MADRID-BOSTON PROJECT
FINAL ENVIRONMENTAL IMPACT STATEMENT

Table of Contents

List of Figures

List of Tables

List of Plates

List of Appendices

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.

AANDC	Aboriginal Affairs and Northern Development Canada, now INAC
Ah	A soil horizon enriched with organic matter.
CCME	Canadian Council of Ministers of the Environment. CCME is comprised of the environment ministers from the federal, provincial, and territorial governments. These 14 ministers normally meet at least once a year to discuss national environmental priorities and determine work to be carried out under the auspices of CCME. The CCME seeks to achieve positive environmental results, focusing on issues that are national in scope and that require collective attention by a number of governments.
Coarse fragments	Mineral rock fragments found in the soil: gravel (2-64 mm), cobbles (65-250 mm) and boulders (> 250 mm).
Cryosol	Mineral soils that have permafrost within 1 m of the surface or within 2 m, but show marked evidence of cryoturbation within the active layer, as indicated by disrupted, mixed or broken horizons, or displaced material.
Cryoturbation	Refers to the mixing of materials from various horizons of the soil due to freezing and thawing (also known as frost churning).
EA	Environmental Assessment
EIS	Environmental Impact Statement
Esker	A long winding ridge of stratified sand and gravel formed by glacial meltwater.
Fluvial	Refers to sediments deposited by streams or flowing water; it does not refer to deposition by waves or mass wasting processes such as mudflows.
Glaciofluvial	Deposits and landforms created by glacial rivers and streams.
Glaciolacustrine	Parent materials deposited in lakes associated with glacial melting. Most lacustrine parent materials in Canada were deposited in lakes that existed during the glacial periods and are called glaciolacustrine sediments. These sediments are typically well-sorted sands, silts, and clays. Well-sorted means that one particle size (e.g., clay) is dominant in the texture.
Gleyed soil / horizon	A soil having one or more neutral gray horizons as a result of water logging and lack of oxygen. The term "gleyed" also designates horizons having yellow and gray mottles as a result of intermittent water logging.
Gleysol	Refers to soils formed under chronic reducing conditions inherent in poorly drained mineral soils and wet conditions, with a high water table

	and long periods of water saturation.
Humus	A mixture of organic debris in the soil; it is formed from plant and animal litter accumulated at the soil surface and roots. Dead organic material in the soil that undergoes continuous breakdown and change.
KIA	Kitikmeot Inuit Association
Lacustrine	Related to lakes; in soils, refers to deposits associated with lake level fluctuations (e.g., benches or terraces that mark former shorelines or lakebed materials exposed by an uplifting of the land).
LSA	Local Study Area
masl	meters above sea level
Moraine (morainal deposit)	An accumulation of unconsolidated mineral debris (soil and rock), carried and deposited by glaciers.
NIRB	Nunavut Impact Review Board
NTKP	Naonaiyaotit Traditional Knowledge Project
Organic Deposit	Organic deposits develop as a result of the accumulation of organic matter (peat) in wet lowlands and in areas of intense seepage. Poorly or moderately decomposed peat layers can reach a depth of several meters. Climate, local geology and the rate of water movement through these areas affect their depth, acidity and fertility.
Parent Material	The natural material (mineral or organic) from which soil is formed.
Peat	Peat is an accumulation of partially decayed organic matter formed under conditions of excess moisture from precipitation or slowly moving groundwater. Peat deposits form in wetlands dominated by Sphagnum and Carex species and are distributed primarily in the temperate zone of the northern hemisphere.
Pedogenic	Processes that lead to the formation of soil (soil evolution).
Periglacial	Landform and soil processes that result from seasonal thawing of snow in areas underlain by permafrost and its subsequent re-freezing in form of ice wedges and other structures.
Permafrost	Soil that stays at or below the freezing point of water (0°C) continuously for two or more years. Overlying permafrost is a thin active layer of soil (typically 0.6 to 4 m thick) that seasonally thaws during the summer.
pH	The pH is a measure of the hydrogen ion (H+) content of the soil. Term commonly used to describe soil reaction.
Reclamation	A process of converting disturbed land into useful landscapes that meet a variety of goals (typically, creating productive ecosystems). It includes material placement and stabilization, capping with soil/overburden, re-grading, placing cover soils, and revegetation.

Regosol	Soils that have insufficient horizon development to meet the requirements of the other soil orders.
RSA	Regional Study Area
Seepage	The movement of a liquid (e.g., water) through a porous medium (e.g., soil) beneath the ground surface. It typically occurs on slopes or if a water table there is perched above a non-permeable layer.
SMU	Soil Mapping Unit (a group of soils that are expected to behave similarly).
Soil horizon	A layer of mineral or organic soil material approximately parallel to the land surface that has characteristics altered by processes of soil formation. It differs from adjacent horizons in properties such as color, structure, texture, and consistence and in chemical, biological, or mineralogical composition.
Soil reaction	An indicator of soil acidity or alkalinity measured on the pH scale; it affects the availability of nutrients and the reactivity of various substances in the soil.
Soil salvage	Conservation of valuable soil by stripping it off the surface when the site is first disturbed (e.g., before excavation of overburden). Salvaged soils are either stockpiled for future use or they are immediately used for covering reclaimed surfaces in a different location.
Texture (of mineral soil)	The solid material of mineral soil is composed of different size fractions of particles: gravel (> 2 mm in diameter), sand (2 mm to 53x10-6 m), silt (53 to 2x10-6 m), and clay (< 2x10-6 m). The soil texture is the particular mix of particle sizes found in any soil. In Canadian soils texture is almost entirely determined by the geomorphic processes responsible for depositing the original sediment.
Thermokarst	Land-surface configuration that results from the melting of ground ice in a region underlain by permafrost. In areas that have appreciable amounts of ice, small pits, valleys, and hummocks are formed when the ice melts and the ground settles unevenly.
Till (glacial till)	Till or glacial till is an unsorted, coarsely graded, and extremely heterogeneous sediment deposited directly by the glacier. It is mostly derived from the subglacial erosion of previous unconsolidated sediments. Its content may vary from clays to mixtures of clay, sand, gravel and boulders. An accumulation of till is called moraine.
TK	Traditional Knowledge
VEC	Valued Ecosystem Component
Veneer	A layer of unconsolidated material 0.1 to 1 m thick deposited on the surface of the underlying material. It conforms closely to the underlying topography and is too thin to mask irregularities in its surface.
VSEC	Valued Socio-economic Component

7. Landforms and Soils

Soils and special landforms are considered to be a Subject of Note in this Environmental Impact Statement (EIS) and any potential effects of the Hope Bay Project (the Project) and the Madrid-Boston Project (Phase 2) activities on these components of terrestrial environment will be discussed as linkages to other Valued Ecosystem Component (VECs). For example, the potential for Phase 2 activities to affect soil quality will be considered within the VECs Vegetation and Special Landscape Features (Volume 4, Section 8) and Human Health and Environmental Risk Assessment (Volume 6, Section 5).

The objective of this section is to describe the physical, chemical, and biological conditions associated with landforms and soils that are of specific interest to Phase 2 and its brief overlap with the Doris Project (approximately 2 years). This section provides the information requested in the EIS Guidelines (NIRB 2012) and supports other terrestrial ecology VEC sections such as vegetation, wildlife, human health, permafrost, and ground stability. Presented information includes existing conditions of the soils and landforms surrounding the proposed Phase 2 Project and discussion of the potential effects of Project development to soils and landforms. The provided information is based on the *Inuit Traditional Knowledge for TMAC Resources Inc. Proposed Hope Bay Project, Naonaiyaotit Traditional Knowledge Project (NTKP)* (Banci and Spicker 2015) and the *Hope Bay Belt Project: 2010 Terrain and Soils Baseline Report* (Appendix V4-7A).

7.1 INCORPORATION OF TRADITIONAL KNOWLEDGE

Inuit Traditional Knowledge for TMAC Resources Inc. Proposed Phase 2, Naonaiyaotit Traditional Knowledge Phase 2 (NTKP) (Banci and Spicker 2015) was reviewed for information on land use from focus groups conducted in the Kitikmeot region in 2010. This report identifies landforms important for Inuit traditional lifestyle and highlights the importance of the land as a sacred space (e.g., for burial sites), habitat for wildlife, and a source for carving material and copper. The information conveyed by the report highlights the interconnectedness between all aspects of environment and human activities.

Land morphology and soil type are important for the local Inuit in that they affect land use, facilitate wildlife movement, provide habitat for vegetation, and offer valuable resources. For example, landforms such as eskers, cliffs, rocky ridges, wetlands, ocean shores, and riverbanks are valuable because they provide habitat for wildlife such as caribou, grizzly bears, wolves, foxes, wolverines, and birds. These landforms provide prime hunting and trapping grounds for people. Pools under cliffs are important as a source of water during travel. Similarly, the areas with well-drained soil are important as blueberry habitat, while the areas where the soil is slightly saline provide habitat for wild peas. The above information guided the identification of traditionally important elements of existing landforms, terrain, and soils in the study area.

7.1.1 Incorporation of Traditional Knowledge for VEC Selection

The TK report provides information on traditional land use activities in the Kitikmeot region, where the Project is located. The report describes important environmental components (e.g., landforms) and conditions (e.g., permafrost), presents maps showing sacred burial sites, locations of valuable resources, and annual patterns of behaviour of valued animal species.

Information on traditional land use and value by local Inuit was used for scoping and refining the potential VEC list and to determine if the valued components could interact with the Project. This, along with information from consultation with regulatory agencies, was used to determine the final VEC list. Special landforms, soils, permafrost, and ground stability were selected for consideration as VECs.

The Valued Socio-economic Components (VSECs) include traditional and non-traditional land use, food security, including harvesting, which are all directly associated with the quality and health of terrestrial ecosystems. Because of the dependence of VSECs on functioning ecosystems, the Nunavut Impact Review Board (NIRB) also identified terrestrial ecology, landforms, soils, permafrost, and ground stability as potential VECs.

7.1.2 Incorporation of Traditional Knowledge for Spatial and Temporal Boundaries

The traditional knowledge (TK) report informed the development of spatial boundaries including consideration for land features reported as important to Inuit. For example, the TK report indicates that areas with well-drained soil are important for blueberries, which are reported as abundant throughout the area. The TK report also notes that areas where the soil might be slightly saline are where wild peas are harvested.

The information on traditional use of lands by Inuit provides insight on the value people place on the land and environment. The spatial boundaries have been developed to include areas in which the Phase 2 Project may have an effect on landforms and soils of special importance to Inuit, permafrost integrity, and terrain stability.

No specific traditional knowledge regarding the temporal aspects of the environmental effects on Landforms and Soils were presented in the TK report. However, TMAC recognizes the enduring relationship between the Inuit and land and considers this in all temporal boundaries of the Project activities and components.

7.1.3 Incorporation of Traditional Knowledge for Project Effects Assessment

Information on traditional use of land by the Inuit together with the knowledge of local ecological, geomorphologic, pedogenic, and periglacial processes was used to focus the discussion about the potential effects of the Phase 2 development on local landforms and soils. For example, the information that eskers are particularly important landscape elements for local people and wildlife identified these as special landforms that have high social as well as ecological values.

7.1.4 Incorporation of Traditional Knowledge for Mitigation and Adaptive Management

Landforms and soils support terrestrial ecosystems and vegetation and the habitat, and forage they provide for many Arctic wildlife species, and at-risk plants and lichens.

Outlined within the socio-economic and land use baseline (Appendix V6-3A), concerns regarding the potential for the Project to directly affect wildlife or degrade their forage and habitat quality were raised during focus group sessions and interviews with hunters from the Kitikmeot communities.

Mitigation measures largely pertain to reducing the potential for adverse effects on landscape features that provide TK uses or habitat for wildlife species, particularly those used by Inuit (Table 7.1-1). Avoidance of Project interactions with VECs is the most effective method of reducing Phase 2 Project effects.

To avoid interactions with special landscape features, baseline information was used to develop environmental sensitivity maps to inform Phase 2 Project design and reduce potential effects to landforms that can support ecosystems or vegetation that provide TK use, habitat for important wildlife, or have greater potential to support rare plants. Terrestrial ecosystem surveys and mapping, vegetation surveys, terrain and soil mapping, were all used to identify landforms and the resultant ecosystems that are often considered important, due to their scarcity on the landscape, sensitivity, special habitat features they provide, and/or cultural importance (Table 7.1-1). These features are assessed in Vegetation and Special Landscape Features (Volume 4, Section 8).

Table 7.1-1. Features included in Environmental Sensitivity Mapping to Inform Project Design

Feature Type	Rationale for Inclusion
Riparian ecosystems and floodplains	Deciduous shrubs are an important food source for ungulates; provide nesting and cover habitat for various wildlife species (e.g., breeding birds); and are used by Inuit for tools, fuel, and hunting.
Ecosystems that can contain esker complexes	Esker-related ecosystems provide important denning habitat for mammals such as foxes, wolves, wolverine, and ground squirrels, and travel corridors for many wildlife species; used as travel routes by Inuit peoples.
Sensitive or rare wetlands	These ecosystems provide important habitat to grizzly bears and caribou in the spring. Shallow open water provides habitat for water bird species. Furthermore, the ecosystems provide food and other materials for Inuit traditional uses.
Bedrock cliff	Steep, exposed bedrock cliffs provide important bird nesting habitat and hunting for Inuit as well as habitat for rare plant species.
Bedrock-lichen veneer ecosystems	Dry, windswept areas support a continuous mat of lichens, an important food source for caribou.
Beaches, marine backshores and intertidal areas	These marine associated areas provide habitat for rare plant species and are travel and foraging areas for Inuit and a variety of wildlife.
Rare plants and lichens known locations	Rare plant species are important to biodiversity and may be federally protected.

