

MADRID-BOSTON PROJECT

FINAL ENVIRONMENTAL IMPACT STATEMENT

Table of Contents

Table of Contents	i
List of Figures.....	i
List of Tables.....	ii
List of Appendices.....	ii
Glossary and Abbreviations	v
3. Limnology and Bathymetry	3-1
3.1 Incorporation of Traditional Knowledge	3-1
3.1.1 Incorporation of Traditional Knowledge for Existing Environment and Baseline Information	3-1
3.2 Existing Environment and Baseline Information	3-1
3.2.1 Proximity to Designated Environmental Areas	3-5
3.2.2 Data Sources.....	3-5
3.2.3 Methods	3-6
3.2.3.1 Limnology.....	3-6
3.2.3.2 Stream and River Temperatures	3-13
3.2.3.3 Bathymetry	3-13
3.2.4 Characterization of Existing and Baseline Conditions	3-13
3.2.4.1 Limnology.....	3-14
3.2.4.2 Stream and River Temperature	3-20
3.2.4.3 Bathymetry	3-20
3.3 Valued Components	3-22
3.3.1 Potential Valued Components and Scoping.....	3-22
3.3.2 Valued Components Excluded from the Assessment	3-22
3.4 References.....	3-23

List of Figures

FIGURE	PAGE
Figure 3.2-1. Hope Bay Project Location and Existing and Proposed Madrid-Boston Project Infrastructure	3-2
Figure 3.2-2. Freshwater Local and Regional Study Areas.....	3-3

FINAL ENVIRONMENTAL IMPACT STATEMENT

Figure 3.2-3. Limnology and Bathymetry Sampling Locations in the North Belt LSA and RSA, 1995 to 2017	3-9
Figure 3.2-4. Limnology and Bathymetry Sampling Locations in the South Belt LSA and RSA, 1993 to 2017	3-11
Figure 3.2-5. August Temperature Profiles for Doris Lake and Reference Lake B, 2010 to 2017.....	3-18
Figure 3.2-6. August Temperature Profiles for Aimaokatalok Lake (Station 6), 2006 to 2017	3-19

List of Tables

TABLE	PAGE
Table 3.2-1. Summary of Physical Limnology Sampling in the LSA and RSA, 1993 to 2017	3-7
Table 3.2-2. Summary of Stream and River Temperature Sampling in the LSA and RSA, 1993 to 2016	3-15
Table 3.2-3. Bathymetric Surveys Conducted in the LSA and RSA, 1993 to 2010	3-17
Table 3.2-4. Summary of Lake Secchi Depths in the LSA and RSA, 2009 to 2017	3-17
Table 3.2-5. Summary of Stream and River Water Temperatures in the LSA and RSA, 1993 to 2016..	3-21
Table 3.2-6. Summary of Lake Morphologies in LSA and RSA.....	3-21

List of Appendices

Appendix V5-3A. Lake Bathymetry Surveys in the LSA and RSA
Appendix V5-3B. Boston Property N.W.T.: Environmental Data Report (1993)
Appendix V5-3C. Boston Property N.W.T.: Environmental Data Report (1994)
Appendix V5-3D. Doris Lake Project, Northwest Territories: 1995 Environment Study
Appendix V5-3E. Boston Property N.W.T.: Environmental Data Report 1995
Appendix V5-3F. Hope Bay Belt Project: Environmental Baseline Studies Report 1996
Appendix V5-3G. Hope Bay Belt Project: 1997 Environmental Data Report
Appendix V5-3H. Hope Bay Belt Project: 1998 Environmental Data Report
Appendix V5-3I. Hope Bay Belt Project: 2000 Supplemental Environmental Baseline Data Report
Appendix V5-3J. Aquatic Baseline Studies: Doris Hinge Project Data Compilation Report, 1995-2000
Appendix V5-3K. Doris North Project: Aquatic Studies 2003
Appendix V5-3L. Doris North Project: Aquatic Studies 2004
Appendix V5-3M. Doris North Project: Aquatic Studies 2005

- Appendix V5-3N. Bathymetric Surveys: Hope Bay Project, Hope Bay, Nunavut
- Appendix V5-3O. Doris North Project: Aquatic Studies 2006
- Appendix V5-3P. Boston and Madrid Project Areas: 2006 - 2007 Aquatic Studies
- Appendix V5-3Q. Doris North Project: Aquatic Studies 2007
- Appendix V5-3R. Hope Bay Project: Aquatic Studies 2008
- Appendix V5-3S. 2009 Freshwater Baseline Report, Hope Bay Belt Project
- Appendix V5-3T. Hope Bay Belt Project: 2010 Freshwater Baseline Report
- Appendix V5-3U. Hope Bay Project: 2017 Madrid-Boston Freshwater Baseline Report

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
the Project	Madrid-Boston Project
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 Subjects of Note in this Environmental Impact Statement (EIS) as they were not identified as potential Valued Ecosystem Components (VECs) in the EIS Guidelines (NIRB 2012) and any Madrid-Boston Project (the Project) activities that could affect these subjects will be addressed as linkages to other VECs. For example, the potential for Project 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 the Madrid-Boston Project and its brief overlap with the Doris Project (approximately 3 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 waterbodies in the Project area 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

The Madrid-Boston Project 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 and varies in width between 7 km and 20 km. The Madrid-Boston Project 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 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, the Project 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
Madrid-Boston Project Infrastructure

