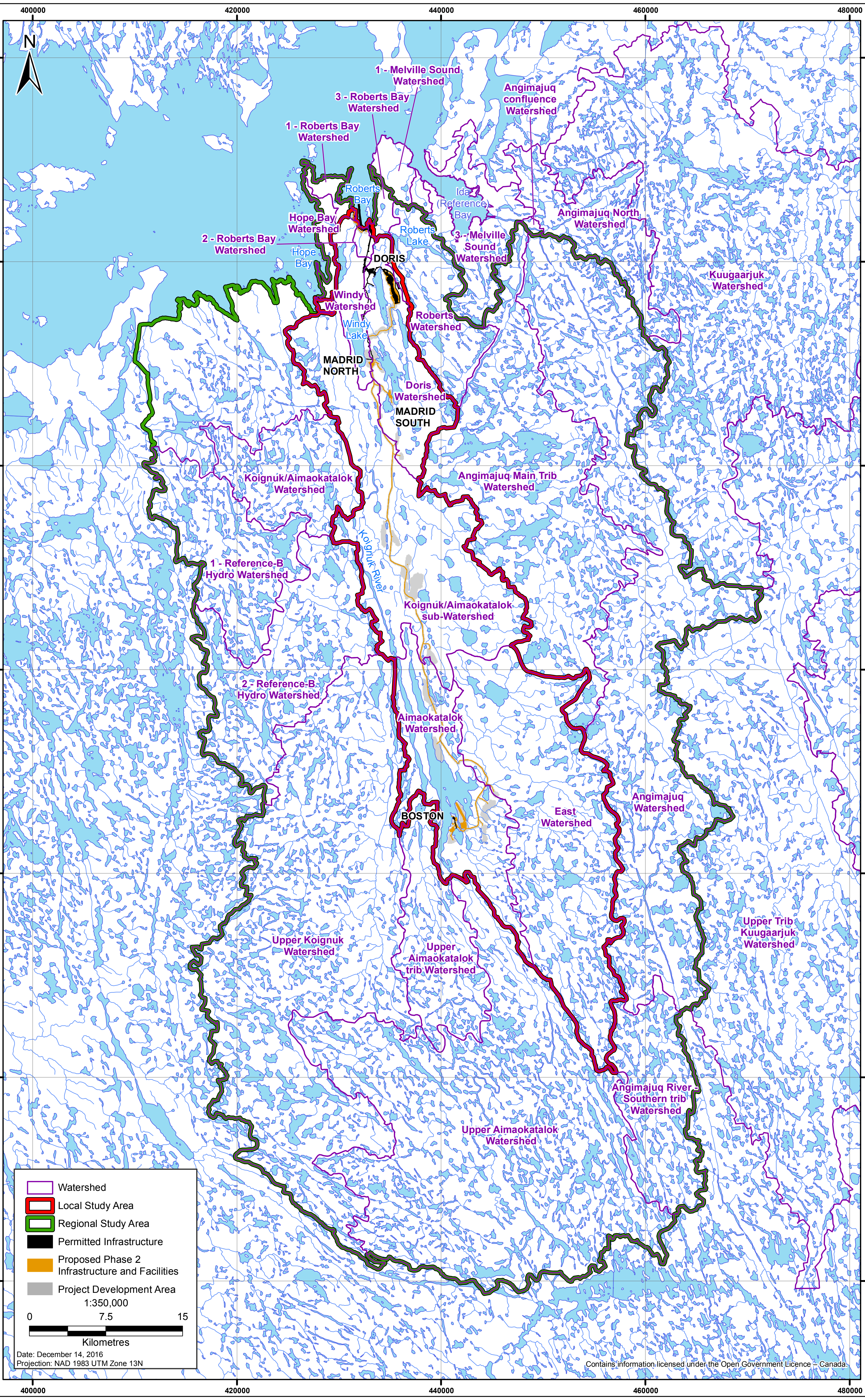


Figure 3.2-2
Freshwater Local and Regional Study Areas



Winter is characterized by extreme cold, with mean monthly temperatures ranging from -33.4ºC to -3.1ºC, and the coldest temperatures in January and February. There is a short snow-free season (mid-June through September) with temperatures ranging from -2.5ºC to 13.9ºC, and the warmest temperatures typically recorded in July (see Volume 4, Chapter 1). The Doris meteorological station reports total summer rainfall (June to September) ranging from 47.8 mm (2012) to 97.8 mm (2011; see Volume 4, Chapter 1). The region's vegetation is characterized by shrub tundra vegetation such as dwarf birch (*Betula nana*), willow (*Salix* sp.), Labrador tea (*Ledum decumbens*), avens (*Dryas* sp.), and blueberries (*Vaccinium* sp.) (Rescan 2011c, Appendix V4-8A).

The freshwater LSA for this EIS includes the Doris, Windy, and Koignuk-Aimaokatalok sub-watersheds in the north, and the Aimaokatalok and East watersheds in the south (Figure 3.2-2). Water from the northern Doris and central Madrid watersheds flows northward into Roberts Bay via Little Roberts Outflow and Glenn Outflow, while water from the southern Boston watersheds flows into Hope Bay via the larger Koignuk River system. The largest lakes in the northern and central belt include Doris, Windy, Patch, Glenn, and Ogama lakes, with Aimaokatalok Lake being the largest lake in the southern belt. The hydrology in Phase 2 area is dominated by snowmelt (Volume 5, Chapter 1). The lakes are typically frozen from November to June with ice thickness ranging between 1.5 to 2.0 m (Rescan 2010, 2011a). Winter flow is largely absent because of negligible groundwater reserves outside of the permafrost and the lack of unfrozen surface water. Due to the influences of climate and permafrost, there is one major flood period (freshet) in June that quickly recedes into summer, with occasional high–flow events from storms during the open-water season.

This section provides a summary of the methods and results from the freshwater limnological and bathymetric sampling carried out in Phase 2 area and surrounding region.