Reducing potential effects by avoidance is, where practicable, the most effective mitigation measure to reduce the potential for serious damage or harm. Hence, the locations of these features were identified and Phase 2 Project infrastructure was relocated, where feasible, to avoid effects to these features.

7.2 EXISTING ENVIRONMENT AND BASELINE INFORMATION

This section summarizes the existing biophysical environments relevant to the assessment of potential effects of Phase 2. It outlines the methodologies for baseline data collection, evaluation of the adequacy of data, confidence levels associated with baseline data, and identification of significant gaps in knowledge and understanding. Any uncertainties or baseline gaps and the steps taken to fill information gaps are discussed.

7.2.1 Data Sources

Data used to describe baseline conditions include:

- information from scientific field studies, supplemented by Inuit traditional and community knowledge, where available;
- references to supporting documents, including annual baseline data reports, engineering, and technical reports (included as appendices to the Application); and
- desktop research such as other environmental assessment (EA) reports and regional studies.

The initial stages of the assessment involved a thorough review of climatic and geological data, regional maps, scientific papers, traditional knowledge information, and professional reports describing environmental conditions in the region. This information was used to interpret field data in a regional context.

TK information was accessed by a review of published work by Banci and Spicker (2015). Regional climatic data from Environment Canada meteorological stations were reviewed along with meteorological data collected on-site for the Hope Bay Project. Regional maps and publications from

Natural Resources Canada, Centre for Mapping and Earth Observation were accessed to review regional geological data, including glaciation and distribution of post-glacial surficial deposits. Scientific and professional publications were searched and accessed through on-line resources.

7.2.2 Spatial Boundaries

7.2.2.1 Project Development Area

The Project Development Area (PDA; Figure 7.2-1) is the area which has the potential for infrastructure to be developed. The PDA includes buffers around the footprints of structures to allow for latitude in the final placement of a structure. Components with buildings and other infrastructure in close proximity are defined as pads with buffers, whereas roads are defined as linear corridors with buffers. The buffers for pads varied depending on the local physiography and other buffered features such as sensitive environments or riparian areas. The buffer for roads was 100 m either side. Since the infrastructure for the Doris Project is in place, the PDA exactly follows the footprints of these features. In all cases, the PDA does not include the Project design buffers applied to potentially environmentally sensitive features. These are detailed in Volume 3, Section 2 (Project Design Considerations).

7.2.2.2 Local Study Area

The Local Study Area (LSA) is the area within which there is a reasonable potential for direct effects on a VEC due to an interaction with a Phase 2 Project component or activity (Figure 7.2-1). This boundary was selected based on empirical data and expert opinion regarding the scale at which immediate and localized disturbances typically occur. The boundaries of the Landforms and Soils LSA encompasses the PDA plus a 1-km radius buffer, excluding marine waters. The LSA is the same for all the Terrestrial Environment VECs (e.g., Vegetation, Wildlife and Wildlife Habitat) and is defined by a combination of sub-watershed boundaries and 1 km buffers surrounding proposed Phase 2 Project components including infrastructure and connecting roads. The LSA covers an area of approximately 56,340 ha.

7.2.2.3 Regional Study Area

The Regional Study Area (RSA) is the broader spatial area representing the maximum limit where potential effects may occur (Figure 7.2-1). The RSA is the same as the Terrestrial Wildlife and Wildlife Habitat RSA and covers an area of approximately 491,823 ha. The RSA includes habitat and ecosystems for wildlife with larger home range that could potentially interact with the PDA.

7.2.3 Temporal Boundaries

The Project represents a significant development in the mining of the Hope Bay Greenstone Belt. Even though the Phase 2 Project spans the conventional Construction, Operation, Reclamation and Closure, and Post-closure phases of a mine project, Phase 2 is a continuation of development currently underway. Phase 2 has four separate operational sites: Roberts Bay, Doris, Madrid (North and South), and Boston. The development of these sites is planned to be sequential. As such, the temporal boundaries of this Project overlap with a number of Existing and Approved Authorizations (EAAs) for the Hope Bay Project and the extension of activities.

For the purposes of the EIS, distinct phases of the Phase 2 Project are defined (Table 7.2-1). It is understood that construction, operation and closure activities will, in fact, overlap among sites; this is further described in Volume 3, Section 2.

The assessment also considers a Temporary Closure phase should there be a suspension of Phase 2 Project activities during periods when the it becomes uneconomical due to market conditions. During this phase, the Phase 2 Project would be under care and maintenance. This could occur in any year of Construction or Operation with an indeterminate length (one- to two-year duration would be typical).

Figure 7.2-1
Hope Bay Project Terrestrial Environment Study Area Boundaries

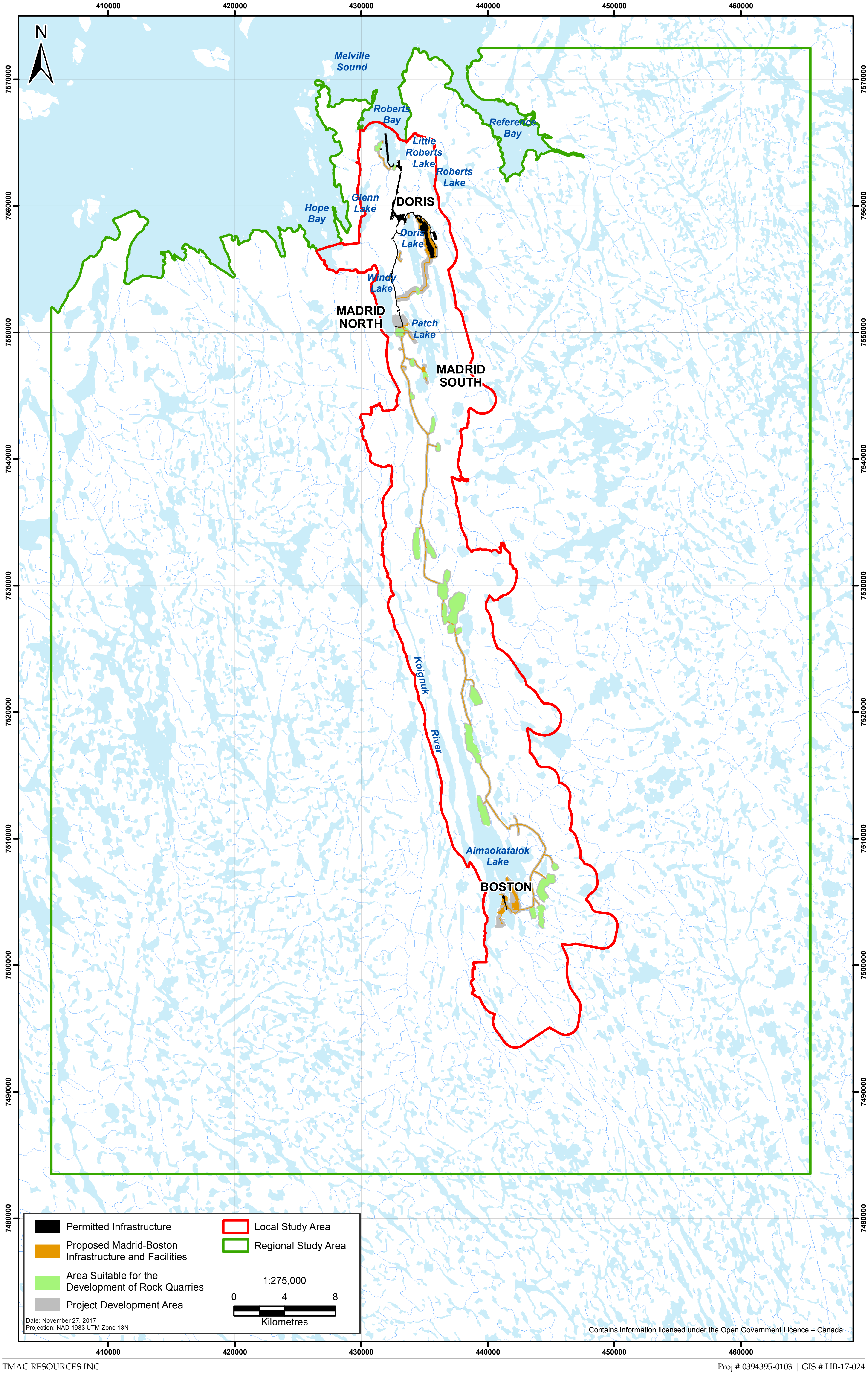


Table 7.2-1. Temporal Boundaries for the Effects Assessment for Vegetation and Special Landscape Features

Phase	Project Year	Calendar Year	Length of Phase (Years)	Description of Activities
Construction	1 - 4	2019 - 2022	4	• **Roberts Bay:** construction of access road (Year 1), marine dock and additional fuel facilities (Year 2 – Year 3) • **Doris**: expansion of the Doris TIA and accommodation facility (Year 1) • **Madrid North:** construction of concentrator and road to Doris TIA (Year 1 – Year 2) • **All-weather Road**: construction (Year 1 – Year 3) • **Boston**: site preparation and installation of all infrastructures including process plant (Year 2 – Year 5).
Operation	5 - 14	2023 - 2032	10	• **Roberts Bay**: sealift operations (Year 1 – Year 14) • **Doris**: processing and infrastructure use (Year 1 – Year 14) • **Madrid North:** mining (Year 1 – 13); ore transport to Doris process plant (Year 1 -13); ore processing and concentrate transport to Doris process plant (Year 2 – Year 13) • **Madrid South:** mining (Year 11 – Year 14); ore transport to Doris process plant (Year 11 – Year 14) • **All-weather Road**: operational (Year 4 – Year 14) • **Boston**: winter access road operating (Year 1 – Year 3); mining (Year 4 – Year 11); ore transport to Doris process plant (Year 4 – Year 6); and processing ore (Year 5 – Year 11)
Reclamation and Closure	15 - 17	2033 - 2035	3	• **Roberts Bay**: facilities will be operational during closure (Year 15 – Year 17) • **Doris**: camp and facilities will be operational during closure (Year 15 – Year 17); mine, process plant, and TIA decommissioning (Year 15 – Year 17) • **Madrid North:** all components decommissioned (Year 15 – Year 17) • **Madrid South:** all components decommissioned (Year 15 – Year 17) • **All-weather Road**: road will be operational (Year 15 – Year 16); decommissioning (Year 17) • **Boston**: all components decommissioned (Year 15 – Year 17)
Post-Closure	18 - 22	2036 - 2040	5	• **All Sites:** Post-closure monitoring
Temporary Closure	N/A	N/A	N/A	• **All Sites:** Care and maintenance activities, generally consisting of closing down operations, securing infrastructure, removing surplus equipment and supplies, and implementing on-going monitoring and site maintenance activities

7.2.4 Methods

Terrain maps of the study area were created using aerial photography collected in 1996 and anaglyph data collected in 2010. Terrain polygons were delineated at a scale of 1:20,000. In the absence of a terrain classification system for Nunavut the terrain was described according to the Terrain Classification System for British Columbia (Howes and Kenk. 1997), which for many years has been successfully used in the Arctic for that purpose.

Detailed soil inspections and necessary corrections of the terrain mapping were made during terrain and soil surveys carried out in 1996 (124 inspections) and 2010 (163 inspections). Soil pits were excavated to a depth of approximately 70 cm, or to permafrost if encountered first. In the absence of a soil description system for Nunavut, the soils were described according to the Field Manual for Describing Terrestrial Ecosystems (BC MELP and BC MOF 1998).

Terrain and soils information was compiled and analysed, and soils in the LSA were grouped into 11 soil mapping units (SMUs) based on attributes such as drainage, landscape position, and dominant surficial material. The terrain mapping polygon boundaries were used to form the boundaries of the SMUs. Soil polygons were delineated at a scale of 1:20,000.

In 2010, a total of 70 soil samples were collected from representative locations throughout the study area. Mineral soils were sampled at two depths: 0 to 10 cm and 10 to 20 cm, and analysed at ALS Environmental labs in Burnaby, BC for pH, organic carbon content, and total metals concentrations. More details regarding the methods and standards used during the baseline study program are provided in the *Final Environmental Impact Statement* (Appendix V4-7A [Rescan 2011]).

In 2014, 33 soil, berry, and lichen samples were co-collected from 30 sites and analysed for metals. This data is used to develop site-specific bio transfer factors (i.e., the relationship between soil metals and vegetation tissue metals). The information can be used in the future to identify changes to soil and vegetation metal concentrations that may be attributed to the Phase 2 Project. The results of these analyses have been used to support the Human Health and Environmental Risk Assessment (Volume 6, Section 5) that is required by the EIS guidelines issued for the Project (NIRB 2012).

7.2.5 Characterization of Baseline Conditions

This section presents baseline information on the existing environment and serves as the basis for the assessment of Phase 2 Project effects. It contains key information such as:

- a description of the existing conditions;
- the scientific importance of the baseline results;
- discussion of any exceptional existing conditions such as an elevated baseline conditions above an expected environmental or regulatory threshold; and
- data gaps or uncertainties that could potentially affect the confidence in the effects assessment.

The Hope Bay Project area is a 5- to 10-km-wide and 80-km long belt that extends from the south shore of Melville Sound (Roberts Bay, approximately 125 km southwest of Cambridge Bay, Nunavut) south, past Aimaokatalok (Spyder) Lake (Figure 7.2-1). The Hope Bay Project is located in the Kitikmeot region of Nunavut. The nearest settlements are Omingmaktok (Bay Chimo), located 62 km to the west, and Kingaok (Bathurst Inlet), located 130 km southwest.