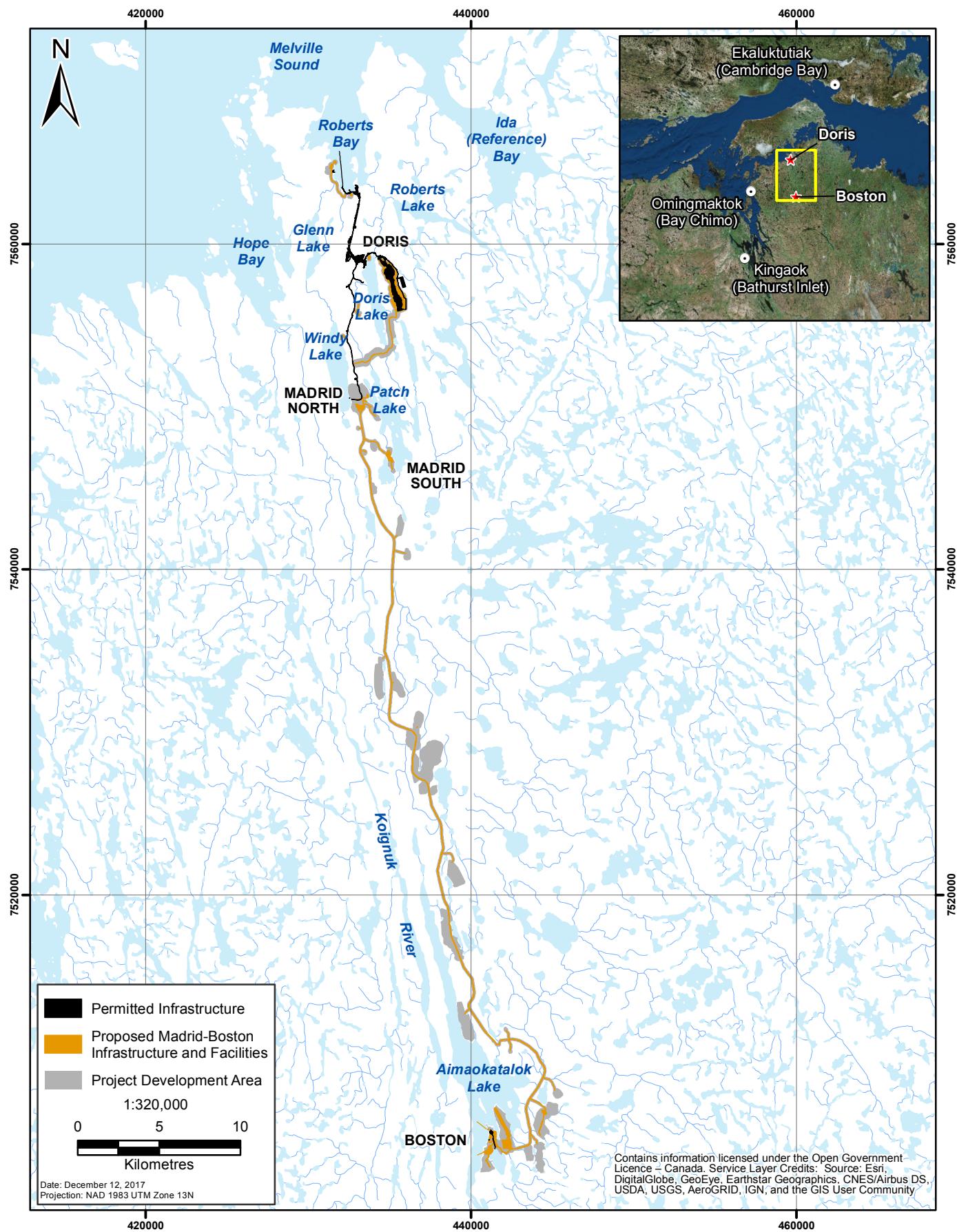
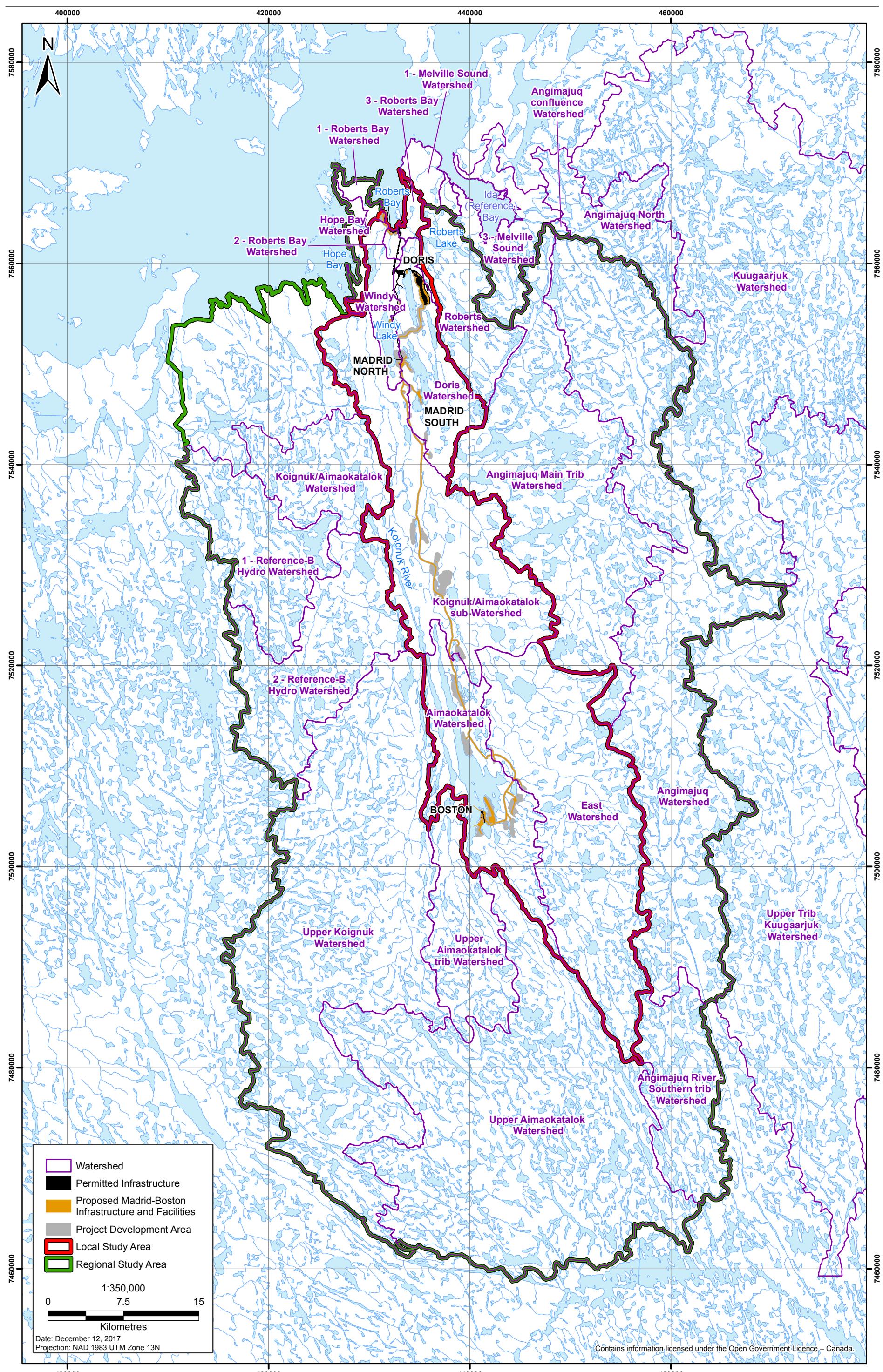


Figure 3.2-2
Freshwater Local and Regional Study Areas



Winter in the Project area is characterized by extreme cold, with mean monthly temperatures ranging from -33.4°C to -3.1°C , and the coldest temperatures occurring in January and February. There is a short snow-free season (mid-June through September) with temperatures ranging from -2.5°C to 13.9°C , and the warmest temperatures typically occurring 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.; Volume 4, Chapter 8).