3.2.1 Proximity to Designated Environmental Areas

There are currently no existing or proposed parks or conservation areas near Phase 2 activities. The nearest conservation area is the Queen Maud Gulf Migratory Bird Sanctuary approximately 50 km east of the Phase 2 area by air and over 300 km by water (as Melville Sound is isolated from the Queen Maud Gulf by the Kent Peninsula).

The Draft Nunavut Land Use Plan (Nunavut Planning Commission 2014) has designated the Phase 2 area as having high mineral potential and being within an area of Arctic Char abundance. The proposed Hiukitak River Cultural Area on the eastern shore of northern Bathurst Inlet is approximately 100 km beyond the Phase 2 freshwater RSA boundary. Past activities near the Phase 2 Project are outlined in the Assessment Methodology chapter (Volume 2, Chapter 4).

3.2.2 Data Sources

The characterization of existing environment and baseline data for limnology and bathymetry is based on studies conducted in lakes, streams, and rivers of the LSA and RSA between 1992 and 2010 and the Aquatic Effects Monitoring Program (AEMP) for the Doris Gold Mine Project conducted from 2010 to 2015. The lake limnology characterization is focused on the recent studies from 2009 to 2015 because of consistent methodology and instrumentation. The baseline and existing environment studies are detailed in the following reports:

- Boston Property N.W.T. Environmental Data Report (Rescan 1993; Appendix V5-3B);
- Boston Property N.W.T. Environmental Data Report (Rescan 1994; Appendix V5-3C);
- Hope Bay Belt Project: 2000 Supplemental Environmental Baseline Data Report (Rescan 2001; Appendix V5-3D);

- o Aquatic Baseline Studies: Doris Hinge Project Data Compilation Report, 1995-2000 (RL&L and Golder 2002; Appendix V5-3E);
- o Doris North Project: Aquatic Studies 2003 (RL&L and Golder 2003; Appendix V5-3F);
- o Bathymetric Surveys: Hope Bay Project, Hope Bay, Nunavut (Golder 2006; Appendix V5-3G);
- o Boston and Madrid Project Areas: 2006 – 2007 Aquatic Studies (Golder 2008; Appendix V5-3H);
- o Hope Bay Project: Aquatic Studies 2008 (Golder 2009; Appendix V5-3I);
- o 2009 Freshwater Baseline Report, Hope Bay Belt Project (Rescan 2010, Appendix V5-3J);
- o Hope Bay Belt Project: 2010 Freshwater Baseline Report (Rescan 2011a, Appendix V5-3K);
- o Doris North Gold Mine Project: 2010 Aquatic Effects Monitoring Program Report (Rescan 2011b);
- o Doris North Gold Mine Project: 2011 Aquatic Effects Monitoring Program Report (Rescan 2012);
- o Doris North Gold Mine Project: 2012 Aquatic Effects Monitoring Program Report (Rescan 2013);
- o Doris North Project: 2013 Aquatic Effects Monitoring Program Report (ERM Rescan 2014);
- o Doris North Project: 2014 Aquatic Effects Monitoring Program Report (ERM 2015); and
- o Doris North Project: 2015 Aquatic Effects Monitoring Program Report (ERM 2016).

The Doris Project Aquatic Effects Monitoring Program reports are available on the Nunavut Water Board (NWB) FTP site (ftp://ftp.nwb-oen.ca).

3.2.3 Methods

3.2.3.1 Limnology

Physical limnology profiles were collected from 10 lakes in the LSA (seven in the North Belt and three in the South Belt) and seven lakes throughout the RSA from 1993 to 2015 (Table 3.2-1). Sampled lakes focused on those closest to existing and proposed infrastructure within the LSA, and at reference sites or far-field (downstream) sites in the RSA. Profiles were typically collected over the deepest area of the lake or in a spatially significant location (i.e., within and outside of mine footprints, or near future tailings or waste rock piles). Multiple sites were sampled in the largest lakes including Doris, Patch, and Aimaokatalok within the LSA (Figures 3.2-3 and 3.2-4). A summary of the sampling programs, including sampling locations and replication is shown in Table 3.2-1.

Temperature profiles were collected during the under-ice (April, May, or June) and open-water seasons (July, August, and/or September). All profiles were collected using a YSI meter. At shallower lake stations (<10 m), temperatures were typically recorded onto datasheets at 0.5 m intervals, while at deeper lake stations (>10 m), temperatures were recorded at 1 m intervals. The profiles normally ended at approximately 0.5 to 1 m above the sediment surface to minimize the disturbance of bottom sediments.

Light attenuation was estimated in each lake using a 20-cm black and white Secchi disk. Measurements were collected by lowering the disk on a metred line through the water column on the shaded side of the boat until it disappeared from sight. The depth of disappearance was identified as the Secchi depth (D_s). Secchi depths were used to calculate the euphotic zone depth (EZD), which is defined in this chapter as the depth in the water column at which 1% of surface radiation occurs. This generally represents the zone in a water column where integrated photosynthesis equals the integrated respiration (i.e., compensation depth). Above this depth net primary production is possible given sufficient nutrients. The EZD was calculated as follows:

Table 3.2-1. Summary of Physical Limnology Sampling in the LSA and RSA, 1993 to 2015