The LSA and PDA do not overlap with protected or conservation areas. A Territorial Park and a large bird sanctuary are located in the Hope Bay Project vicinity. Ovayok Territorial Park is situated 15 km east of Cambridge Bay on Victoria Island. The park covers an area of approximately 16 km^2. The central feature of the park is the mountain called Ovayok (Mount Pelly). Since ancient times (from 4,500 years ago), Ovayok has been an important landmark and a key stopping place during the seasonal movements of nomadic peoples living in this area. The Queen Maud Gulf Migratory Bird Sanctuary is Canada's largest federal protected area, encompassing 61,765 km^2. The sanctuary is dominated by wetlands, streams, ponds, and shallow lakes, and it was designated as a wetland of international importance in 1982. Known traditional burial sites and sources of carving stone and copper are located 40 to 100 km west of the Project.

7.2.5.1 Climate

Temperature ranges are typical of Arctic regions of Canada, and permafrost occurs throughout the LSA. During the winter period (October to May), the mean daily temperature ranges between -35°C and -9°C. During the summer (June to September), it ranges between 0°C and 5°C. Average length of frost-free period is 66 days (Environment Canada 2015). At Doris Bay, hourly temperatures range between -42°C and +27°C. The majority of the strong winds come from west to northwest (Golder Associates 2005). Precipitation in the LSA is relatively low. Monthly precipitation average ranges from 5 to 26 mm, with the majority occurring during the summer months (Environment Canada 2016). The climatic conditions of the LSA are discussed in detail in *Climate and Meteorology* (Volume 4, Section 1).

7.2.5.2 Topography

In general, the LSA has low to moderate surface relief with less than 200 m elevation difference between low and high points. The topography is gently rolling with long and narrow drainage basins oriented in a north-south direction with similarly oriented rock outcroppings.

There are, however, clear geomorphologic differences between sections of the LSA. The north end of the LSA (comprising the area from Roberts Bay to Wolverine Lake) is typical of coastal lowlands in the Arctic, with lakes and ponds occurring in low relief areas and ridges, cliffs, and rock outcroppings occurring in higher relief areas. The elevation ranges from sea level at Roberts Bay to 158 m at the summit of the Doris Mesa (Plate 7.2-1).

The south end of the LSA, adjacent to Aimaokatalok Lake, has low to moderate surface relief (Plate 7.2-2). It is characterized by lowlands occurring as plains and terraces interspersed with numerous small thaw lakes. Bedrock is close to the surface with several boulder fields and areas of shattered rock. Several large (over 10 km long) and many smaller eskers and associated outwash terraces are oriented north to north west but are generally located outside the LSA (Figure 7.2-2).

The topography of the central section of the LSA is generally subtle with large, level terraces and plains. There are numerous round thaw lakes and many wetlands in this area.

7.2.5.3 Landforms

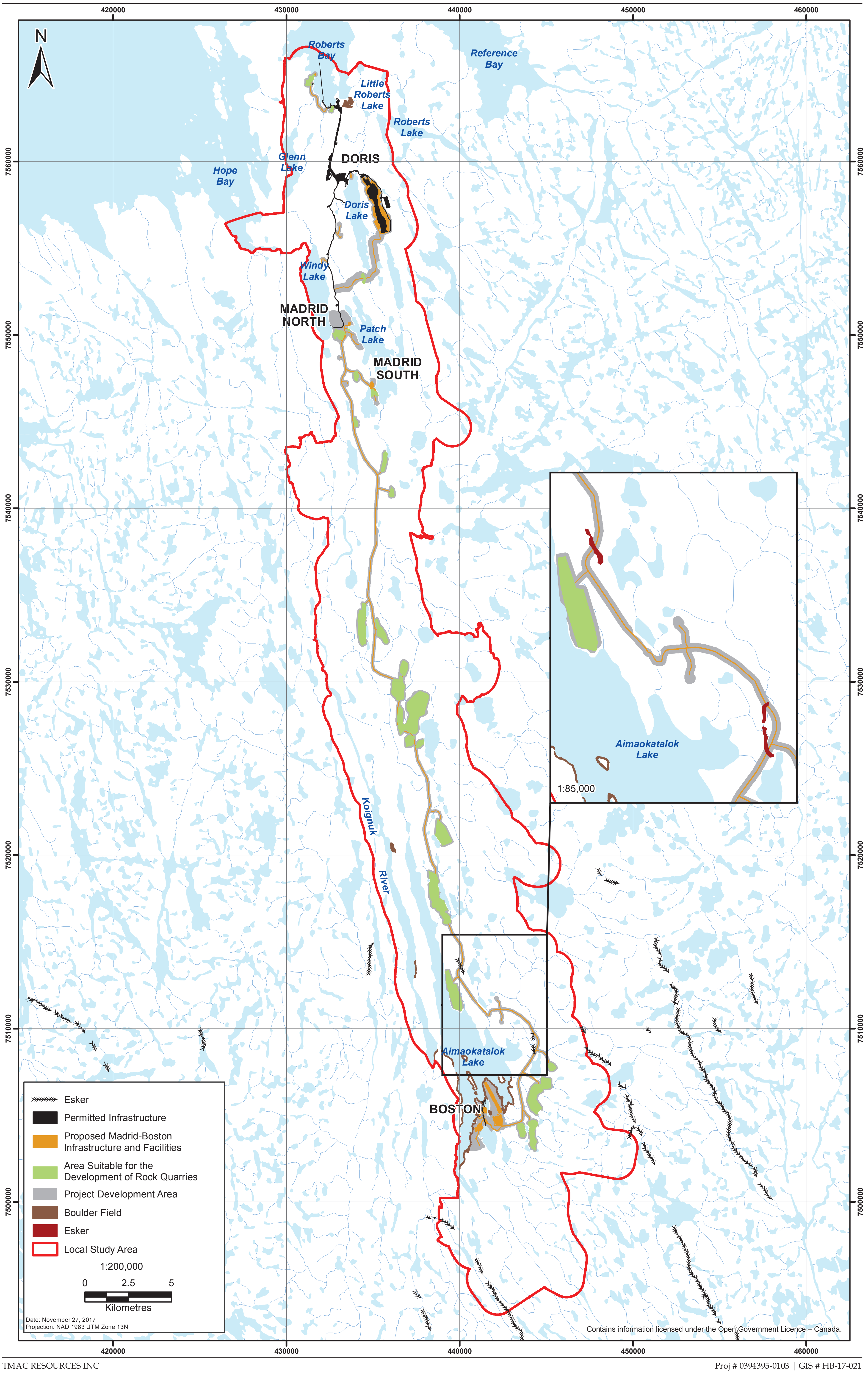
A number of distinct landform types, including eskers, kames, dykes, and boulder fields exist throughout the Kitikmeot region. Several large eskers occur in the RSA (most are located, outside the LSA), and are elongated, sinuous ridges up to 100 m wide and several kilometres long. They were formed from sands, gravels, cobbles, and boulders deposited in the glacial melt water channels flowing sub-glacially. Coarse fragment content in eskers varies from 35% to 85%. Studies suggest that majority of eskers located in the Kitikmeot region likely contain massive ice cores (Dallimore and Wolfe 1988; Gowan and Dallimore 1990; Dallimore and Davis 1992; Wolfe et al. 1997; Moorman and Michel 2003; Robinson et al. 2003; Macumber et al. 2011).

Besides being a unique geomorphologic landscape feature, eskers provide ecological functions. For example, the annual pattern of groundwater flow within the esker active soil layer governs soil moisture and nutrient regimes in lower sections of eskers and adjacent ecosystems. Since burrowing material is limited in the areas dominated by boulder fields and shallow morainal veneers over bedrock, the unconsolidated, coarse mineral material of eskers provides excellent potential for denning sites for wildlife.

Plate 7.2-1. View of terrain in the north end of the LSA.

Plate 7.2-2. View of terrain in south end of the LSA.

Figure 7.2-2
Eskers and Boulder Fields within the Local Study Area



The northern and central sections of the LSA feature several kames (i.e., irregularly shaped mounds composed of sand, gravel and till). A large, magmatic rock dyke located in the north-eastern section of the LSA extends more than 20 km. Because of its elongated shape and elevation above the landscape, the rock dyke likely provides some of the ecological functions similar to eskers.

In the Arctic, weathered bedrock, from which finer fractions have been removed by various periglacial processes, often produce boulder fields (Sonesson 1985). Intense frost heaving also causes fracturing of bedrock and subsequent migration of large rock fragments to the surface. These phenomena have created several boulder fields and belts in the LSA.

Repeated freezing and thawing of the soil creates patterns on the ground surface. Frostboils (also known as mud boils or mud circles) are typically circular (1 to 3 m in diameter) upwellings of mud that are created by frost heave and cryoturbation in permafrost areas. Common characteristics include an elevated center devoid of vegetation, an organic layer on the outer edge, and resistance of the soil surface to vegetation colonization. Extensive areas of tundra “patterned ground” covered by frostboils are commonly found in the LSA. Similar patterns created by slightly different processes can be also observed in wetland areas. Wetland polygons are typically larger, angular and have depressions in their centers.

Thermokarst typically occurs in wetlands as a system of very irregular hummocks and hollows that form by frost heaving and ice accumulation at the bottom of organic horizons. When the ice eventually thaws and collapses, depressions are formed.

7.2.5.4 Surficial Geology

The LSA is located on the Canadian Shield, in the Slave Geological Province. It extends over the Hope Bay volcanic belt surrounded by mostly granitic and sedimentary rocks. The bedrock in the study area is mostly composed of Precambrian mafic volcanic rocks with minor component of felsic volcanics, volcaniclastic rocks, metasedimentary rocks, and iron formations. These rocks were metamorphosed from greenschist to amphibolite-facies and intruded by granite, granodiorite, and gneiss (Kerr and Knight 2001). Coarse fragments found in the surficial deposits have predominantly volcanic lithology.

Periodic changes in the global climate of the Quaternary period (about 2 million to 8.5 thousand years ago) caused four major glaciations. As a result, a third of the LSA is covered by glacial till (morainal surficial materials; Table 7.2-2), which has been deposited by the last glacial ice sheet. Following deglaciation, the area was initially submerged by a postglacial sea. Later, due to isostatic uplift, which is still occurring, the land gradually emerged from the sea (Prest 1970). As a result of these processes, till is now commonly covered by glaciomarine sediments or reworked by marine processes. Marine and glaciomarine deposits are typically found in low elevation areas. Till veneers are common in elevated areas containing extensive bedrock outcrops (Kerr and Knight 2001).

Glaciofluvial materials deposited over glacial till or bedrock form elongated eskers and kames. Esker textures are variable (sandy to cobbly) and texture often changes rapidly over short distances (Kerr and Knight 2001). Fluvial sediments associated with meandering and braided streams vary in thickness from 1 to 5 m. Their textures vary from silt to gravel occurring in well sorted layers or as massive deposits.

Peaty organic deposits, typically less than 1 m deep, develop in topographic depressions and on valley bottoms in wetlands. Ice wedge polygons are common in these areas and permafrost is commonly encountered there at depths of 10 to 20 cm.

Proportions of different surficial materials found within the LSA are shown in Table 7.2-2.

Table 7.2-2. Surficial Materials found within the LSA, PDA, and under Proposed Phase 2 and Hope Bay Project Infrastructure Footprint

		LSA		PDA		Hope Bay Project Infrastructure		Phase 2 Infrastructure Footprint	
Surficial Material	**Map Symbol**	**Area (ha)**	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**	**Area (ha)**	**%**
Anthropogenic	A	7	< 1%	3	< 1%	2	< 1%	< 1	< 1%
Bedrock	R	2,531	4%	332	8%	181	11%	178	12%
Weathered bedrock	D	2,832	5%	320	8%	200	12%	200	14%
Colluvial	C	830	1%	83	2%	40	2%	40	3%
Eolian	E	504	< 1%	127	3%	89	5%	89	6%
Flood Plain	FP	45	< 1%	-	< 1%	-	-	-	-
Fluvial	F	699	1%	28	< 1%	3	< 1%	2	< 1%
Glaciofluvial	FG	146	< 1%	23	< 1%	18	1%	12	1%
Glaciolacustrine	LG	3,570	6%	416	10%	166	10%	149	10%
Glaciomarine	WG	7,205	13%	500	12%	183	11%	138	9%
Ice	I	5	< 1%	-	0%	-	-	-	-
Lacustrine	L	499	< 1%	45	1%	6	< 1%	6	< 1%
Lake	LA	7,574	13%	74	2%	73	4%	1	< 1%
Marine	W	92	< 1%	14	< 1%	2	< 1%	1	< 1%
Morainal	M	18,936	34%	1,612	38%	586	35%	519	35%
Organic	O	8,974	16%	597	14%	144	8%	126	9%
Pond	PO	380	< 1%	2	< 1%	< 1	< 1%	< 1	< 1%
Rivers/Streams	RI	768	1%	7	< 1%	< 1	< 1%	< 1	< 1%
Salt Water	SW	741	1%	7	< 1%	1	< 1%	< 1	< 1%
Unknown	U	3	< 1%	-	-	-	-	-	-
Total Area		**56,340**	**100%**	**4,189**	**100%**	**1,696**	**100%**	**1,463**	**100%**

7.2.5.5 Soils

Interactions between soil parent materials and topography, local climate, biotic influences, and hydrology influence soil development (paedogenesis). In Nunavut, the local climate, and more specifically permafrost, cryoturbation, and relatively short period of intense thaw within the top soil horizons (active layer) have the most significant effects on pedogenic processes.

The RSA is underlain by continuous permafrost with sporadic occurrences of massive ground ice (SENES Consultants Limited 2013). Permafrost describes soil or bedrock that remains at or below freezing (0ºC) for two or more years. Under these conditions, soil development generally occurs only close to the ground surface during the short frost-free period each year. The water/ice content of the surficial material and the thickness of organic layer govern the depth of the active layer (the soil depth to which the permafrost melts each summer). The active layer can vary from 0.2 m in thick organic layers to over 3 m in well-drained eskers or bedrock outcrops.