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 the Project area is dominated by snowmelt (Volume 5, Chapter 1). The lakes are typically frozen from October to June with ice thickness ranging between 1.5 to 2.0 m (Rescan 2010, 2011b). 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 the Project area and surrounding region.

3.2.1 Proximity to Designated Environmental Areas

There are currently no existing or proposed parks or conservation areas near Project activities. The nearest conservation area is the Queen Maud Gulf Migratory Bird Sanctuary approximately 50 km east of the Project 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 Project 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 Project's freshwater RSA boundary. Past activities near the 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 1993 and 2017, and the Aquatic Effects Monitoring Program (AEMP) for the Doris Gold Mine Project conducted from 2010 to 2017. 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);
- Doris Lake Project, Northwest Territories: 1995 Environment Study (Klohn-Crippen Consultants Ltd. 1995; Appendix V5-3D);
- Boston Property N.W.T.: Environmental Data Report 1995 (Rescan 1995; Appendix V5-3E);

- Hope Bay Belt Project: Environmental Baseline Studies Report 1996 (Rescan 1997; Appendix V5-3F);
- Hope Bay Belt Project: 1997 Environmental Data Report (Rescan 1998; Appendix V5-3G);
- Hope Bay Belt Project: 1998 Environmental Data Report (Rescan 1999; Appendix V5-3H);
- Hope Bay Belt Project: 2000 Supplemental Environmental Baseline Data Report (Rescan 2001; Appendix V5-3I);
- Aquatic Baseline Studies: Doris Hinge Project Data Compilation Report, 1995-2000 (RL&L / Golder 2002; Appendix V5-3J);
- Doris North Project: Aquatic Studies 2003 (RL&L / Golder 2003; Appendix V5-3K);
- Doris North Project: Aquatic Studies 2004 (Golder 2005; Appendix V5-3L);
- Doris North Project: Aquatic Studies 2005 (Golder 2006b; Appendix V5-3M);
- Bathymetric Surveys: Hope Bay Project, Hope Bay, Nunavut (Golder 2006a; Appendix V5-3N);
- Doris North Project: Aquatic Studies 2006 (Golder 2007; Appendix V5-3O);
- Boston and Madrid Project Areas: 2006 - 2007 Aquatic Studies (Golder 2008a; Appendix V5-3P);
- Doris North Project: Aquatic Studies 2007 (Golder 2008b; Appendix V5-3Q);
- Hope Bay Project: Aquatic Studies 2008 (Golder 2009; Appendix V5-3R);
- 2009 Freshwater Baseline Report, Hope Bay Belt Project (Rescan 2010; Appendix V5-3S);
- Hope Bay Belt Project: 2010 Freshwater Baseline Report (Rescan 2011b; Appendix V5-3T);
- Doris North Gold Mine Project: 2010 Aquatic Effects Monitoring Program Report (Rescan 2011a);
- Doris North Gold Mine Project: 2011 Aquatic Effects Monitoring Program Report (Rescan 2012);
- Doris North Gold Mine Project: 2012 Aquatic Effects Monitoring Program Report (Rescan 2013);
- Doris North Project: 2013 Aquatic Effects Monitoring Program Report (ERM Rescan 2014);
- Doris North Project: 2014 Aquatic Effects Monitoring Program (ERM 2015);
- Doris North Project: 2015 Aquatic Effects Monitoring Program Report (ERM 2016);
- Doris Project: 2016 Aquatic Effects Monitoring Program Report (ERM 2017a);
- Doris Project: 2017 Aquatic Effects Monitoring Program Report (in preparation); and
- Hope Bay Project: 2017 Madrid-Boston Freshwater Baseline Report (ERM 2017b; Appendix V5-3U).

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 11 lakes in the LSA (8 in the North Belt and 3 in the South Belt) and 8 lakes throughout the RSA from 1993 to 2017 (Table 3.2-1 and Figures 3.2-3 and 3.2-4). 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 is presented in Table 3.2-1.

Table 3.2-1. Summary of Physical Limnology Sampling in the LSA and RSA, 1993 to 2017

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	<u>South Belt</u> Aimaokatalok Stickleback	<u>South Belt</u> Aimaokatalok Stickleback Trout	<u>North Belt</u> Doris Patch <u>South Belt</u> Aimaokatalok Stickleback Trout	<u>North Belt</u> Doris Little Roberts Windy	<u>North Belt</u> Doris Little Roberts Ogama Patch	<u>North Belt</u> Doris Little Roberts Wolverine	<u>North Belt</u> Doris Little Roberts Stickleback	<u>North Belt</u> Doris Little Roberts Trout	<u>North Belt</u> Doris Little Roberts	<u>North Belt</u> Doris Little Roberts
RSA					Pelvic Boston Reference Lake	Pelvic Boston Reference Lake	Pelvic	Roberts Reference Lake A (Golder)	Roberts	Roberts
# of Sites / Lake	n = 4 (Aimaokatalok); n = 1 (all other lakes)	n = 4 (Aimaokatalok); n = 1 (all other lakes)	n = 5 (Aimaokatalok); n = 2 (Doris); n = 1 (all other lakes)	n = 5 (Aimaokatalok); n = 1 (all other lakes)	n = 5 (Aimaokatalok); n = 1 (all other lakes)	n = 4 (Aimaokatalok); n = 1 (all other lakes)	n = 1	n = 2 (Roberts); n = 1 (all other lakes)	n = 1	n = 2 (Roberts); n = 1 (all other lakes)
Year	2006	2007	2008	2009	2010	2011	2012	2013 to 2016	2017	
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, August
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	<u>North Belt</u> Doris Little Roberts Ogama P.O. Patch Windy Wolverine <u>South Belt</u> Aimaokatalok Stickleback Trout	<u>North Belt</u> Doris Glenn Little Roberts Ogama P.O. Patch Windy Wolverine <u>South Belt</u> Aimaokatalok Stickleback Trout	<u>North Belt</u> Doris Glenn Little Roberts Imniagut Little Roberts Nakhaktok Ogama Patch P.O. Trout	<u>North Belt</u> Doris Little Roberts Windy	<u>North Belt</u> Doris Little Roberts Wolverine	<u>North Belt</u> Doris Little Roberts Stickleback	<u>North Belt</u> Doris Little Roberts Trout	<u>North Belt</u> Doris Little Roberts Trout	<u>North Belt</u> Doris Little Roberts Trout	<u>North Belt</u> Doris Windy <u>South Belt</u> Aimaokatalok Stickleback
RSA	Boston Reference Lake Roberts Pelvic	Boston Reference Lake Roberts Pelvic	Boston Reference Lake Roberts Pelvic	Naiqunnguit Reference A Reference B	Reference B Reference D	Reference B Reference D	Reference B Reference D	Reference B Reference D	Reference B	Reference B
# of Sites / Lake	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 = 2 (Doris & Patch); n = 1 (all other lakes)	n = 6 (Aimaokatalok); n = 2 (Doris); n = 1 (all other lakes)	n = 2 (Doris); n = 1 (all other lakes)	n = 2 (Doris); n = 1 (all other lakes)	n = 2 (Doris); n = 1 (all other lakes)	n = 1	n = 6 (Aimaokatalok); n = 1 (all other lakes)