Year	1993	1994	1995	1996	1997	1998	2000	2003	2004	2005
Month Sampled	August	August	May, June, July, August	April, August	April, July, August	April, July	August	July, August, September	June, July, August, September	July, August, September
Sampling Equipment	Not reported	Not reported	Secchi/YSI probe	Not reported	Secchi/YSI probe	Secchi/YSI probe	Not reported	Secchi/Oxyguard DO-temperature probe	Secchi/Oxyguard DO-temperature probe	Secchi/Oxyguard DO-temperature probe
Parameters	Temperature, Secchi depth	Temperature, Secchi depth	Temperature, Secchi depth	Temperature, Secchi depth	Temperature, Secchi depth	Temperature, Secchi depth	Temperature, Secchi depth	Temperature, Secchi depth	Temperature, Secchi depth	Temperature, Secchi depth
LSA	South Belt Aimaokatalok Stickleback	South Belt Aimaokatalok Stickleback Trout	North Belt Doris Patch Windy South Belt Aimaokatalok Stickleback Trout	North Belt Doris Patch Windy South Belt Aimaokatalok Trout	North Belt Doris Ogama Patch Wolverine Windy South Belt Aimaokatalok Stickleback Trout	North Belt Doris Ogama Patch Wolverine Windy South Belt Aimaokatalok Stickleback Trout	North Belt Doris	North Belt Doris	North Belt Doris	North Belt Doris
RSA				Little Roberts	Little Roberts Pelvic Boston Reference Lake	Pelvic Boston Reference Lake	Little Roberts Pelvic	Little Roberts Roberts Reference Lake A (Golder)	Little Roberts Roberts	Little Roberts Roberts
Site Replication	n = 1	n = 1	n = 3 (Aimaokatalok); n = 1 (all other lakes)	n = 3 (Aimaokatalok); n = 1 (all other lakes)	n = 4 (Aimaokatalok); n = 1 (all other lakes)	n = 3 (Aimaokatalok); n = 1 (all other lakes)	n = 1	n = 2 (Roberts); n = 1 (all other lakes)	n = 1	n = 2 (Roberts); n = 1 (Doris and Little Roberts)

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Month Sampled	May, July, August, September	May, July, August, September	May, July, August, September	August	April, July, August, September	April, July, August, September	April, July, August, September	April, July, August, September	April, July, August, September	April, July, August, September
Sampling Equipment	Secchi/Oxyguard DO-temperature probe	Secchi/Horiba multi-parameter probe	Secchi/Hach probe	Secchi/YSI probe	Secchi/YSI probe	Secchi/YSI probe	Secchi/YSI probe	Secchi/YSI probe	Secchi/YSI probe	Secchi/YSI probe
Parameters	Temperature, Secchi depth	Temperature, Secchi depth	Temperature, Secchi depth	Temperature, Secchi depth	Temperature, Secchi depth	Temperature, Secchi depth	Temperature, Secchi depth	Temperature, Secchi depth	Temperature, Secchi depth	Temperature, Secchi depth
LSA	North Belt Doris Ogama Patch Wolverine P.O. Windy Glenn South Belt Aimaokatalok Stickleback Trout	North Belt Doris Ogama Patch Wolverine P.O. Windy Glenn South Belt Aimaokatalok Stickleback Trout	North Belt Doris Ogama Patch Wolverine P.O. Windy Glenn South Belt Aimaokatalok Stickleback Trout	North Belt Doris Ogama Patch Wolverine P.O. Nakhaktok Imniagut Windy Glenn	North Belt Doris Windy South Belt Aimaokatalok Stickleback Trout	North Belt Doris	North Belt Doris	North Belt Doris	North Belt Doris	North Belt Doris
RSA	Little Roberts Roberts Pelvic Boston Reference Lake	Little Roberts Roberts Pelvic Boston Reference Lake	Little Roberts Roberts Pelvic Boston Reference Lake	Little Roberts Naiqunnguut Reference A Reference B	Little Roberts Reference B Reference D	Roberts Little Roberts Reference B Reference D	Roberts Little Roberts Reference B Reference D	Little Roberts Reference B Reference D	Little Roberts Reference B Reference D	Little Roberts Reference B Reference D
Site Replication	n = 2 (Aimaokatalok); n = 1 (all other lakes)	n = 2 (Aimaokatalok); n = 1 (all other lakes)	n = 2 (Aimaokatalok); n = 1 (all other lakes)	n = 1	n = 1	n = 1	n = 1	n = 1	n = 1	n = 1

Figure 3.2-3
Limnology and Bathymetry Sampling Locations in the North Belt LSA and RSA, 1995 to 2015