Permafrost restricts the downward flow of water, causing precipitation and melt water to move horizontally, either as a surficial runoff or as shallow underground seepage within the active layer of the soil. Consequently, the soils within the seepage areas are often waterlogged throughout most of the growing season. Annual frost heaving of the soil upon freezing and the subsequent settlement during thawing creates several phenomena, including cryoturbation (e.g., patterned ground and thermokarst) and solifluction (downslope movement of waterlogged soil).

The presence of shallow permafrost and cryoturbation affect both the pedogenic process and soil classification. Most soils in the LSA are classified as Cryosols and are usually poorly developed. In general, the rates of soil development in the LSA are very slow, typically in the order of a few millimetres per century (SENES Consultants Limited 2013), while peat-derived organic materials (Organic Cryosols) accumulate considerably faster.

Permafrost and soils with high ground ice content, such as those found in most Organic Cryosols (Grosse et al. 2011), have particularly profound effects on terrain and soils. Degradation of permafrost can impact local topography (e.g., causing thermokarst, thaw slumps, or active layer detachments), hydrology (e.g., change flow patterns in soil active layer), vegetation (e.g., change compositional patterns and diversity), and can influence dynamics of greenhouse gas release from the soil (Jorgenson and Osterkamp 2005; Walter 2006; Shur and Jorgenson 2007; Turetsky et al. 2007).

Soils that have developed from morainal, organic, and glaciomarine materials dominate the LSA. In general, coarse morainal soils occupy higher elevation areas, whereas finer glaciomarine soils and peaty organic soils accumulate in valley bottoms and on plains. Post-glacial down-slope washing, however, has resulted in mixing of the surficial materials, particularly in the lower slope positions.

Soils in the LSA were grouped into eleven Soil Mapping Units (SMUs) according to their parent materials, dominant soil order, surface expression, and drainage classes. Soil mapping units identified in the study area include three morainal mapping units, two glaciomarine/glaciolacustrine/lacustrine mapping units, two organic mapping units, one fluvial mapping unit, one bedrock mapping unit, one thin veneer mapping unit (< less than 0 cm of soil), and one marine beach unit (Table 7.2-3).

Table 7.2-3. Summary of Soil Mapping Unit Characteristics

Dominant Surficial Material/s	Soil Mapping Unit	Characteristics	Area (ha)	Proportion of LSA (%)
Anthropogenic	A	areas altered by human activity	10	< 1
Beach	Z	well-drained, coarse textures, beaches	49	< 1
Bedrock	R	bedrock or saprolite with some rapidly drained, thin Brunisols or Regosols in high elevations	4,937	9
Glaciofluvial/ Fluvial	F	moderately to poorly drained, Cryosols or Gleysols, permafrost at 40-60 cm	817	1
Glaciomarine/ Glaciolacustrine/ Lacustrine	W1	moderately well drained, in valleys, Turbic Cryosols, permafrost at 30-70 cm	1,455	3
	W2	imperfectly to poorly drained, on valley bottoms, Turbic Cryosols, permafrost at 20-60 cm	9996	18
Ice	I	areas covered by ice	5	< 1
Morainal	MR	very rapidly to well drained, high elevation, bedrock outcrops	3,969	7
	M1	rapidly to moderately well-drained, permafrost at 60-80 cm	7,499	13
	M2	imperfectly to poorly drained, lower slopes, permafrost at 40-80 cm	5,655	10

Dominant Surficial Material/s	Soil Mapping Unit	Characteristics	Area (ha)	Proportion of LSA (%)
Organic	O1	imperfectly to very poorly drained, Organic Cryosols, permafrost near surface	7,526	13
	O2	very poorly drained, bogs or palsas, Organic Cryosols, permafrost near surface	2,124	4
Very thin Eolian or Morainal veneers (< 20 cm)	V	rapidly drained, thin Brunisols or Regosols on bedrock or saprolite in high elevations	3,352	6
Water	Water	lakes, ponds, rivers, streams, salt water	8,946	16
Total			**56,340**	**100**

The dominant soils in the LSA are classified as Static, Turbic, or Organic Cryosols and Distric Brunisols. LSA Cryosols generally have permafrost within 20 to 60 cm of the surface and are imperfectly to very poorly drained. They are typically associated with finely textured marine sediments or organic deposits located in lower landscape positions. Brunisols are usually moderately well to rapidly drained and typically do not have permafrost within 100 cm of the surface. They are associated with coarser deposits and occur in higher elevated landscape positions. Less common soils are poorly drained Gleysols and well-drained Regosols.

7.2.5.6 Mineral Soil Chemistry

In 2010 and 2014, soils in the LSA were inspected and sampled at a depth of 0 to 20 cm. A total of 103 soil samples were collected at 68 sites and analyzed for soil reaction (pH), organic carbon content, and concentrations of 31 metals. Soil chemical analysis results indicate that soils in the LSA are mildly alkaline to strongly acidic. The median soil pH value is mildly acidic (pH 6.15; Table 7.2-4). While organic carbon content of soil ranges from 0.05% to 42.1%, mineral soils generally have low organic carbon content (median value is 1.6%), which is typical of the upland tundra ecosystems in the region. A summary of soil chemical data is provided in Appendix V4-7B.

Most metal concentrations in the study area are below the industrial limits of the CCME Soil Quality Guidelines for the Protection of Environmental Health (CCME 2016). The most conservative CCME soil guidelines were used for COPC screening for all parameters (CCME 2016). Agricultural guidelines for soil metal concentrations were used for all metals except barium, for which the residential/parkland guideline was used, as this is lower than the agricultural guideline. The agricultural limit guidelines (reflecting the quality of the sites as habitats for harvestable plants and wildlife) were exceeded for chromium in four sites and for copper and nickel at one site (Table 7.2-4, Figure 7.2-3).

7.2.5.7 Terrain Conditions Sensitive to Development, including Permafrost, Sensitive Landforms, High Ice-Content Soils, Ice Lenses, Thaw-Sensitive Slopes, and Talik Zones

Permafrost occurs continuously throughout the Southern Arctic Ecozone. It extends to depths of approximately 90 m at Yellowknife, reaches more than 270 m near Lac de Gras, and near Contwoyto Lake it is estimated to occur to a depth of about 540 m (SENES Consultants Limited 2013).The basal depth of the permafrost (basal 0°C isotherm) near Goose Lake (approximately 260 km south west of the Hope Bay Project) is estimated to range from 490 to 570 m below ground (ERM Rescan 2014). At the Doris site, the average ground temperature ranges between -10ºC and -6ºC and the estimated basal depth of permafrost is about 550 m. At the Boston site, approximately 60 km south, the estimated permafrost depth is approximately 560 m (SRK Consulting 2005).

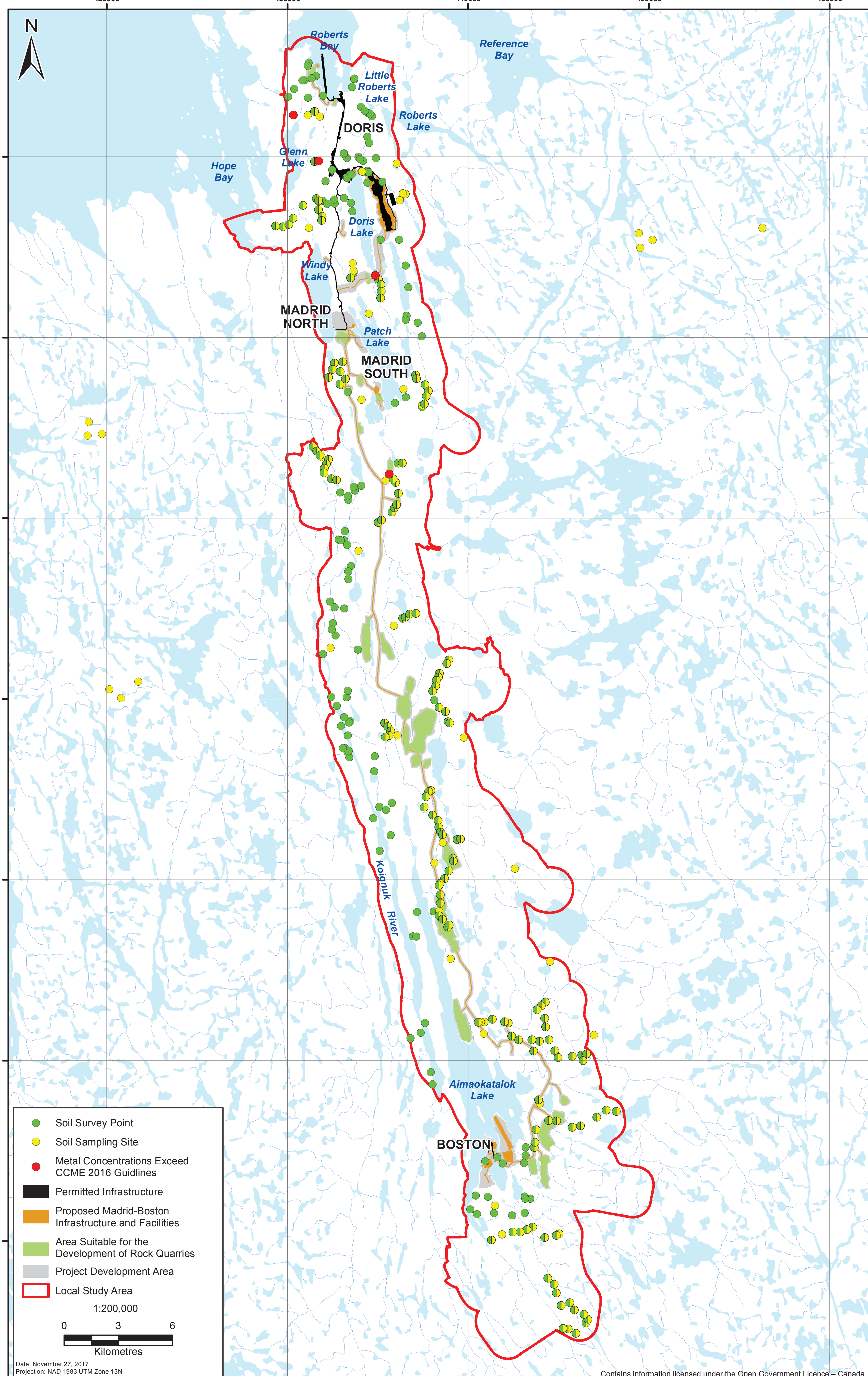
Table 7.2-4. Summary of Soil Chemical Data

Parameter	CCME Soil Quality Guideline - Agricultural Limits	Detection Limit	Standard Deviation	Minimum	Mean	Median	95th Percentile	Maximum
pH	NG	0.10	0.753	4.13	6.14	6.15	7.53	8.18
Total Organic Carbon	NG	0.10	7.74	0.05	3.89	1.63	16.02	42.1
Metal (mg/kg dry weight)								
Aluminum	NG	50.00	6,598	626	10,110	8,635	21,330	27,200
Antimony	20	0.1 - 10	2.28	0.0500	3.52	5.00	5.00	5.00
Arsenic	12	0.05 - 5	0.913	0.645	2.41	2.50	3.78	7.17
Barium	750	0.5 - 1	41.1	6.85	54.1	35.7	131	164
Beryllium	4	0.2 - 0.5	0.172	0.100	0.298	0.250	0.640	0.790
Bismuth	NG	0.2 - 20	4.56	0.100	7.03	10.0	10.0	10.0
Cadmium	1.4	0.05 - 0.5	0.103	0.0250	0.183	0.250	0.250	0.250
Calcium	NG	50.00	2,633	984	3,651	2,710	9,040	14,000
Chromium	64	0.5 - 2	20.6	1.00	30.9	25.3	65.6	81.8
Cobalt	40	0.1 - 2	4.19	1.00	7.17	6.59	14.4	17.1
Copper	63	0.5 - 1	11.4	1.30	16.9	15.8	38.3	67.7
Iron	NG	50.00	8,675	1,200	16,729	15,200	30,955	39,800
Lead	70	0.5 - 30	5.51	1.42	11.5	15.0	15.0	15.0
Lithium	NG	2 - 5	10.5	1.00	15.6	12.4	34.4	50.0
Magnesium	NG	20 - 50	3,849	1,100	5,891	4,810	13,010	17,900
Manganese	NG	1.00	131	10.4	190	154	370	790
Mercury	6.6	0.005	0.0213	0.00250	0.0130	0.00760	0.0506	0.158
Molybdenum	5	0.5 - 4	0.796	0.250	1.48	2.00	2.00	2.00
Nickel	45	0.5 - 5	11.5	2.50	16.7	15.2	34.7	53.5
Phosphorus	NG	50.00	163	113	386	374	676	943
Potassium	NG	100 - 200	1,730	100	1,842	970	4,858	7,790
Selenium	1	0.2 - 0.5	0.0691	0.100	0.205	0.250	0.250	0.250
Silver	20	0.1 - 2	0.438	0.0500	0.715	1.00	1.00	1.00
Sodium	NG	100 - 200	248	50.0	309	240	711	1,450

Parameter	CCME Soil Quality Guideline - Agricultural Limits	Detection Limit	Standard Deviation	Minimum	Mean	Median	95th Percentile	Maximum
Strontium	NG	0.50	14.4	4.56	19.6	15.0	40.3	79.9
Thallium	1	0.05 - 1	0.200	0.0250	0.373	0.500	0.500	0.500
Tin	5	2 - 5	0.691	1.00	2.05	2.50	2.50	2.50
Titanium	NG	1.00	420	18.7	711	589	1471	1760
Uranium	23	0.05	0.536	0.0250	0.796	0.532	1.76	2.23
Vanadium	130	0.2 - 2	18.8	1.00	36.1	32.3	70.0	82.0
Zinc	200	1.00	18.0	6.40	29.6	26.6	59.1	80.5

Notes:
CCME = Canadian Council of Ministers of the Environment
a CCME (2016) Soil Quality Guidelines for the Protection of Environmental and Human Health.
For calculation purposes, values that were below the method detection limit were replaced with values that were half of the method detection limit.
Shaded cells indicate that the soil metal concentration exceeds the CCME guideline.
NG = no guideline
Values for metals are shown in mg per kg of soil (ppm) and for organic carbon in %. For calculation purposes, values that were below the method detection limit were replaced with values that were half of the method detection limit. CCME (2016) = Canadian Council of Ministers of the Environment, Soil Quality Guidelines for the Protection of Environmental and Human Health. Shaded cells indicate that the soil metal concentration exceeds the CCME guideline. NG = no guideline

Figure 7.2-3
Distribution of Soil Inspection Sites in the Local Study Area



Depending on site topography and the type of dominant surficial material, the depth of the active layer above permafrost recorded in the Goose Lake area ranged from 1.3 to 4.2 m below grade (ERM Rescan 2014). At the Boston site, the depth of the active layer was 2 m below ground surface and the depth of zero amplitude (at which the seasonal changes in air temperature no longer affect the ground temperature) was estimated to be about 11 m below surface (SRK Consulting 2005). Recent data from the Goose Lake area (located 230 km south of the PDA) indicated that active layer thaw starts in early- to mid-June, and freeze-up progresses from late September to as late as end of December (ERM Rescan 2014).