Figure 3.2-3

Limnology and Bathymetry Sampling Locations in the North Belt LSA and RSA, 1995 to 2017

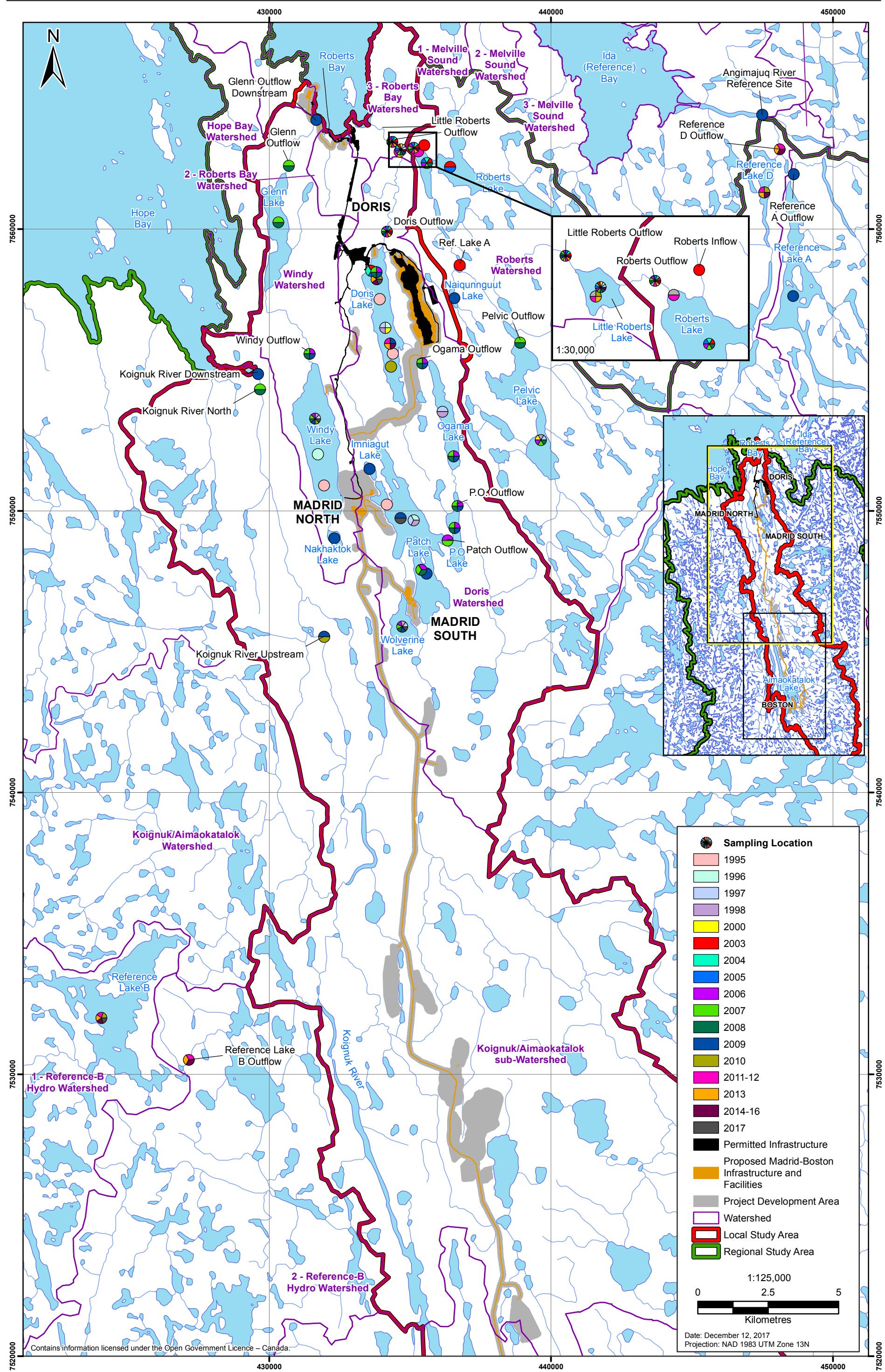
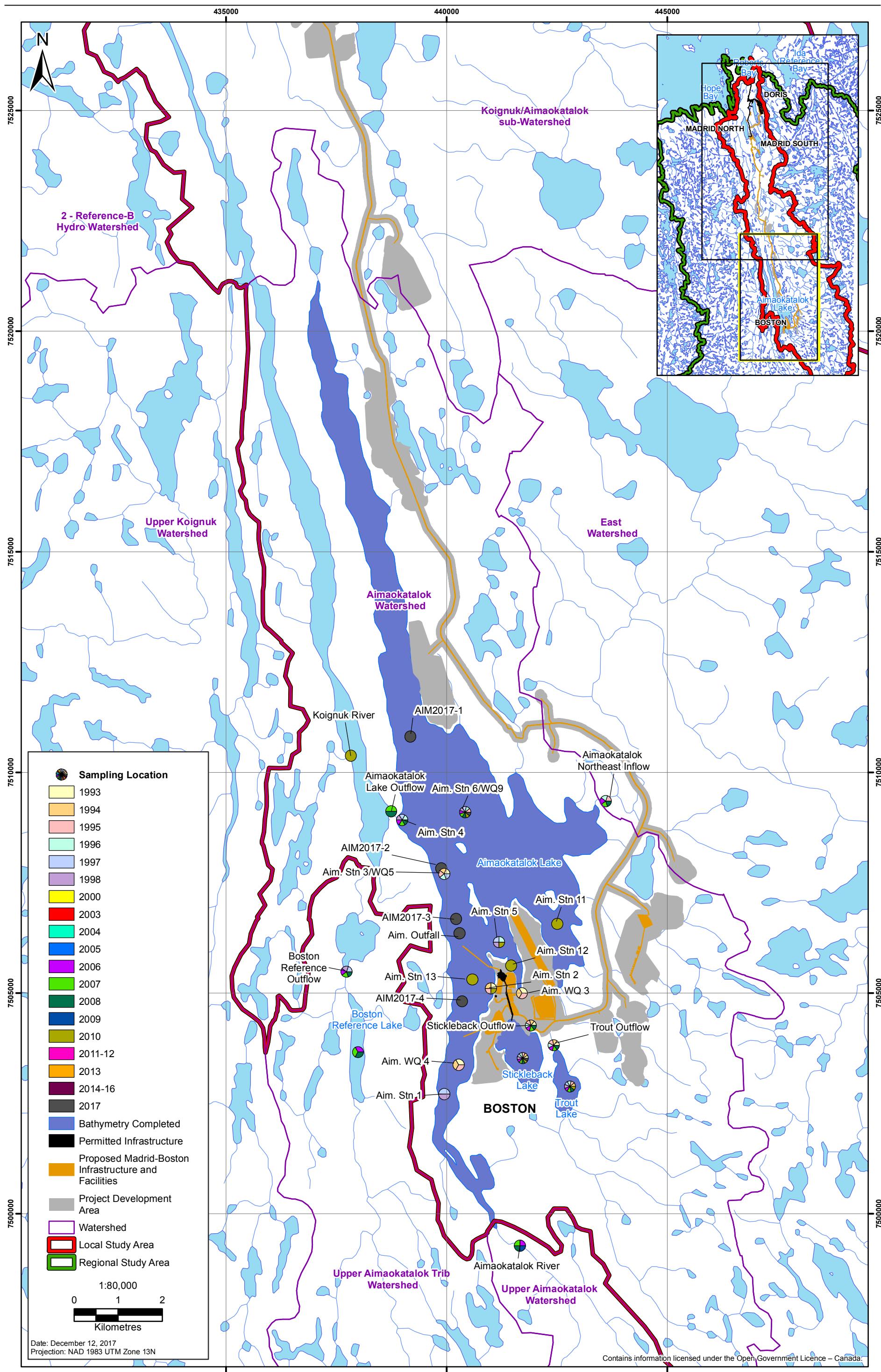