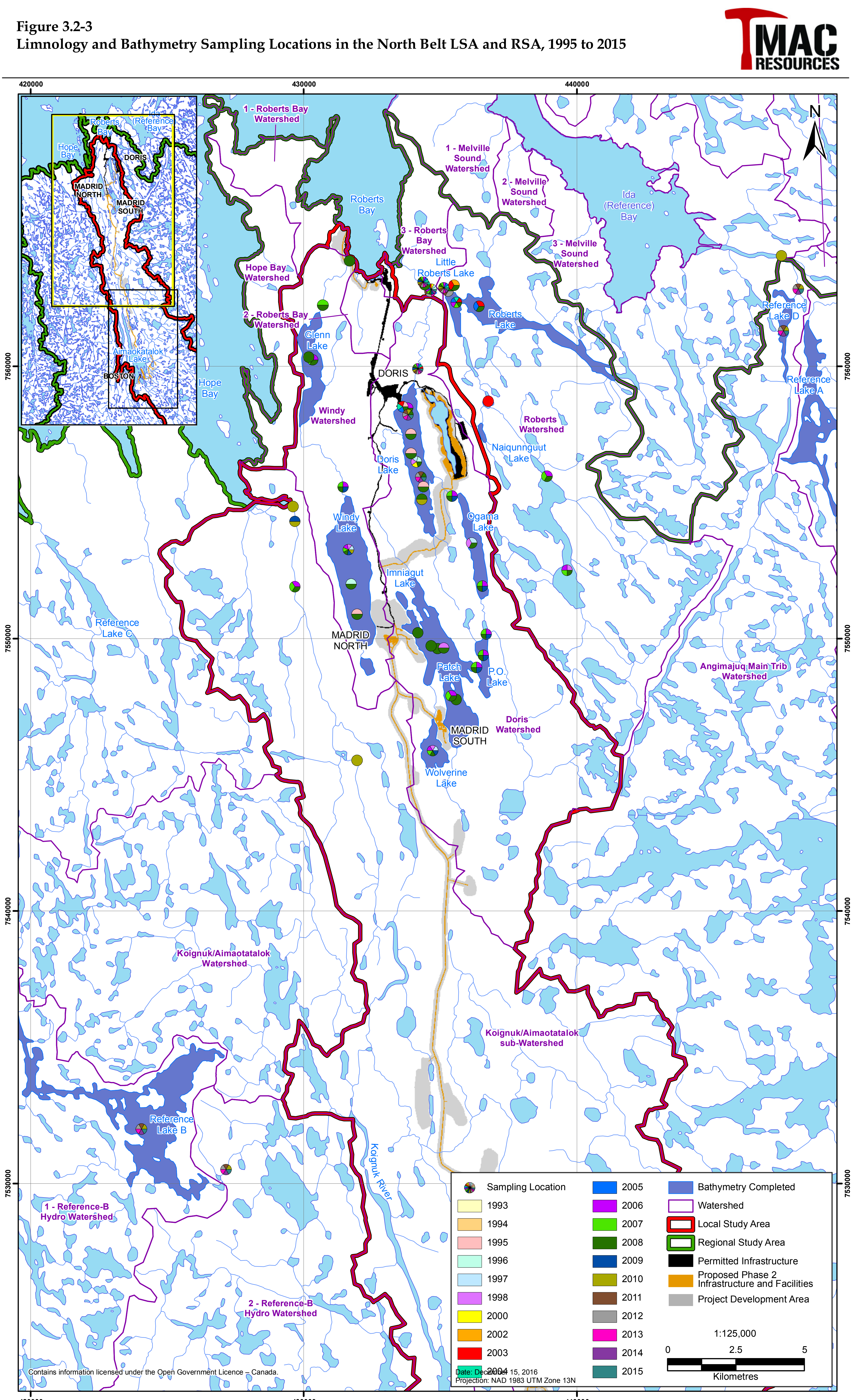
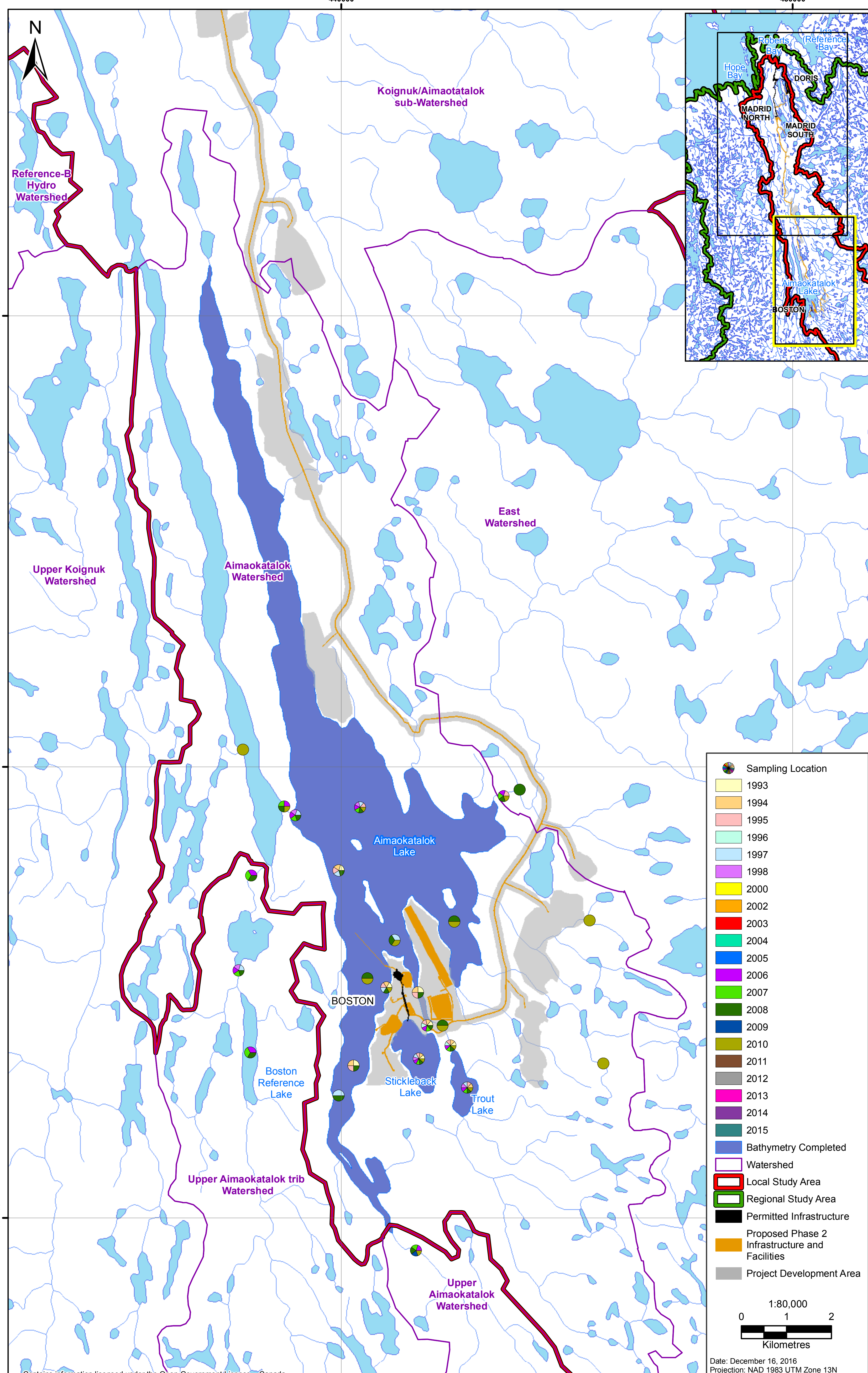


Figure 3.2-4
Limnology and Bathymetry Sampling Locations in the South Belt LSA and RSA, 1995 to 2015



$$k' = 1.7/D_s\ ;$$

where k' = light extinction coefficient, D_s is the Secchi depth, and 1.7 is a constant derived from experimental data (Parsons, Maita, and Lalli 1984).

$$EZD = 4.6/k'$$

3.2.3.2 Stream and River Temperatures

Stream and river temperatures were collected from 12 streams in the LSA (six in the North Belt and six in the South Belt) and seven streams in the RSA from 1993 to 2015 (Table 3.2-2). River temperatures were collected under-ice from the Koignuk River in 2009 and 2010 and stream temperatures were collected during the open-water season (Figures 3.2-3 and 3.2-4). Stream and river temperatures were measured *in situ* using an YSI probe. A summary of the sampling programs, including sampling locations and replication, is shown in Table 3.2-2.