In the Arctic, sensitivity of particular deposits to surface disturbance is typically associated with the depth of active layer above permafrost and with the annual patterns of groundwater movement through those deposits during the frost–free period. Surface disturbance in sensitive terrain can lead to subsidence and considerable (often irreversible) changes in local hydrology (Jorgenson and Osterkamp 2005; Lantz et al. 2009).

It is expected that most of the areas dominated by bedrock, weathered bedrock, and colluvium (SMU-R) will display relatively low sensitivity to surface disturbance. Most of this resilience is associated with the presence of rigid mineral material and low water and ice content resulting from elevated topographic position. Similarly, rapidly drained, very thin eolian, and morainal veneers resting on elevated bedrock or saprolite (SMU-V and SMU-MR), typically found on upper slopes and crests, will not be sensitive to disturbance. Well-drained, coarse materials deposited as beaches (SMU-Z) are also likely to be resilient to development (Table 7.2-5).

Sensitivity of morainal deposits typically found in mid-slope positions (SMU-M1) can be highly variable depending on specific slope morphology and hydrology. In general, increasing site elevation decreases soil sensitivity but specific patterns of site groundwater dynamics can significantly modify that rule. Morainal deposits located on lower slopes or in low topographic positions (e.g., SMU-M2) are likely to have high ice content and as such display greater susceptibility to surface disturbance.

Turbic Cryosols that developed on imperfectly to poorly drained Glaciomarine, Glaciolacustrine, and Lacustrine materials deposited in the valleys are typically very sensitive to surface disturbance (Table 7.2-5). Similarly, organic surficial deposits (SMU-O1 and O2), and Cryosols or Gleysols associated with riparian zones (SMU-F), where Glaciofluvial of Fluvial material is covered by thin organic veneers, are more susceptible to surface disturbance, which may result in permafrost or ice lens degradation.

A number of studies suggest that ice cores are a characteristic feature of eskers at the time of their origin (Banerjee and McDonalds 1975; Moorman and Michel 2003; Huddart and Stott 2010). Evidence of massive ice cores located within glaciofluvial deposits (e.g., eskers) were reported in studies conducted in Northwest Territories (Dallimore and Wolfe 1988; Dallimore and Davis 1992; Wolfe et al. 1997; Moorman and Michel 2003; Robinson et al. 2003; Macumber et al. 2011). The above findings suggest that the majority of glaciofluvial deposits located in the west Kitikmeot region of Nunavut may contain massive ice cores. Because there are only a few small eskers that overlap with the proposed Phase 2 Project infrastructure near the south-eastern boundary (Figure 7.2-2 in Section 7.2.5.2), few potential impacts to these landforms are predicted.

Table 7.2-5. Sensitivity of Soils to Surficial Development

Dominant Surficial Material/s	Soil Mapping Unit	Area (ha)	Proportion of LSA (%)	Characteristics	Sensitivity to Development
Bedrock	R	4,937	9	bedrock or saprolite with some rapidly drained, thin Brunisols or Regosols in high elevations	Resilient
Very thin Eolian or Morainal veneers (< 20 cm)	V	3,352	6	rapidly drained, thin Brunisols or Regosols on bedrock or saprolite in high elevations	Resilient
Beach	Z	49	0	well-drained, coarse textures, beaches	Resilient
Morainal	MR	3,969	7	very rapidly to well drained, high elevation, bedrock outcrops	Resilient
	M1	7,499	13	rapidly to moderately well-drained, permafrost at 60-80 cm	Moderately Sensitive
	M2	5,655	10	imperfectly to poorly drained, lower slopes, permafrost at 40-80 cm	Sensitive
Glaciofluvial/ Fluvial	F	817	1	moderately to poorly drained, Cryosols or Gleysols, permafrost at 40-60 cm	Sensitive
Glaciomarine/ Glaciolacustrine/ Lacustrine	W1	1,455	3	moderately well-drained, in valleys, Turbic Cryosols, permafrost at 30-70 cm	Sensitive
	W2	9,996	18	imperfectly to poorly drained, on valley bottoms, Turbic Cryosols, permafrost at 20-60 cm	Very Sensitive
Organic	O1	7,526	13	imperfectly to very poorly drained, Organic Cryosols, permafrost near surface	Very Sensitive
	O2	2,124	4	very poorly drained, bogs or palsas, Organic Cryosols, permafrost near surface	Very Sensitive
Water	Water	8,946	16	not classified	not classified
Anthropogenic	A	10	0.02	not classified	not classified
Ice	I	5	0.01	not classified	not classified

7.3 VALUED COMPONENTS

7.3.1 Potential Valued Components and Scoping

The VEC scoping process follows the process outlined in the *Effects Assessment Methodology* (Volume 2, Section 4). The EIS Guidelines (NIRB) proposed a number of VECs related to Terrestrial Environment to be considered for inclusion in the effects assessments, including:

1. Terrestrial ecology;
2. Landforms and soils; and
3. Permafrost and ground stability.

The selection of VECs began with those proposed in the EIS Guidelines and was further modified through consultation with stakeholders (local communities, regulatory agencies, available TK, professional expertise, other recent projects in Nunavut, and the NIRB's final scoping report (Appendix B of the EIS Guidelines). TK information was gathered at focus group meetings with members of Kitikmeot communities. The TK report (Banci and Spicker 2015) provides information on valued ecological resources within the Project area. These are described in the socio-economic and land use baseline report (Appendix V6-3A). Based on TMAC-led public consultation, the TK report (Banci and Spicker 2015), consultation with regulatory agencies, and regulatory considerations, Landforms and Soils were classified as a Subject of Note.

Landforms and Soils are considered a Subject of Note and are not further assessed in the EIS because the potential for effects on landforms and soils are considered under other VECs (e.g., Vegetation and Special Landscape Features, Permafrost, Wildlife and Wildlife Habitat, Human Health and Ecological Risk). Additional information specific to subjects such as potential Project impacts on soil erosion, compaction, acidification, and eutrophication, as well as discussion of implications of Project design related to local terrain conditions were provided here to further qualify assessments of environmental effects discussed under above listed VECs. All information requested in the NIRB-issued EIS guidelines relating to Landforms and Soils is included in the EIS.

7.3.2 Project Overview

The Madrid-Boston Project consists of proposed mine operations at the Madrid North, Madrid South, and Boston deposits. The Madrid-Boston Project is part of a staged approach to continuous development of the Hope Bay Greenstone Belt, comprising existing operations at Doris, a bulk sample followed by commercial mining at Madrid North and Madrid South, and commercial mining of the Boston deposit. The Madrid-Boston Project would use and expand upon the existing Doris Project infrastructure.

The Madrid-Boston Project is the focus of this application. Because the infrastructure of existing and approved projects will be utilized by the Madrid-Boston Project, and because the existing and approved projects have the potential to interact cumulatively with the Madrid-Boston Project, existing and approved project are described below.

7.3.2.1 Existing and Approved Projects

Existing and approved projects include:

- the Doris Project (NIRB Project Certificate 003, NWB Type A Water Licence 2AM-DOH1323);
- the Hope Bay Regional Exploration Project (NWB Type B Water Licence 2BE-HOP1222);
- the Madrid Advanced Exploration Program (NWB Type B Water Licence 2BB-MAE1727); and
- the Boston Advanced Exploration Project (NWB Type B Water Licence 2BB-BOS1727).

<u>The Doris Project</u>

The Doris Project was approved by NIRB in 2006 (NIRB Project Certificate 003) and licenced by NWB in 2007 (Type A Water Licence 2AM-DOH0713). The Type A Water Licence was amended in 2010, 2011 and 2012 and received modifications in 2009, 2010, and 2011.

Construction of the Doris Project began in early 2010. In early 2012, the Doris Project was placed into care and maintenance, suspending further Project-related construction and exploration activity along the Hope Bay Greenstone Belt. Following TMAC's acquisition of the Hope Bay Project in March of 2013, NWB renewed the Doris Project Type A Water Licence (Type A Water Licence 2AM-DOH1323), and TMAC advanced planning, permitting, exploration, and construction activities. In 2016, NIRB approved an amendment to Project Certificate 003 and NWB granted Amendment No. 1 to Type A Water Licence 2AM-DOH1323, extending operations from two to six years through mining two additional mineralized zones (Doris Connector and Doris Central zones) to be accessed via the existing Doris North portal. Amendment No. 1 to Type A Water Licence 2AM-DOH1323 authorizes a mining rate of approximately

2,000 tonnes per day of ore and a milling throughput of approximately 2,000 tonnes per day of ore. The Doris Project began production early in 2017.

The Doris Project includes the following components and facilities:

- The Roberts Bay offloading facility: marine jetty, barge landing area, beach laydown area, access roads, weather havens, fuel tank farm/transfer station, waste storage facilities and incinerator, and quarry;
- The Doris site: 280 person camp, laydown areas, service complex (e.g., workshop, wash bay, administration buildings, mine dry), two quarries (mill site platform and solid waste landfill), core storage areas, batch plant, brine mixing facilities, vent raise (3), air heating units, reagent storage, fuel tank farm/transfer station, potable water treatment, waste water treatment, incinerator, landfarm and handling/temporary hazardous waste storage, explosives magazine, and diesel power plant;
- Doris Mine works and processing: underground portal, overburden stockpile, temporary waste rock pile, ore stockpile, and processing mill;
- Tailings Impoundment Area (TIA): Schedule 2 designation for Tail Lake with two dams (North and South dams), sub-aerial deposition of flotation tailings, emergency tailings dump catch basins, pump house, and quarry;
- All-season main road with transport trucks: Roberts Bay to Doris site (4.8 km, 150 to 200 tractor and 300 fuel tanker trucks/year);
- Access roads from Doris site used predominantly by light-duty trucks to: Tail Lake (5.9 km), the explosives magazine (0.5 km), Doris Lake float plane dock (0.5 km), solid waste disposal site (0.2 km), and to the tailings decant pipe (0.4 km),from the Roberts Bay offloading facility to the location where the discharge pipe enters the ocean (0.6 km); and
- All-weather airstrip (914 m), winter airstrip (1,524 m), helicopter landing site and building, and Doris Lake float plane and boat dock.

Water is managed at the Doris Project through:

- freshwater input from Doris Lake for mining, milling, and associated activities and domestic purposes;
- freshwater input from Windy Lake for domestic purposes;
- process water input primarily from Tail Lake;
- saline water from mining, porewater from waste rock, and ore discharged to Tail Lake;
- sewage and greywater treated in a waste water treatment plant and discharged to Tail Lake; and
- water from Tail Lake treated and discharged to Roberts Bay via a discharge pipeline, with use of a marine outfall mixing box (MOMB).

<u>Hope Bay Regional Exploration Project</u>

The Hope Bay Regional Exploration Project has been renewed several times since 1995. The current extension expires in June 2022. Much of the previous work for the program was based out of Windy Lake and Boston camps. These camps were closed in October 2008 with infrastructure either decommissioned or moved to the Doris site. All exploration activities are now based from the Doris site and in the future from the Boston site. Components and activities for the Hope Bay Regional Exploration Project include:

- operation of helicopters from Doris (4 hours per day in the summer months); and
- the use of exploration drills, which are periodically moved by helicopter.

Madrid Advanced Exploration

In 2017, the NWB approved a Type B Water Licence (2BB-MAE1727) for the Madrid Advanced Exploration Program to support continued exploration and a bulk sample program at the Madrid North and Madrid South sites, located approximately 4 km south of the Doris site. The program includes extraction of a bulk sample totaling 50 to 60 tonnes, which will be trucked to the mill at the Doris site for processing and placement of tailings in the tailings impoundment area (TIA). All personnel will be housed in the Doris camp.

The Madrid Advanced Exploration Program includes the following components and activities.