Figure 3.2-4

Limnology and Bathymetry Sampling Locations in the South Belt LSA and RSA, 1993 to 2017



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 calibrated YSI meter. Temperatures were typically recorded onto datasheets at 0.5 m intervals at shallower lake stations (< 10 m) and 1 m intervals at deeper lake stations (> 10 m). The profiles normally ended 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:

$$k' = 1.7/D_s$$

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 13 streams in the LSA (7 in the North Belt and 6 in the South Belt) and 7 streams in the RSA from 1993 to 2016 (Table 3.2-2 and Figures 3.2-3 and 3.2-4). River temperatures were collected under-ice from the Koignuk River in 2009 and 2010 and stream and river temperatures were collected during the open-water season. Stream and river temperatures were measured *in situ* using a YSI probe. A summary of the sampling programs is presented in Table 3.2-2.

3.2.3.3 Bathymetry

Bathymetric surveys have been conducted in Madrid-Boston 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. 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 (7 in the North Belt and 3 in the South Belt) and 3 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 (1994, 2011b), RL&L and Golder (2002, 2003), and Golder (2006a, 2009).

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 mainly on data collected from 2009 to 2017.

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 2.0 m in early spring. 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 2011b). Ice-off usually commenced in mid-June with the presence of liquid water along the perimeter of lakes, with fully open waters in early July.

Overall, the winter water column structure was typical of ice-covered Arctic lakes. Water temperatures were coldest just below the ice, ranging from -0.3°C to 2.0°C, warming slightly with depth in deeper lakes (~1 to 3°C), and reaching a maximum temperature of 3.3°C near the water-sediment interface.

During the open-water season, most lakes in the Madrid-Boston Project area were shallow enough to become fully mixed, especially during years with high winds. In deeper lakes such as Aimaokatalok Lake (Station 6: 28.5 m), Doris Lake (20.0 m), and Reference Lake B (11.7 m), the water column was sensitive to annual climatic fluctuations and had some 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 2016, and well mixed between 2012 and 2014 and in 2017 (Figure 3.2-5). As well, lake temperatures in August 2012 and 2014 were colder than other years (Figure 3.2-5). In Aimaokatalok Lake, lake profiles collected in August showed that the entire lake was well-mixed in 2007 and 2008, and was weakly stratified over the deepest section of the lake in 2017 (Figure 3.2-6). In both 2006 and 2010, most of Aimaokatalok Lake was well mixed in August, except over the deepest sections of the lake where a thermocline was present at approximately 20 m depth (Figure 3.2-6). Typically, water temperatures in the region were warmest in August (range: 8 to 16°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). Water clarity was relatively low overall, with a mean Secchi depth of 1.5 m throughout the LSA lakes; however, most lakes were shallow enough that sunlight usually penetrated to the lakebed. 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), Patch (2.3 m), Glenn (1.0 m), and Ogama lakes (1.2 m). Mean Secchi depths were greater than 2.5 m in Aimaokatalok (2.8 m), Windy (3.6 m), and Wolverine (2.6 m) lakes (Table 3.2-4). Mean Secchi depths were greater in the RSA lakes (4.8 m) compared to the LSA lakes (Table 3.2-4), although this was mainly due to the clearer waters found in Reference Lake B (mean = 6.5 m, n = 25). The adjusted mean for the RSA lakes excluding Reference Lake B (mean = 2.3 m, n = 18) was similar to that observed in the North (1.5 m) and South Belt LSA lakes (2.6 m; Table 3.2-4).

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, Chapters 4 and 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 relatively 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.