3.2.3.3 Bathymetry

Bathymetric surveys have been conducted in Phase 2 Project area since 1993. In some cases, surveys were completed a second time to increase accuracy or resolution of the survey using improved technology and techniques; however, only results from the most recent surveys for each site are presented in this report. Bathymetric surveys have been conducted in 10 lakes in the LSA (seven in the North Belt and three in the South Belt) and three lakes in the RSA (Table 3.2-3).

Bathymetric surveys were always conducted from small boats. Surveys were generally conducted by collecting continuous depth measurements along regularly spaced transects across the width of each lake, followed by one, or a series of, transect(s) through the long axis of the lake using a Differential Global Positioning System (DGPS) and depth sounder. Perimeter transects around topographical features of interest (e.g., sudden changes in depth) were completed on an as-needed basis. A hand-held GPS, pre-loaded with transect tracks, was used to maintain the correct course with the boat. For most surveys, on-land benchmarks were established via DGPS surveys of the lake shorelines. Specific methods and equipment used for each survey are described in Rescan (2011a), Rescan (1994), Golder (2006 and 2009), and RL&L and Golder (2002 and 2003).

3.2.4 Characterization of Existing and Baseline Conditions

A summary of limnology and bathymetry results from the lake, stream, and river sampling program in the LSA (North and South Belt) and RSA is presented below. The discussion focuses on data collected from 2009 to 2015.

3.2.4.1 Limnology

Lakes in the LSA and RSA were typically covered with landfast, consolidated first-year ice from October into May, with ice thicknesses that usually ranged between 1.5 m and 2 m in early spring (Rescan 2010; Rescan 2011a). Ice thickness on sampled lakes varied little year to year (e.g., Windy Lake, April 27, 2009: 1.87 m; April 19, 2010: 1.80 m) and over the spatial extent of lakes (e.g., 2009 Doris Lake North: 2.0 m, Doris Lake South: 2.0 m, Rescan 2010; 2010 Aimaokatalok Lake, Stn 5: 1.8 m, Stn 6: 1.6 m, Stn 11: 1.8 m, Rescan 2011a). Ice-off usually commenced in mid-June with the presence of liquid water along the perimeter of lakes, with full open waters by July.

Overall, the winter water column structure was typical of ice-covered Arctic lakes. Water temperatures were coldest just below the ice, ranging from -0.3ºC to 2.0ºC, warming slightly with depth in deeper lakes (~1 to 3ºC), and reaching a maximum temperature of 3.3ºC near the water-sediment interface (Rescan 2010, 2011a, 2011b, 2012, 2013; ERM Rescan 2014; ERM 2015).

During the open-water season, most lakes in the Phase 2 Project area were shallow enough to become fully mixed, especially during years with high winds (Rescan 2010, 2011a, 2011b, 2012, 2013; ERM Rescan 2014; ERM 2015). In deeper lakes such as Doris Lake (20.0 m), Station 6 in Aimaokatalok Lake (28.5 m), Reference Lake A (31.5 m), and Reference Lake B (11.7 m), the water column was sensitive to annual climatic fluctuations and had considerable variability in surface water temperatures and the degree of summer stratification. For example, the waters in Doris Lake were strongly stratified during the summers of 2011 and 2015, weakly stratified in 2010, and were well mixed between 2012 and 2014 (Figure 3.2-5; Rescan 2010, 2011a, 2012, 2013; ERM Rescan 2014; ERM 2015). As well, 2012 and 2014 lake temperatures were considerably colder throughout the belt than in 2010, 2011, and 2013, and were considerably warmer in 2015 (Figure 3.2-5).

Typically, water temperatures were warmest in August (range: 8 to 15°C) and there was often a gradual decline in temperature with depth during early/mid-summer (July and/or August) followed by lake mixing and isothermal temperatures in late summer (August and/or September).

Light penetration and water clarity were estimated by the measured Secchi depths. Secchi depths ranged from 0.7 m to 9.0 m (Table 3.2-4). Generally speaking, water clarity was relatively low, with a mean Secchi depth of 1.6 m throughout the LSA lakes. Reduced water clarity was likely attributable to the re-suspension of fine sediments due to shallow lake depths, the well mixed nature of the lakes, and the location of some lakes in fine sediment surroundings (e.g., Glenn Lake). It is likely that increased primary productivity in lakes such as Doris Lake also contributed to decreased water clarity. Several larger lakes in the LSA had mean Secchi depths less than 2.5 m including Doris (1.3 m), Aimaokatalok (2.4 m), Patch (2.1 m), Glenn (1.0 m), and Ogama lakes (1.2 m). Mean Secchi depths were greater than 2.5 m in Windy (3.0 m), Wolverine (3.0 m), and Imniagut lakes (3.5 m).

Overall, mean Secchi depths were greater in the RSA lakes (3.5 m) compared to the LSA lakes, although this was mainly due to the clearer waters found in Reference Lake B (mean = 6.4 m, n = 16). The adjusted mean for the RSA lakes excluding Reference Lake B was similar to that observed in the North and South Belt LSA lakes (mean = 1.9 m, n = 30).