- Use of existing infrastructure associated with the Doris Project:
  - camp facilities to support up to 70 personnel as required to undertake the advanced exploration activities;
  - mill to process ore;
  - TIA;
  - landfill and hazardous waste areas, particularly if closure and remediation becomes required for the Madrid Advanced Exploration Program infrastructure;
  - fuel tank farms; and
  - Doris airstrip and Roberts Bay facility for transport of personnel and supplies.
- Use of existing infrastructure at the Madrid and Boston areas:
  - borrow and rock quarry facilities: existing Quarries A, B, and D along the Doris-Windy all-weather road (AWR);
  - AWR between Doris and Windy Lake for transportation of personnel, ore, waste, fuel, and supplies; and
  - future mobilization of existing exploration site infrastructure, should it become necessary.
- Construction of additional facilities at Madrid North and South:
  - access portals and ramps for underground operations at Madrid North and at Madrid South;
  - 4.7 km extension of the existing AWR originating from the Doris to the Windy exploration area (Madrid North) to the Madrid South deposit, with branches to Madrid North, Madrid North vent raise, and the Madrid South portal;
  - development of a winter road route (WRR) from Madrid North to access Madrid South until AWR has been constructed;
  - all weather access road and tailings line from Madrid North to the south end of the TIA;
  - borrow and rock quarry facilities; two quarries referenced as Quarries G and H;
  - waste rock and ore stockpiles;
  - water and waste management structures; and
  - additional site infrastructure, including compressor building, brine mixing facility, saline storage tank, air heating facility, four vent raises, workshop and office, laydown area, diesel generator, emergency shelter, fuel storage facility/transfer station.

- Undertaking of advanced exploration access to aforementioned deposits through:
  - continued field mapping and sampling, as well as airborne/ground/downhole geophysics;
  - diamond drilling from the surface and underground; and
  - bulk sampling through underground mining methods and mine development.

Boston Advanced Exploration

The Boston Advanced Exploration Project Type B Water Licence No. 2BB-BOS1217 was renewed as Water Licence No. 2BB-BOS1727 in July 2017 and includes:

- the Boston camp (120 person), maintenance shops, workshops, laydown areas, water pumphouse, vent raise, warehouse, site service roads, sewage and greywater treatment plant, fuel storage and transfer station, landfarm, solid waste landfill and a heli-pad;
- mine works, consisting of underground development for exploration drilling and bulk sampling, temporary waste rock pile, and ore stockpile;
- potable water and industrial water from Aimaokatalok Lake; and
- treated sewage and greywater discharged to the tundra.

7.3.2.2 The Madrid-Boston Project

The Madrid-Boston Project includes: the Construction and Operation of commercial mining at the Madrid North, Madrid South, and Boston sites; the continued operation of Roberts Bay and the Doris site to support mining at Madrid and Boston; and the Reclamation and Closure and Post-closure phases of all sites. Excluded from the Madrid-Boston Project for the purposes of the assessment are the Reclamation and Closure and Post-closure components of the Doris Project as currently permitted and approved.

Construction

Madrid-Boston construction will use the infrastructure associated with Existing and Approved Projects. This may include:

- an all-weather airstrip at the Boston exploration area and helicopter pad;
- seasonal construction and/or operation of a winter ice strip on Aimaokatalok Lake;
- Boston camp with expected capacity for approximately 65 people during construction;
- Quarry D Camp with capacity for up to 180 people;
- seasonal construction/operation of Doris to Boston WRR;
- three existing quarry sites along the Doris to Windy AWR;
- Doris camp with capacity for up to 280 people;
- Doris airstrip, winter ice strip, and helicopter pad;
- Roberts Bay offloading facility and road to Doris; and
- Madrid North and Madrid South sites and access roads.

Additional infrastructure to be constructed for the proposed Madrid-Boston Project includes:

- expansion of the Doris TIA (raising of the South Dam, construction of West Dam, development of a west road to facilitate access, and quarrying, crushing, and screening of aggregate for the construction);

- construction of an off-loading cargo dock at Roberts Bay (including a fuel pipeline, upland mooring points, beach landing and gravel pad, shore manifold);
- construction of an additional tank farm at Roberts Bay (consisting of two 5 ML tanks);
- expansion of accommodation facility (from 280 to 400 person), mine dry and administrative building, water treatment at Doris site;
- complete development of the Madrid North and Madrid South underground workings;
- incremental expansion of infrastructure at Madrid North and Madrid South to accommodate production mining, including vent raise, access road, process plant buildings;
- construction of a 1,200 tpd concentrator, fuel storage, power plant, mill maintenance shop, warehouse/reagent storage at Madrid North;
- all weather access road and tailings line from Madrid North to the south end of the TIA;
- AWR linking Madrid to Boston (approximately 53 km long, nine quarries for permitting purposes, four of which will likely be used);
- all-weather airstrip, airstrip building, helipad and heliport building at Boston;
- construction of a 2,400 tpd process plant at Boston;
- all infrastructure necessary to support mining and processing activities at Boston including construction of a new 300-person accommodation facility, mine office and dry and administration buildings, additional fuel storage, laydown area, ore pad, waste rock pad, diesel power plant and dry-stack tailings management area (TMA);
- infrastructure necessary to support ongoing exploration activities at both Madrid and Boston; and
- wind turbines near the Doris (2), Madrid (2), and Boston (2) sites.

<u>Operation</u>

Madrid-Boston Project is intended to cover the proposed incremental development of the Hope Bay Greenstone Belt. The Operation phase includes:

- mining of the Madrid North, Madrid South, and Boston deposits;
- operation of a concentrator at Madrid North;
- transportation of ore from Madrid North, Madrid South, and Boston to the Doris process plant, and transporting the concentrate from the Madrid North concentrator to the Doris process plant;
- extending the operation at Roberts Bay and Doris;
- processing the ore and/or concentrate from Madrid North, Madrid South, and Boston at the Doris process plant with disposal of the detoxified tailings underground at Madrid North, flotation tailings from the Doris process plant pumped to the expanded Doris TIA, and discharge of the TIA effluent to the marine environment;
- operation of a concentrator at Madrid North and disposal of tailings at the Doris TIA;
- operation of a process plant and wastewater treatment plant at Boston with disposal of flotation tailings to the Boston TMA and the detoxified leached tailings in the underground mine at Boston;
- operation of two wind turbines for power generation; and
- ongoing maintenance of transportation infrastructure at all sites (cargo dock, jetty, roads, and quarries).

Reclamation and Closure

Areas which are no longer needed to carry out Madrid-Boston Project activities will be progressively reclaimed during Construction and Operation. Where practicable, progressive rehabilitation will be implemented to achieve the site abandonment goal and closure principles (see Volume 3, Chapter 2, Section 5).

At Reclamation and Closure, all sites will be deactivated and reclaimed in the following manner (see Volume 3, Chapter 2, Section 5.5):

- Camps and associated infrastructure will be demolished and/or disposed of in approved non-hazardous site landfills.
- Non-hazardous landfills will be progressively covered with quarry rock, as cells are completed. At final closure, the facility will receive a final quarry rock cover which will ensure physical and geotechnical stability.
- Rockfill pads occupied by construction camps and associated infrastructure and laydown areas will be re-graded to ensure physical and geotechnical stability and promote free-drainage, and any obstructed drainage patterns will be re-established.
- Landfarms will be closed by removing and disposing of the liner, and re-grading the berms to ensure the area is physically and geotechnically stable.
- Mine waste rock will be used as structural mine backfill.
- The Doris TIA surface will be covered with waste rock. Once the water quality in the reclaim pond has reached the required discharge criteria, the North Dam will be breached and the flow returned to Doris Creek.
- The Madrid to Boston AWR and Boston Airstrip will remain in place after Reclamation and Closure. Peripheral equipment will be removed. Where rock drains, culverts, or bridges have been installed, the roadway or airstrip will be breached and the element removed. The breached opening will be sloped and armoured with rock to ensure that natural drainage can pass without the need for long-term maintenance.

A low permeability cover, including a geomembrane, will be placed over the Boston TMA. The contact water containment berms will be breached and the liner will be cut to prevent collecting any water. The balance of the berms will be left in place to prevent localized permafrost degradation.

7.4 SUPPORTING AND SUPPLEMENTAL INFORMATION

The following sections provide supplemental information as requested in the EIS guidelines (NIRB 2012; Section 8.1.4). The information provided below pertains to the LSA.

7.4.1 Potential for Soil Erosion Associated with the Project Components and Activities

Erosion of the most valuable, organically enriched and biologically most active soil surficial horizons negatively affects soil quality. The area of land affected by soil erosion and the severity of this adverse effect are generally expected to be most prevalent during the Construction and Closure phases of the Project life. Roads, especially those built on slopes, in wetlands, and in areas characterized by erodible surficial materials, are expected to contribute to soil erosion for as long as they are active (Daigle 2010).

Proposed construction activities involving disturbance of soil surface, vegetation removal, and stockpiling of loose material (e.g., waste rock stockpiling, quarrying or TIA embankment construction) are typically associated with increased soil erosion. Similarly, progressive reclamation activities (completed during Construction and Operation), gradual covering of landfill cells, as well as dismantling of Project components and associated reclamation activities during Closure will expose the soils to increased risk of erosion. However, soil disturbance that potentially may lead to soil erosion is expected only within the PDAs, as the development activity will be confined to these areas. Because it is assumed that the entire area of the PDAs is lost for the duration of the Project (Project Description Section 2), the effects of Project activities on soil erosion are assessed only for the Closure and Post-closure phases.

In newly decommissioned/reclaimed areas, where soil surface is disturbed or devoid of vegetation, the most fertile surficial fractions of soil may be lost due to wind erosion. Wind erosion of exposed soils may also result in dust and sediment entering waterways. However, based on the dust modeling, most of these effects are contained within the PDA, which is considered lost. The results of dust modeling are discussed in the Air Quality effects assessment (Volume 4, Section 2).

Exposed mineral soils are also sensitive to water erosion. For example, the ice-rich surficial materials, once excavated and stockpiled, will thaw. This process is associated with the release of seepage and sediment. On disturbed slopes, soil erosion can also occur during spring snow/ice melt and during rainfall events. Spring melt water movement in the active layer of the soil is generally very dynamic in permafrost regions. While this phenomenon can exacerbate potential erosion problems in disturbed sloping areas, it appears that the LSA geomorphology is generally subtle. The majority of the areas (92%) proposed for development are level, very gently, or gently sloping (Table 7.4-1, Figure 7.4-1). With the implementation of erosion mitigation procedures on construction or reclamation sites, such topographic conditions are generally associated with low risk of erosion and sediment transport. Description of activities and management measures to avoid or minimize soil erosion during the Project life are provided in the Project Description (Volume 3, Sections 3 to 5).

Table 7.4-1. Summary of Slope Gradients in the LSA

Slope Class	Slope Gradient Range	Slope Gradient Descriptor	LSA (ha)	LSA (%)	PDA (ha)	PDA (%)
0	0-2%	level	12,842	23%	905	22%
1	3-5%	very gently sloping	19,692	35%	1,725	41%
2	6-15%	gently sloping	11,240	20%	1,234	29%
3	16-26%	moderately gently sloping	2,179	4%	194	5%
4	27-40%	moderately sloping	618	1%	41	< 1%
5	41-70%	moderately steeply sloping	150	< 1%	7	< 1%
6	> 70%	steeply sloping	7	< 1%	0.3	< 1%
NR - not rated	-	-	-	-	-	-
water	-	-	9,612	17%	82	2%
Total			**56,340**	**100**	**4,189**	**100%**

Note: *LSA = Local Study Area; PDA = Project Development Area*

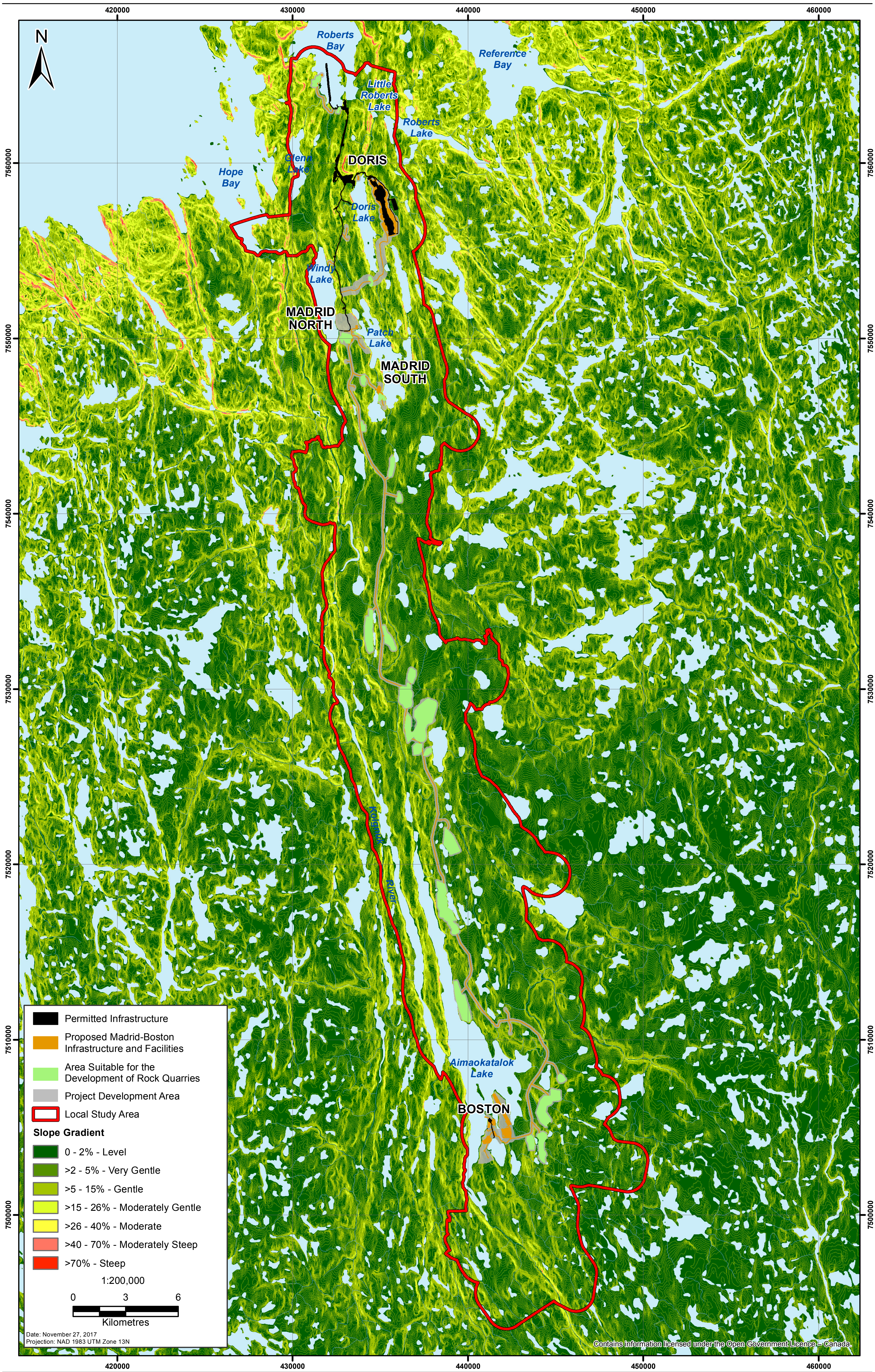
Even on relatively flat terrain, however, exposed finer soils may be susceptible to splash erosion, which can result in a loss of soil structure and crusting of the surface, thereby impeding development of seeded protective vegetation. Reclamation activities performed on sensitive soils will involve optimization of seeding times to avoid spring snowmelt and summer rainy periods.