Table 3.2-2. Summary of Stream and River Temperature Sampling in the LSA and RSA, 1993 to 2016

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

	1993/1994 August	2000 July	2003 August/September	2006 August	2006 N/A ¹	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> P.O. Wolverine	<u>North Belt</u> Imniagut Little Roberts <u>South Belt</u> Stickleback Trout
RSA			Roberts			Reference B Reference D

¹Month not reported in the original report.

Table 3.2-4. Summary of Lake Secchi Depths in the LSA and RSA, 2009 to 2017

	Secchi Depth, D _s (m)			Euphotic Depth (m) [†]		
	Min	Mean [*]	Max	Min	Mean	Max
LSA - North Belt (n = 76)	0.7	1.5	4.4	1.9	4.1	11.8
LSA - South Belt (n = 8)	1.4	2.6	3.8	3.8	7.1	10.2
RSA (n = 43)	1.1	4.8	9.0	3.0	12.9	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

August Temperature Profiles for Doris Lake
and Reference Lake B, August 2010 to 2017

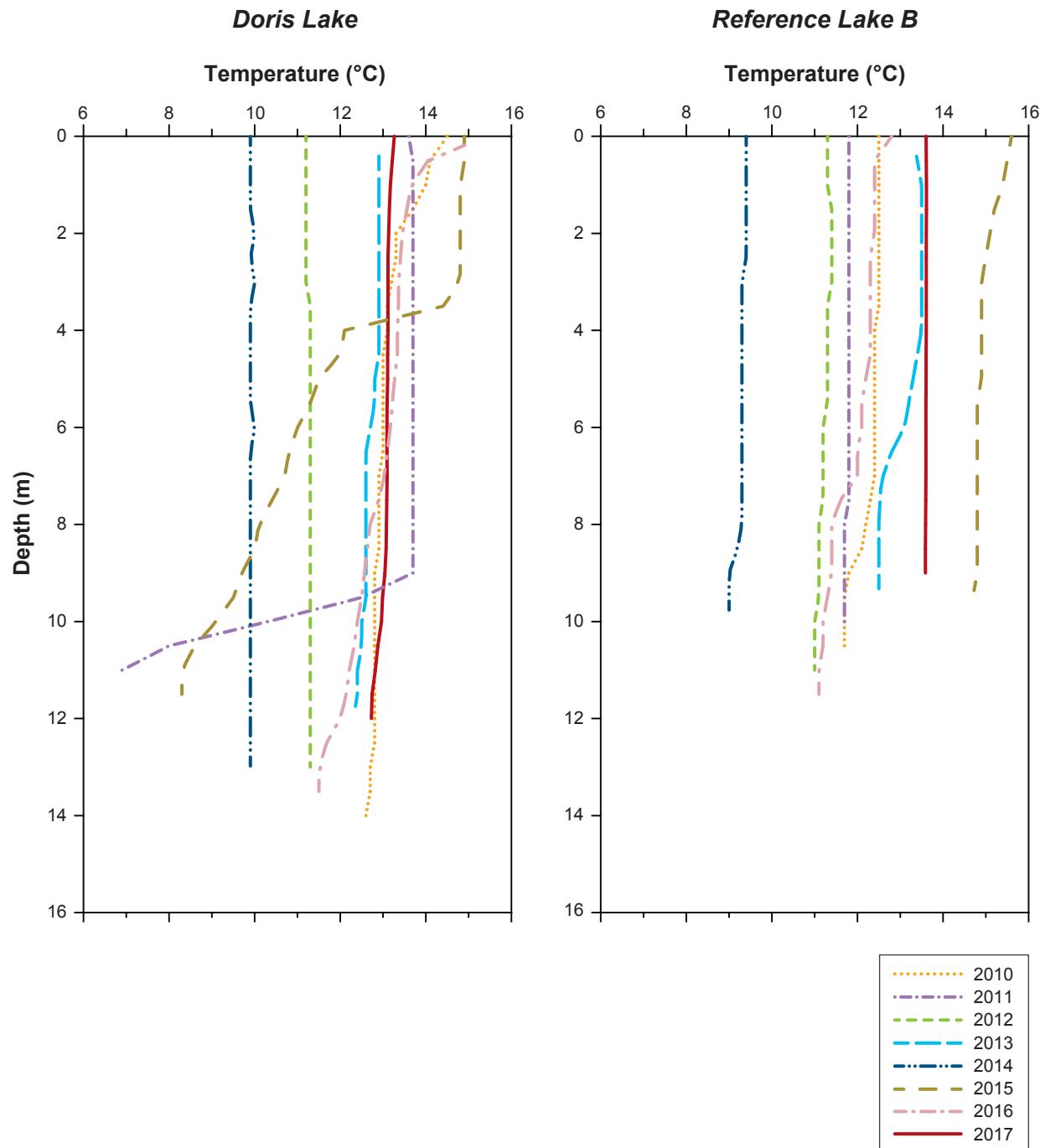
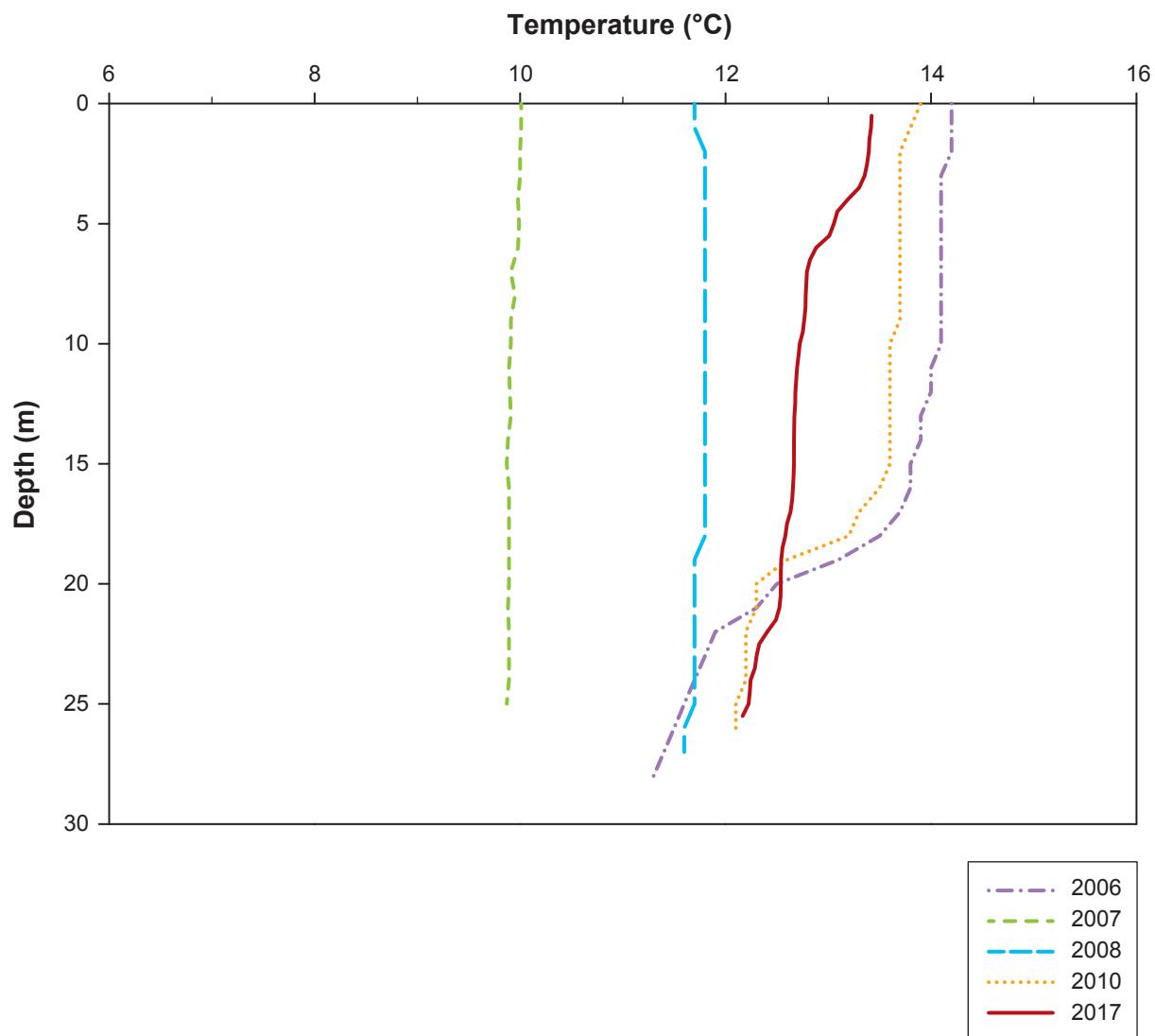