The euphotic depth generally extended throughout the water column to the sediment surface. Some lakes have increased phytoplankton productivity (e.g., Doris Lake: Volume 5, Chapter 4; Volume 5, Chapter 6) or have lake margins composed of deposits of fine sediments (e.g., Windy and Glenn lakes). As well, the deeper sections of some lakes were below the euphotic depth defined by light penetration, even with relative clear waters (e.g., Reference Lake A and Aimaokatalok Lake). Light levels were determined to be generally sufficient to support phytoplankton and periphyton photosynthesis throughout the water column and in the benthic environment in all but the deepest areas of some lakes.

3.2.4.2 Stream and River Temperature

Under-ice water temperatures measured along the Koignuk River in 2009 and 2010 ranged from 0°C to 0.9°C. Hydrometric monitoring in the Phase 2 area indicated that all monitored streams freeze solid in the winter, except the Koignuk River, which retained under-ice liquid water in isolated pools separated by frozen sections of the river (Rescan 2011a).

Table 3.2-2. Summary of Stream and River Temperature Sampling in the LSA and RSA, 1993 to 2015

Year	1993	1994	1995	1996	2002	2003	2004	2005	2006
Month Sampled	Aug	Aug	July, August	June, August	August	July, August, September	June, July, August, September	June, July, August, September	June, July, August, September
Sampling Equipment	Not reported	Not reported	YSI probe	Not reported	Thermograph	Thermograph	Oxyguard temperature-DO probe	Oxyguard temperature-DO probe	Oxyguard temperature-DO probe
LSA	South Belt Trout OF Stickleback OF	South Belt Trout OF Stickleback OF	South Belt Trout OF Stickleback OF Aimaokatalok NE Inflow	South Belt Trout OF Stickleback OF		North Belt Doris OF	North Belt Doris OF	North Belt Doris OF	North Belt Doris OF Ogama OF Patch OF P.O. OF Windy OF South Belt Aimaokatalok NE Inflow Aimaokatalok River Aimaokatalok OF Stickleback OF Trout OF Koignuk River
RSA					Roberts OF		Little Roberts OF Roberts OF	Little Roberts OF Roberts OF	Little Roberts OF Roberts OF Boston Reference Lake OF
Site Replication	n = 1	n = 1	n = 1	n = 1	n = 1	n = 1	n = 1	n = 1	n = 1

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015
Month Sampled	May, June, July, August, September	June, July, August, September	May, June, July, August, September	April	June, July, August, September	June, July, August, September	June, July, August, September	June, July, August, September	June, July, August, September
Sampling Equipment	Horiba multi-parameter probe	Hach multiparameter probe/HOBO temperature logger	YSI Probe	YSI Probe	YSI Probe	YSI Probe	YSI Probe	YSI Probe	YSI Probe
LSA	North Belt Doris OF Glenn OF Ogama OF Patch OF P.O. OF Windy OF South Belt Aimaokatalok NE Inflow Aimaokatalok River Aimaokatalok OF Stickleback OF Trout OF Koignuk River	North Belt Doris OF Glenn OF Ogama OF Patch OF P.O. OF Windy OF South Belt Aimaokatalok NE Inflow Aimaokatalok River Aimaokatalok OF Stickleback OF Trout OF Koignuk River	North Belt Koignuk River (downstream, upstream)	North Belt Koignuk River (upstream) South Belt Koignuk River	North Belt Doris OF	North Belt Doris OF	North Belt Doris OF	North Belt Doris OF	North Belt Doris OF
RSA	Little Roberts OF Roberts OF Boston Reference Lake OF	Boston Reference Lake OF Little Roberts OF Roberts OF Pelvic OF	Little Roberts OF Reference Lake A OF Reference Lake B OF Angimajuq River		Little Roberts OF Roberts OF Reference B OF Reference D OF	Little Roberts OF Roberts OF Reference B OF Reference D OF	Little Roberts OF Roberts OF Reference B OF Reference D OF	Little Roberts OF Roberts OF Reference B OF Reference D OF	Little Roberts OF Roberts OF Reference B OF Reference D OF
Site Replication	n = 1	n = 1	n = 1	n = 1	n = 1	n = 1	n = 1	n = 1	n = 1

Table 3.2-3. Bathymetric Surveys Conducted in the LSA and RSA, 1993 to 2010

	Year					
	1993/1994 **August**	**2000** **July**	**2003** **August/September**	**2006** **August**	**2006** **N/A1**	**2010** **August**
Sampling Equipment	Raytheon echosounding chart recorder to record depths and a topographical map for positioning or DGPS and Lowrance depth sounder	Trimble ProXRS differential GPS and Seamax echosounder	BioSonics (Model DT-X) hydroacoustic system	ODOM Hydrtrac Survey Echo Sounder with a 200-kHz transducer and low-resolution sidescan sonar. Trimble DGPS (Ag123)	BioSonics (Model DT-X) ecosounder with 200 kHz-transducer and Garmin GPSMap 76CSx GPS unit	Garmin GPS Map 526s depth sounder and Trimble XRS Pro GPS
LSA	<u>South Belt</u> Aimaokatalok	<u>North Belt</u> Ogama		<u>North Belt</u> Doris Patch Windy <u>South Belt</u> Aimaokatalok	<u>North Belt</u> Wolverine P.O.	<u>North Belt</u> Imniagut <u>South Belt</u> Stickleback Trout
RSA			Roberts			Little Roberts Reference B Reference D