Soil characteristics that affect soil erodibility (such as texture, structure, proportion of coarse fragments) among the inspected SMUs (24% of the LSA) suggest that some soils in the LSA are susceptible to soil erosion. Table 7.4-2 shows the proportions of land within each of the SMUs where soils are displaying high, moderate, and low sensitivity to erosion.

Table 7.4-2. Predicted Sensitivity to Soil Erosion among the Inspected SMUs

Soil Management Unit		Characteristics	Sensitivity to Erosion	Proportion of SMU
Glaciofluvial/Fluvial	F	moderately to poorly drained, Cryosols or Gleysols, permafrost at 40-60 cm	high	49%
			moderate	24%
			low	27%
Morainal	M1	rapidly to moderately well-drained, permafrost at 60-80 cm	high	37%
			moderate	13%
			low	49%
	M2	imperfectly to poorly drained, lower slopes, permafrost at 40-80 cm	high	25%
			moderate	18%
			low	58%
	MR	very rapidly to well-drained, high elevation, bedrock outcrops	high	20%
			moderate	23%
			low	57%
Organic	O1	imperfectly to very poorly drained, Organic Cryosols, permafrost near surface	high	69%
			moderate	16%
			low	15%
	O2	very poorly drained, bogs or palsas, Organic Cryosols, permafrost near surface		
			high	94%
			low	6%
Bedrock	R	bedrock or saprolite with some rapidly drained, thin Brunisols or Regosols in high elevations	high	37%
			moderate	10%
			low	53%
Very thin Eolian or Morainal veneers (< 20 cm)	V	rapidly drained, thin Brunisols or Regosols on bedrock or saprolite in high elevations	high	25%
			moderate	10%
			low	65%
Glaciomarine/ Glaciolacustrine/ Lacustrine	W1	moderately well-drained, in valleys, Turbic Cryosols, permafrost at 30-70 cm	high	58%
			moderate	32%
			low	10%
	W2	imperfectly to poorly drained, on valley bottoms, Turbic Cryosols, permafrost at 20-60 cm	high	66%
			moderate	20%
			low	14%
Beach	Z	well-drained, coarse textures, beaches	low	100%

Figure 7.4-1
Slope Gradients within the Local Study Area



A large proportion of soils developed on glaciomarine, glaciolacustrine, and lacustrine deposits (W1 and W2) display high sensitivity to erosion (Table 7.4-2). Any disturbances occurring on sloping terrain or involving creation of inclined slopes in these SMUs will require careful erosion prevention and sediment control. Development of Project infrastructure is proposed over 300 ha of SMUs W2 and W1. After Closure the area disturbed by the Hope Bay Development (which is the combined footprint of both Phase 1 and Phase 2) will cover 14 ha of SMU-W1 and 371 ha of SMU-W2 (Table 7.4-3).

Table 7.4-3. Proportions of Soil Mapping Units within the PDA, and under Proposed Phase 2 and Hope Bay Project Infrastructure Footprint

Dominant Surficial Material/s	Soil Mapping Unit	PDA		Hope Bay Project Footprint		Phase 2 Infrastructure Footprint	
		Area (ha)	%	Area (ha)	%	Area (ha)	%
Anthropogenic	A	3	< 1%	2	< 1%	0	< 1%
Beach	Z	6	< 1%	1	< 1%	1	< 1%
Bedrock	R	540	13%	308	18%	305	21%
Glaciofluvial/Fluvial	F	54	1%	15	1%	14	1%
Glaciomarine/ Glaciolacustrine/Lacustrine	W1	135	3%	14	1%	13	1%
	W2	965	23%	371	22%	287	20%
Ice	I	-	-	-	-	-	-
Morainal	MR	357	9%	217	13%	180	12%
	M1	690	16%	259	15%	251	17%
	M2	500	12%	151	9%	139	9%
Organic	O1	420	10%	106	6%	96	7%
	O2	152	4%	31	2%	30	2%
Very thin Eolian or Morainal veneers (< 20 cm)	V	283	7%	147	9%	146	10%
Water	WATER	82	2%	74	4%	2	< 1%
Total Area		**4,189**	**100%**	**1,696**	**100%**	**1,463**	**100%**

While glaciofluvial deposits are typically coarse and contain high proportions of coarse mineral fragments, a considerable percentage of fluvial materials in the LSA have finer, less permeable soils that are highly sensitive to erosion (Table 7.4-2). Nevertheless, streams in the LSA are generally protected against current levels of stream bank erosion and are often covered by a tough organic layer reinforced by a network of intertwined root systems. Phase 2 construction work in the riparian zones (involving less than 14 ha of the SMU-F, Table 7.4-3) is expected to temporarily increase stream bank erosion potential, but mitigation measures for erosion control will be in place as outlined in *Freshwater Water Quality* and *Freshwater Sediment Quality* (Volume 5, Chapters 4 and 5).

When disturbed, deposits currently covered by organic horizons (SMU-O1 and especially SMU-O2) may display high erosion potential due to typically finer mineral soil textures and shallow active layer above the permafrost. Disturbance of the surficial protective organic layer could also lead to permafrost degradation and land subsidence (Racine and Ahlstrand 1991). Development of Phase 2 infrastructure is proposed on 96 ha of SMU-O1 and 30 ha of SMU-O2. After Closure the area disturbed by the entire Hope Bay Development will cover 106 ha of SMU-O1 and 31 ha of SMU-O2 (Table 7.4-3).

Morainal deposits are expected to display variable but generally medium to low erosion potential. Erosion risk will increase if soil disturbance during Phase 2 takes place in the rapidly to moderately well drained SMU-M1 (251 ha of the proposed Project infrastructure, Table 7.4-3), on sloped terrain or if the soil is stockpiled.

Areas dominated by bedrock, thin morainal or eolian veneers and marine beach deposits are expected to exhibit relatively low erosion potential. Development of Phase 2 infrastructure is proposed on 305 ha of SMU-R and 146 ha of SMU-V, and 1 ha of SMU-Z (Table 7.4-3). Appendix V4-7A provides detailed information on spatial distribution of surficial deposits and their characteristics.

7.4.2 Potential Impacts on Soil Quality from Compaction

Soil compaction is typically associated with construction activities, soil handling, or wheel traffic. Consequently, the highest risk of soil compaction within the Project PDA is expected during Construction and Closure. Soil disturbance leading to soil compaction is expected to occur only within the PDAs. Because it is assumed that the entire area of each PDA will be lost for the duration of the Project life, the effects of Project development on soil compaction are discussed only in regards to Closure and Post-closure phases.

Compaction changes soil by decreasing spaces between soil particles and thus limiting gas and water exchange within the soil. This limits root system development and results in decreased percolation and thus higher runoff. In addition to these effects, in areas underlain by permafrost, other factors play role in the effects of disturbance on soil quality. During the growing season, when soils are not frozen, most tundra soils are highly sensitive to compaction associated with even light intensity traffic over the soil surface (Rescan 2011). Soil compaction results in significant soil temperature changes, degradation of organic horizon, and reduction of pore space between soil particles. Compaction, which in turn limits water exchange between soil and atmosphere and reduces water, nutrient, and air movement in the soil, leading to deterioration of soil fertility and decline in plant establishment and growth. In the Arctic, soil compaction can also lead to ground surface subsidence due to thawing of ice-rich permafrost (Racine and Ahlstrand 1991).

Areas dominated by bedrock as well as upland glaciomarine and glaciofluvial deposits are expected to exhibit relatively low susceptibility to compaction, whereas wetlands and tundra located in lower topographic positions (e.g., lower slopes, slope toes, depressions, and valley floors) are most vulnerable (Figure 7.4-2). According to the classification discussed in Table 7.2-5, about 22% of surficial materials located within the LSA are expected to be relatively resilient to compaction. Among the remaining surficial materials 13% are classified as moderately sensitive, 14% as sensitive, and 35% as very sensitive (Table 7.2-5). Table 7.4-4 summarizes the areas of potential disturbance involving soil compaction in each of the soil sensitivity groups. It is predicted that after Closure the soil compaction associated with the Hope Bay Development footprint will potentially affect up to 688 ha of sensitive and very sensitive soils. The area of sensitive and very sensitive soils potentially affected by the development of Phase 2 footprint is 579 ha.

7.4.3 Soil Suitability for Reclamation

The suitability of soils for salvage and reclamation was evaluated based upon the characteristics of the soils that comprise the SMUs. The evaluation of soil suitability was based on the analyses of physical characteristics, as presented in Table 7.4-5. SMUs rated Good or Fair are considered suitable for use. Site specific soil suitability for reclamation should be assessed in areas where salvage is being considered to confirm reclamation suitability of the soils. The principle limitations of soils in each SMU are also identified in Table 7.4-5.

Based on the criteria in Table 7.4-5, the majority of SMUs (36%) in the LSA were rated poor for reclamation uses or unsuitable (25%; primarily bedrock, ice, or water). SMUs rated poor to fair, because of variable soil conditions within the SMU, account for 26% of the LSA. Soils rate fair occur in SMU M2 and comprise 13% of the LSA.

Figure 7.4-2
Distribution of Soils Sensitive to Compaction in the Local Study Area

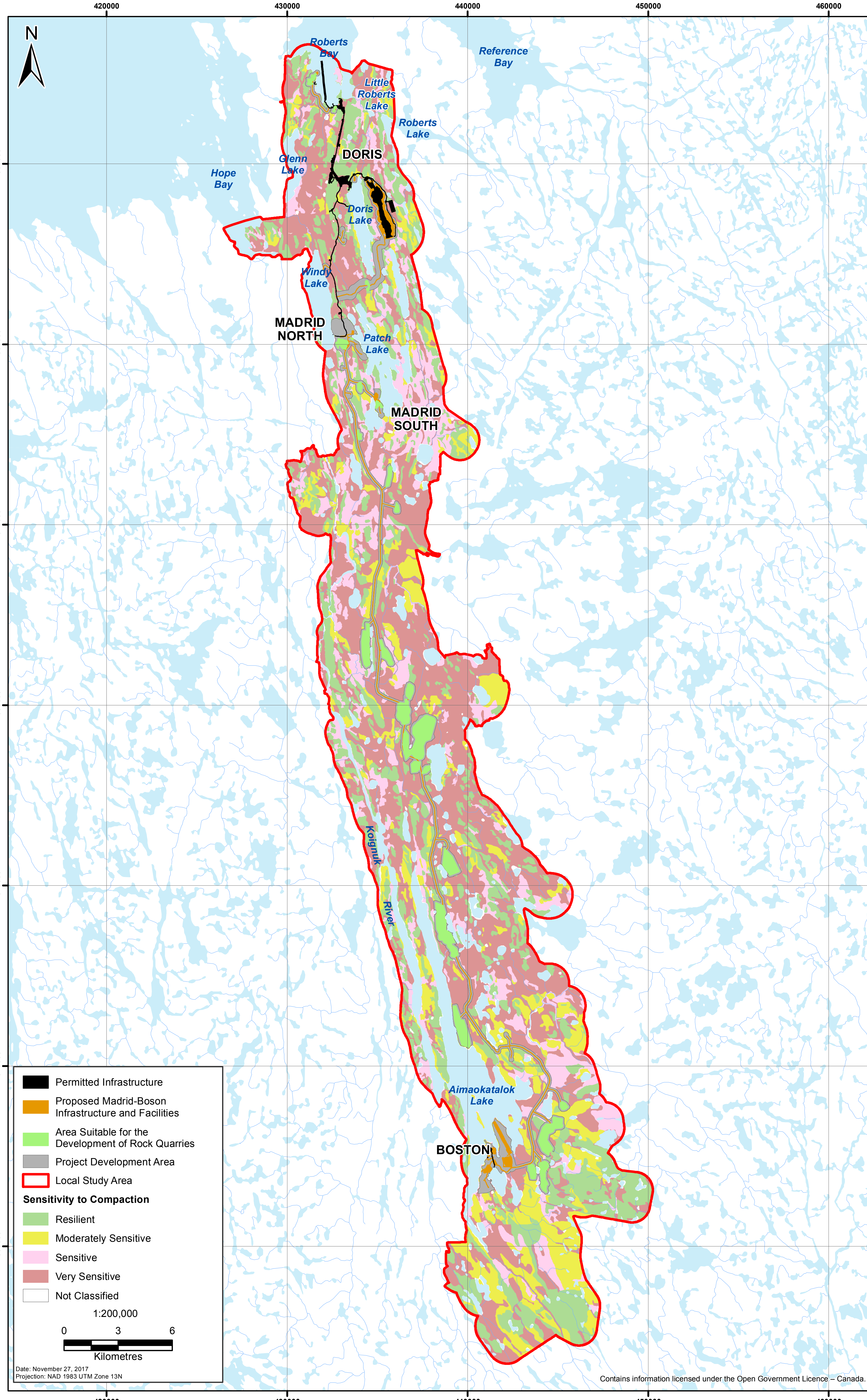


Table 7.4-4. Soil Mapping Units Sensitive to Compaction within the PDA and under Proposed Project Infrastructure