Figure 3.2-6

August Temperature Profiles for
Aimaokatalok Lake (Station 6), 2006 to 2017



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 Madrid-Boston area indicated that all monitored streams freeze solid in the winter, except the Koignuk River, which retained under-ice water in isolated pools separated by frozen sections of the river (Rescan 2011b).

Stream water temperatures during the June freshet ranged from 0.1°C to 13.9°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).

Generally, stream temperatures varied daily by 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 2008a).

Inter-annual variation was observed in stream temperatures, particularly in July. For example, overall mean stream temperatures in July ranged from 6.5°C in 2004 to 18.8°C in 2012.

3.2.4.3 *Bathymetry*

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

Table 3.2-5. Summary of Stream and River Water Temperatures in the LSA and RSA, 1993 to 2016

	Stream Temperature (°C)			
	Min	Mean	Max	n
LSA-North Belt				
April/May	0.0	0.1	0.3	3
June	0.1	4.6	13.4	30
July	3.7	11.8	19.7	30
August	6.3	11.4	16.6	31
September	0.5	4.9	14.2	28
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	3.4	6.5	22
July	5.8	13.7	21.0	22
August	5.9	11.7	15.7	22
September	0.6	3.8	6.7	22

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	8.1	27,275,100	3,378,200	Golder 2006
Little Roberts	4.8	2.2	229,700	102,500	Rescan 2011c
Ogama	5.0	2.5	3,900,300	1,575,500	RL&L and Golder 2002
Patch	14.3	4.1	23,544,600	5,673,800	Golder 2006
Wolverine	4.0	2.1	2,068,000	1,004,400	Golder 2009
P.O.	5.0	2.1	1,780,800	835,000	Golder 2009
Imniagut	4.9	2.5	367,500	147,500	Rescan 2011c
Windy	21.2	11.2	59,137,700	5,287,700	Golder 2006
LSA-South Belt					
Aimaokatalok ¹	30.0	6.0	140,286,500	23,366,400	Rescan 1994, Golder 2006
Stickleback	4.1	2.3	2,322,800	1,000,600	Rescan 2011c
Trout	4.9	1.8	969,000	552,500	Rescan 2011c
RSA					
Roberts	37.5	13.5	51,641,500	3,830,830	RL&L and Golder 2003
Reference B	11.7	4.6	35,021,500	7,694,700	Rescan 2011c
Reference D	11.9	2.4	1,482,200	660,000	Rescan 2011c

¹Morphometry information based on Rescan (1994) and Golder (2006) bathymetric 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 North Belt LSA lakes range from 102,500 m² (Little Roberts) to 5,673,800 m² (Patch) and volumes range from 229,700 m³ (Little Roberts) to 59,137,700 m³ (Windy; Table 3.2-6).

The South Belt LSA is dominated by one large lake (Aimaokatalok Lake), which has a surface area of approximately 23,366,400 m², a volume over 140,000,000 m³, and a maximum depth of 30 m. Stickleback and Trout lakes, two smaller lakes south of Aimaokatalok Lake, are both shallow (maximum depth = 4.1 m and 4.9 m) and have surface areas of 1,000,600 m² and 552,500 m² (Table 3.2-6).

The surveyed RSA lakes vary widely in size and depth, with Reference Lake D having the smallest surface area (660,000 m²) and shallowest depth (average depth: 2.4 m), Reference Lake B having the greatest surface area (7,694,700 m²), and Roberts Lake being the deepest (maximum depth: 37.5 m; Table 3.2-6).

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 Subjects of Note.

3.3.2 Valued Components Excluded from the Assessment

Limnology and bathymetry are considered Subjects 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 Subjects of Note and not further assessed in the EIS because the limited potential for effects is considered under other VECs. In terms of limnology, the Project 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). The Project will not alter 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 (Package P5-4).

Bathymetry is not expected to be altered by Project 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 2017a). The potential effects on bathymetry from alterations in water quantity are assessed under the Hydrology VEC (Volume 5, Chapter 1).

3.4 REFERENCES

Banci, V. and R. Spicker, (Compilers, Editors & GIS). 2016. *Inuit Traditional Knowledge for TMAC Resources Inc. Proposed Hope Bay Project, Naonaiyaotit Traditional Knowledge Project (NTKP)*. Prepared for TMAC Resources Inc. Kitikmeot Inuit Association: Kugluktuk, NU.