[1] *Month not reported in the original report.*

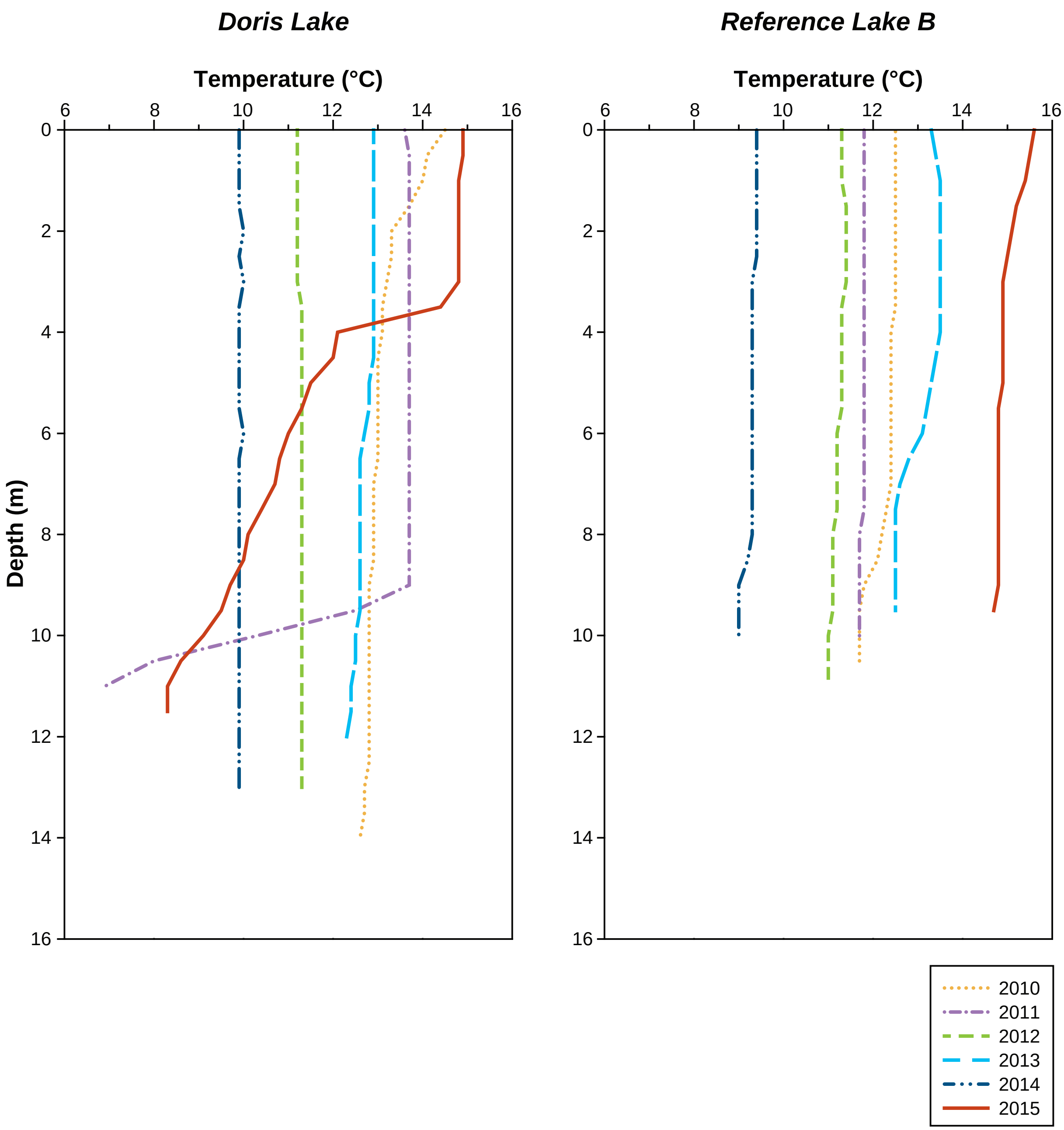
Table 3.2-4. Summary of Lake Secchi Depths in the LSA and RSA, 2009 to 2014

	Secchi Depth, Ds (m)			Euphotic Depth (m)†		
	Min	**Mean***	**Max**	**Min**	**Mean**	**Max**
LSA - North Belt (*n* = 41)	0.7	1.5	3.5	1.9	4.0	9.5
LSA - South Belt (*n* = 6)	1.4	2.2	2.7	3.8	6.0	7.3
RSA (*n* = 46)	0.9	3.5	9.0	2.4	9.4	24.4

Note: n is the number of Secchi disk observations available for the characterization of existing light penetration conditions.
**Only sites with Secchi depths less than the bottom depth were included in the calculation of mean Secchi depth.*
†Only sites with Secchi depths less than the bottom depth were included in the calculation of euphotic depth.

Figure 3.2-5

Temperature Profiles for Doris Lake and Reference Lake B, August 2010 to 2015



Stream water temperatures during the June freshet ranged from 0.1°C to 13.4°C, and increased to between 3.7°C and 21°C by July (Table 3.2-5). Mean temperatures in the LSA streams were similar between July and August and cooled substantially into September (Table 3.2-5) along with the falling air temperatures. These monthly patterns in discrete temperature measurements were corroborated by continuous in-situ temperature sensors deployed in selected streams. Continuous temperature sensors were deployed during the open-water seasons at the following sites:

- Doris Outflow (2003, 2006, and 2008);
- Glenn Outflow (2007);
- Koignuk River (North Belt LSA; 2007);
- Ogama Outflow (2006 and 2007);
- P.O. Outflow (2006 and 2007);
- Patch Outflow (2006 and 2007);
- Windy Outflow (2006 and 2007);
- Little Roberts Outflow (2003, 2006, and 2008);
- Roberts Outflow (2003, 2006, and 2008);
- Aimaokatalok NE Inflow (2006 and 2007);
- Aimaokatalok Outflow (2007);
- Aimaokatalok River (2006 and 2007);
- Boston Reference Outflow (2006 and 2007);
- Stickleback Outflow (2006 and 2007); and
- Trout Outflow (2006 and 2007)

Table 3.2-5. Summary of Stream and River Water Temperatures in the LSA and RSA, 1993 to 2015

	Stream Temperature (°C)			
	Min	**Mean**	**Max**	**n**
LSA - North Belt				
April/May	0.0	0.1	0.3	3
June	0.1	4.9	13.4	22
July	3.7	11.7	19.7	21
August	6.3	11.3	16.6	21
September	0.7	5.6	14.2	18
LSA - South Belt				
April	0.9	n/a	0.9	1
June	0.9	6.9	13.9	14
July	7.6	15.2	20.7	14
August	5.7	11.4	17.4	22
September	1.0	6.8	11.3	13
RSA				
June	0.1	3.3	7.1	27
July	5.8	13.3	21.0	26
August	5.9	11.2	15.6	27
September	0.5	3.8	6.7	27

Generally, stream temperatures had daily temperature variation between 1°C and 4°C, with greater diel variance in July and August. The timing of peak seasonal temperatures varied between July and August across years. Some periods showed stream temperatures varying by almost 10°C over 7- to 10-day intervals in July and August (Golder 2008).

Inter-annual variation was observed in stream temperatures, particularly in July. For example, overall mean stream temperatures in mid-July ranged from 9.4°C in 2014 to 8.8°C in 2012 (Rescan 2013; ERM 2015).

3.2.4.3 Bathymetry

A summary of the lake morphologies are presented in Table 3.2-6 and bathymetric maps of all lakes surveyed are presented in Appendix V5-3A.

Table 3.2-6. Summary of Lake Morphologies in LSA and RSA

Waterbody	Max Depth (m)	Average Depth (m)	Volume (m^3)	Surface Area (m^2)	Source
LSA -North Belt					
Doris	19.4	7.3	27,275,100	3,378,000	Golder 2006
Ogama	7.4	2.6	4,209,800	1,618,700	RL&L and Golder 2002
Patch	14.3	4.1	23,544,100	5,674,000	Golder 2006
Wolverine	4.0	2.3	2,068,100	996,000	Golder 2009
P.O.	5.0	2.1	1,780,700	831,000	Golder 2009
Imniagut	4.9	2.7	367,500	150,000	Rescan 2011a
Windy	21.2	9.9	59,137,500	5,288,000	Golder 2006
LSA - South Belt					
Aimaokatalok [1]	30.0	6.4	147,125,400	22,969,460	Rescan 1994, Golder 2006
Stickleback	6.1	2.5	2,322,700	995,000	Rescan 2011a
Trout	4.9	2.3	968,900	552,000	Rescan 2011a
RSA					
Roberts	37.5	13.5	51,641,500	3,830,830	RL&L and Golder 2003
Little Roberts	4.8	2.3	229,700	102,000	Rescan 2011a
Reference B	11.7	4.7	35,021,500	7,695,000	Rescan 2011a
Reference D	11.9	2.4	1,482,200	660,000	Rescan 2011a

[1]Morphometry information based on Rescan (1994) and Golder (2006) bathymetry surveys that cover the majority of the lake. Aimaokatalok Lake volume calculated from the two surveys with the bathymetry of the non-surveyed areas at the northern and southern arms predicted from the mean depth of the survey area.

Lakes in the North Belt LSA are small to medium sized, with maximum depths ranging from 4.0 m (Wolverine) to 21.2 m (Windy). Several lakes in the area are shallower than 10 m. Surface areas of the sampled lakes range from 150,000 m^2 (Imniagut) to 5,674,000 m^2 (Patch) and volumes range from 367,500 m^3 (Imniagut) to 59,137,500 m^3 (Windy).

The South Belt LSA is dominated by one large lake (Aimaokatalok Lake), which has surface area of over 2,550,000 m^2, a volume of over 137,000,000 m^3, and a maximum depth of 30 m (Rescan 1994). Stickleback and Trout lakes, two smaller lakes south of Aimaokatalok Lake, are both shallow (maximum depth = 4.9 m and 6.1 m, respectively) and have surface areas of 995,000 m^2 and 552,000 m^2, respectively.

Surveyed lakes in the RSA vary widely in size and depth, including the smallest of the sampled lakes (Little Roberts) to the largest (Reference B). Little Roberts is also among the shallowest of lakes (maximum depth = 4.8 m) and Roberts Lake is the deepest (maximum depth = 37.5 m).

3.3 VALUED COMPONENTS

3.3.1 Potential Valued Components and Scoping

Physical limnology and bathymetry were included in the scoping and refining process with all other potential VEC/VSECs (see Volume 2, Chapter 4). Based on TMAC-led public consultation, the NTKP report (Banci and Spicker 2016), and regulatory considerations, limnology and bathymetry were classified as a Subject of Note.

3.3.2 Valued Components Excluded from the Assessment

Limnology and bathymetry are considered a Subject of Note for the EIS. All information requested in the EIS Guidelines (NIRB 2012) relating to limnology and bathymetry are included in this EIS. Limnology and bathymetry are considered a Subject of Note and not further assessed in the EIS because the limited potential for effects on limnology and bathymetry are considered under other VECs. In terms of limnology, Phase 2 has limited potential for altering the physical structure and mixing processes in lakes. In freshwater Arctic systems, lake physical structure and mixing are driven by bathymetry, winds, and temperature (Wetzel 2001). Phase 2 will not be altering wind conditions, and the discharges to the freshwater environment are not expected to have temperatures substantially different from the receiving environment. Other than the heating required for avoiding freezing and maintaining processing efficiency, the temperature of freshwater discharges will be near ambient temperatures. Water will not be discharged from cooling systems, for example. Therefore, Project discharges will not be sources of warm water that can alter mixing in lakes. Maximum discharge volumes from the Boston water treatment plant to Aimaokatalok Lake will occur during freshet when extensive mixing and natural temperature variation occurs (SRK 2016).

Bathymetry is not expected to be altered by Phase 2 activities. The potential effects from erosion and sedimentation are assessed under the Water Quality VEC (Volume 5, Chapter 4). That assessment concluded that the residual effects from sedimentation will be mitigated by the proven management measures for erosion and sediment control. The Doris Project has demonstrated the effectiveness of these mitigation and management measures, and the Aquatic Effects Monitoring Program for the Doris Project has identified no significant sedimentation or alterations of bathymetry resulting from Project activities (ERM 2016). The potential effects on bathymetry from alterations in water quantity are assessed under the Hydrology VEC (Volume 5, Chapter 1).

3.4 REFERENCES

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