ERM. 2015. *Doris North Project: 2014 Aquatic Effects Monitoring Program*. Prepared for TMAC Resources Inc. by ERM Consultants Canada Ltd. : Yellowknife, NT.

ERM. 2016. *Doris North Project: 2015 Aquatic Effects Monitoring Program Report*. Prepared for TMAC Resources Inc. by ERM Consultants Canada Ltd.: Yellowknife, NT.

ERM. 2017a. *Doris Project: 2016 Aquatic Effects Monitoring Program Report*. Prepared for TMAC Resources Inc. by ERM Consultants Canada Ltd.: Yellowknife, NT.

ERM. 2017b. *Hope Bay Project: 2017 Madrid-Boston Freshwater Baseline Report*. Prepared for TMAC Resources Inc. by ERM Consultants Canada Ltd.: Vancouver, BC.

ERM Rescan. 2014. *Doris North Project: 2013 Aquatic Effects Monitoring Program Report*. Prepared for TMAC Resources Inc. by ERM Rescan: Yellowknife, NT.

Golder. 2005. *Doris North Project Aquatic Studies 2004*. Prepared for Miramar Hope Bay Ltd. by Golder Associates Ltd. Report No. 04-1373-009.

Golder. 2006a. *Bathymetric Surveys: Hope Bay Project, Hope Bay, Nunavut*. Prepared for SRK Consulting Canada Inc. by Golder Associates Ltd.: Burnaby, BC.

Golder. 2006b. *Doris North Project Aquatic Studies 2005*. Prepared for Miramar Hope Bay Ltd. by Golder Associates Ltd. Report No. 05-1373-014-F.

Golder. 2007. *Doris North Project Aquatic Studies 2006*. Prepared for Miramar Hope Bay Ltd. by Golder Associates Ltd. Report No. 06-1373-026.

Golder. 2008a. *Boston and Madrid Project Areas: 2006-2007 Aquatic Studies*. Prepared for Hope Bay Mining Ltd. by Golder Associates Ltd.: Edmonton, AB.

Golder. 2008b. *Doris North Project Aquatic Studies 2007*. Prepared for Miramar Hope Bay Ltd. by Golder Associates Ltd. Report No. 07-1373-0018D.

Golder. 2009. *Hope Bay Project: Aquatic Studies 2008*. Prepared for Hope Bay Mining Ltd. by Golder Associates Ltd.: Edmonton, AB.

Golder. 2009. *Hope Bay Project: Aquatic Studies 2008*. Prepared for Hope Bay Mining Ltd. by Golder Associates Ltd.: Edmonton, AB.

Klohn-Crippen Consultants Ltd. 1995. *Doris Lake Project, Northwest Territories: 1995 Environmental Study*. Prepared for BHP Minerals Canada Ltd. by Klohn-Crippen Consultants Ltd.

NIRB. 2012. *Guidelines for the Preparation of an Environmental Impact Statement for Hope Bay Mining Ltd.'s Phase 2 Hope Bay Belt Project* (NIRB File No. 12MN001). Nunavut Impact Review Board: Cambridge Bay, NU.

Nunuvat Planning Commision. 2014. *Draft Nunavut Land Use Plan*.

Parsons, T. R., Y. Maita, and C. M. Lalli. 1984. *A Manual of Chemical and Biological Methods for Seawater Analysis*. Oxford: Pergamon Press.

Rescan. 1993. *Boston Property N.W.T.: Environmental Data Report*. Prepared for BHP Minerals Canada Ltd. by Rescan Environmental Services Ltd.: Vancouver, BC.

Rescan. 1994. *Boston Property N.W.T.: Environmental Data Report*. Prepared for BHP Minerals Canada Ltd. by Rescan Environmental Services Ltd.: Vancouver, BC.

Rescan. 1995. *Boston Property N.W.T.: Environmental Data Report 1995*. Prepared for BHP World Minerals by Rescan Environmental Services Ltd.: Vancouver, BC.

Rescan. 1997. *Environmental Baseline Studies Report 1996*. Prepared for BHP World Minerals by Rescan Environmental Services Ltd.

Rescan. 1998. *Hope Bay Belt Project: 1997 Environmental Data Report*. Prepared for BHP World Minerals by Rescan Environmental Services Ltd.: Vancouver, BC.

Rescan. 1999. *Hope Bay Belt Project: 1998 Environmental Data Report*. Prepared for BHP Diamonds Inc. by Rescan Environmental Services Ltd.: Vancouver, BC.

Rescan. 2001. *2000 Supplemental Environmental Baseline Data Report, Hope Bay Belt Project*. Prepared for Hope Bay Joint Venture by Rescan Environmental Services Ltd.: Yellowknife, NT.

Rescan. 2010. *2009 Freshwater Baseline Report, Hope Bay Belt Project*. Prepared for Hope Bay Mining Limited by Rescan Environmental Services Ltd.: Vancouver, BC.

Rescan. 2011a. *Doris North Gold Mine Project: 2010 Aquatic Effects Monitoring Program Report*. Prepared for Hope Bay Mining Limited by Rescan Environmental Services Ltd.: Vancouver, BC.

Rescan. 2011b. *Hope Bay Belt Project: 2010 Freshwater Baseline Report*. Prepared for Hope Bay Mining Limited by Rescan Environmental Services Ltd.: Vancouver, BC.

Rescan. 2012. *Doris North Gold Mine Project: 2011 Aquatic Effects Monitoring Program Report*. Prepared for Hope Bay Mining Limited by Rescan Environmental Services Ltd.: Vancouver, BC.

Rescan. 2013. *Doris North Gold Mine Project: 2012 Aquatic Effects Monitoring Program Report*. Prepared for Hope Bay Mining Limited by Rescan Environmental Services Ltd.: Vancouver, BC.

RL&L / Golder. 2002. *Aquatic Baseline Studies: Doris Hinge Project Data Compilation Report 1995-2000*. Prepared for Miramar Hope Bay Ltd. by RL&L Environmental Services Ltd. and Golder Associates Ltd.: Edmonton, AB.

RL&L / Golder. 2003. *Doris North Project: Aquatic Studies 2003*. Prepared for Miramar Hope Bay Ltd. by RL&L Environmental Services Ltd./Golder Associates Ltd. Report No. 03-1370-007: Edmonton, AB.

Wetzel, R. G. 2001. *Limnology*. San Deigo, California: Academic Press.