Dominant Surficial Material/s	Soil Mapping Unit	Sensitivity to Compaction	PDA		Hope Bay Project Footprint		Phase 2 Infrastructure Footprint	
			Area (ha)	%	Area (ha)	%	Area (ha)	%
Anthropogenic	A	not classified	3	< 1%	2	< 1%	0	< 1%
Beach	Z	low	6	< 1%	1	< 1%	1	< 1%
Bedrock	R	low	540	13%	308	18%	305	21%
Glaciofluvial/Fluvial	F	high	54	1%	15	1%	14	1%
Glaciomarine/ Glaciolacustrine/ Lacustrine	W1	high	135	3%	14	1%	13	1%
	W2	very high	965	23%	371	22%	287	20%
Morainal	MR	low	357	9%	217	13%	180	12%
	M1	moderate	690	16%	259	15%	251	17%
	M2	high	500	12%	151	9%	139	9%
Organic	O1	very high	420	10%	106	6%	96	7%
	O2	very high	152	4%	31	2%	30	2%
Very thin Eolian or Morainal veneers (< 20 cm)	V	low	283	7%	147	9%	146	10%
Water	WATER	not classified	82	2%	74	4%	2	< 1%
Total Area			**4,189**	**100%**	**1,696**	**100%**	**1,463**	**100%**

7.4.4 Potential Impacts to Soil Quality from Acidification and Nitrification

7.4.4.1 Soil Acidification

Industrial activities involving the use of diesel engines (e.g., power generation or transportation of materials) are expected to result in emission of compounds containing sulphur and nitrogen. Nitrogen oxides (NO_x) and sulphur dioxide (SO_2) emissions have been associated with increased atmospheric acid deposition, which is one of the main factors affecting soil acidification (Reuss, Cosby, and Wright 1987; Galloway 1995).

When acid deposition rates exceed soil capacity to buffer the increase in acidity, the resulting changes in soil chemical properties can modify the availability of nutrients within the soil, increase leaching of base cations, increase the bioavailability of metals to toxic levels, and negatively affect the viability and composition of the soil microbial community (Binkley et al. 1989; Foster 1989). Nutrient imbalances caused by soil acidification have been suggested as a common cause of reduced ecosystem health (Heij and Schneider 1991; Greaver et al. 2012) and reduced species diversity (De Schrijver et al. 2011). All these changes can have a negative influence on soil fertility and lead to poor vegetation nutrient status (Blaser et al. 1999; Watmough S.A. 2002; Fernandez et al. 2003).

A widely used method to assess the potential for soil acidification is the assessment of acid deposition critical loads. A critical load is the maximum amount of acid (deposited in given area within a given period) that a soil can neutralize. The soil’s ability to neutralize (buffer) acid is primarily determined by its base cation weathering rate (release of base cations from minerals to soil solution) which depends on the mineral composition of soil parent material. Several factors (e.g., coarse soil texture, rapid drainage, shallow soil depth, or low organic content in the A horizon) negatively affect soil buffering capacity (Nilsson and Grennfelt 1988; Hornung et al. 1995; Abboud and Turchenek 2009).

It is expected that the LSA soils generally have a low potential to buffer acidity. Baseline studies conducted to support the Project show indicate that the bedrock found in the LSA is mainly non-carbonate-bearing and resistant to weathering. Study of till geochemistry conducted in the Koignuk River valley by Kerr, Knight and Kyer (2000) supports this finding and suggests that granitic clasts are the dominant (90-100%) pebble lithology throughout the study area. While a clear association between the mineral composition of local bedrock and the buffering capacity of soils developed on weathered bedrock or colluvium may be expected, it is usually possible that soils that developed on materials transported by glaciers may possess chemical characteristics different from those of local minerals. A study by Kerr, Knight and Kyer (2000) suggests that in the Koignuk River area surficial materials were transported generally less than 10 km from their bedrock sources. Consequently, it should be expected that non-carbonate-bearing and resistant to weathering granites contributed a substantial proportion of mineral material to the local soils. Additionally, local upland soils are commonly shallow and coarse textured, with low cation exchange capacity, low sulphate adsorption capacity and low pH. The organic carbon content in the surficial horizons is also generally low.

Typical glaciofluvial sediments are dominated by slowly weathering minerals (particularly quartz), since these are most likely to have survived long transport within the glacier. Soils developed on glaciofluvial materials are therefore expected to possess very low buffering capacity. Dominant proportions of quartz, and thus very low acid-buffering capacity, may be also expected in soils that developed on eolian and fluvial parent materials. Organic soils, which typically do not store significant quantities of base cations, also have very limited ability to buffer acids (Aherne 2008).

The empirical method for calculation of the critical loads of acid deposition (e.g., used in Alberta by Abboud and Turchenek 2009) focuses on allocation of a soil parent material to a particular sensitivity class according to dominant minerals present in the soil. A similar approach was used in this assessment: the sensitivity of soils located in the LSA was evaluated according to their parent material mineralogy. Table 7.4-6 summarizes the predicted acid buffering capacity of soils and resulting critical loads of acid deposition in eq/ha/year.

The predicted amounts of acid deposition associated with proposed Project activities were modelled as part of the Air Quality effects assessment (Volume 4, Section 2). The highest acid deposition rates have been predicted for the areas surrounding the proposed Doris and Boston power plants, air exhaust vents at each underground mine, and docked shipping vessels at the port. The predicted maximum annual amount of acid deposited is 106.3 eq/ha/year, which suggests that the predicted levels of acid deposition will not lead to acidification of even most sensitive soils. Figure 7.4-3 shows distribution of soils sensitive to acidification.

7.4.4.2 Soil Nitrification, Ecosystem Eutrophication

Besides its effects on soil acidification, atmospheric deposition of nitrates may lead to increased bioavailability of nitrogen, one of the most important vegetation nutrients. Increases in nutrient availability in oligotrophic ecosystems may lead to competitive displacement of sensitive organisms (lichens, mosses, and evergreen dwarf shrubs) by fast-growing, opportunistic species of grasses and herbs, and in this way contribute to changes in plant species composition and diversity (Bowman and Steltzer 1998; Bobbink and Lamers 2002; Fenn et al. 2003; Bobbink et al. 2010). Increased levels of available macronutrients are also linked with reduction in the richness and density of mycorrhizal fungi in oligotrophic grasslands (Liu et al. 2012).

Figure 7.4-3
Distribution of Soils Sensitive to Acidification in the Local Study Area

TMAC RESOURCES

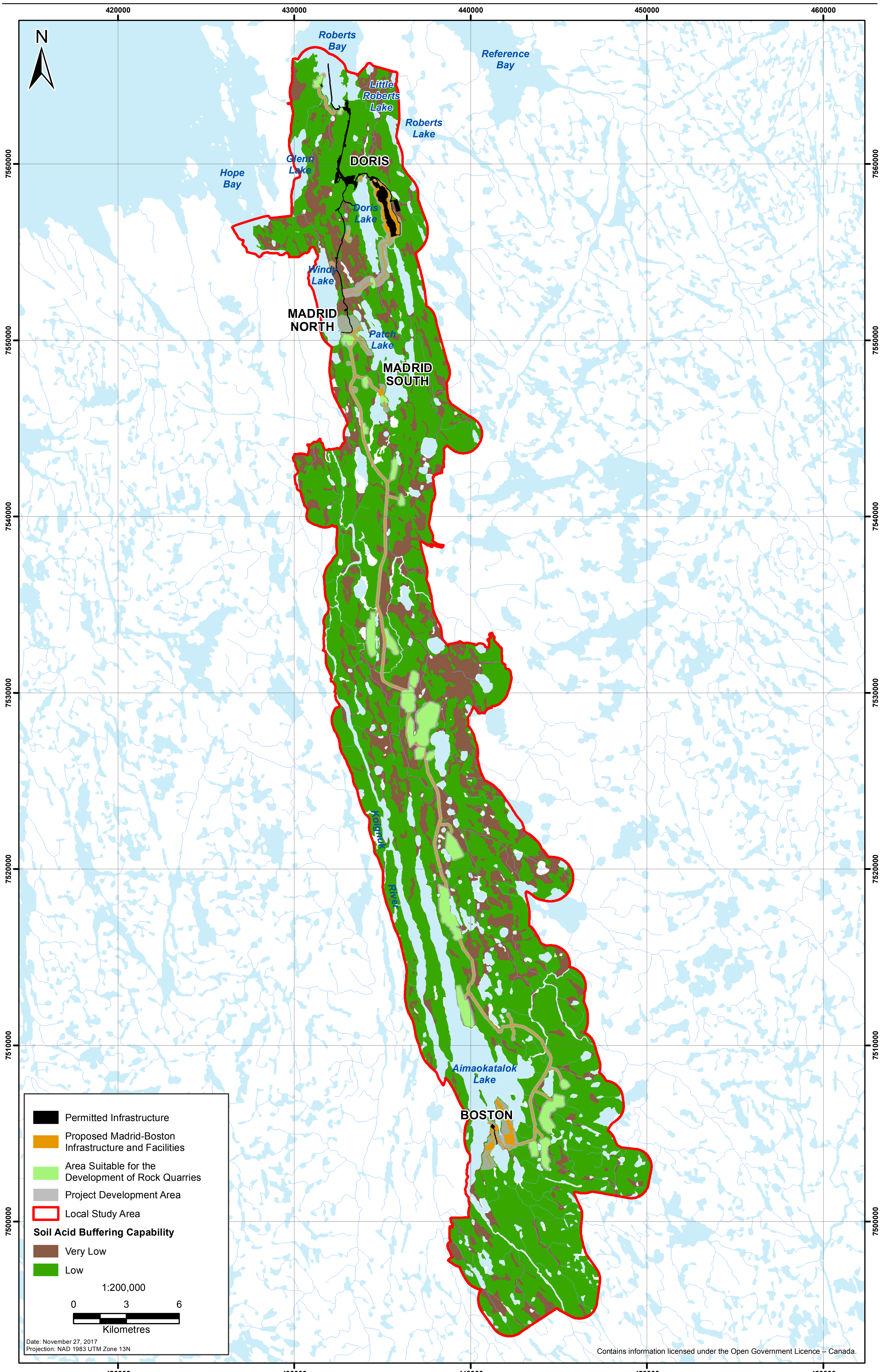


Table 7.4-5. Criteria for Evaluating Suitability of Soil for Use in Reclamation

Dominant Surficial Material/s	Soil Mapping Unit	Soil Classification	Soil Drainage	Soil Depth to Restricting Layer (Permafrost / Bedrock)	Soil Texture	Coarse Fragment Content	Soil Compaction Hazard	Soil Erosion Hazard (excluding slope)	Soil Suitability for Reclamation	Principle Limitations	Area (ha)	Proportion of LSA (%)
Anthropogenic	A	N/A	variable	variable	variable	variable	not classified	variable	poor to fair	disturbance history	10	< 1
Beach	Z	Regosols	well drained	variable	sandy gravelly soils	variable	low	low	poor - fair	coarse texture, potential for high coarse fragments	49	< 1
Bedrock	R	Brunisols or Regosols	rapidly drained	< 20 cm	coarse to coarse textured (sandy loam to loamy sand)	variable	low	low to moderate	unsuitable	soil depth limit salvage potential	4,937	9
Glaciofluvial/ Fluvial	F	Brunisols and Cryosols	poor to moderately well drained	40-60 cm in Cryosols; deeper in Brunisols	gravelly sands (Brunisols) to silty loams (Cryosols)	variable	high	low to high	poor - fair	compaction and erosion hazard in Cryosols, coarse fragment content	817	1
Glaciomarine/ Glaciolacustrine/ Lacustrine	W1	Cryosols	moderately well drained	30-70 cm	moderately fine textured (silty clay loam)	typically, stone free	high	High	poor	fine texture, compaction and erosion hazard	1,455	3
	W2	Cryosols (minor Gleysols)	imperfectly to poorly drained	20-60 cm	fine to fine textured (silty clay loam to silty clay)	typically, stone free	very high	High	poor	fine texture, compaction and erosion hazard	9,996	18
Ice	I	N/A	N/A	N/A	N/A	N/A	not classified	N/A	unsuitable	N/A	5	< 1
Morainal	MR	Brunisols and Regosols	well drained to very rapidly drained	morainal blankets and bedrock or morainal veneers	coarse to coarse textured (sandy loam to loamy sand)	15 to 40%	low	low to moderate	poor to fair	soil depth limit salvage potential in veneers, potential high coarse fragment content	3,969	7
	M1	Brunisols (minor Cryosols)	well to rapidly drained	60-80 cm	moderately coarse to coarse textured (sandy loam to loamy sand)	coarse fragments ranging from 15 to 25%	moderate	low to moderate	fair to good	coarse texture in soils with high sand content	7,499	13
	M2	Cryosols (minor Gleysols)	imperfectly to poorly drained soils	40-80 cm	medium to moderately coarse (silt loam to sandy loam)	coarse fragments ranging from 5 to 15%	high	moderate to high	poor	fine texture, compaction and erosion hazard	5,655	10
Organic	O1	Organic Cryosols	imperfectly to very poorly drained	30-70 cm	N/A	0	very high	high	poor - fair	compaction and erosion hazard, suitable for admixing with other salvaged soils	7,526	13
	O2	Organic Cryosols	imperfect to moderately well drained	< 20 cm	N/A	0	very high	high	poor - fair	soil depth limit salvage potential	2,124	4
Very thin Eolian or Morainal veneers (< 20 cm)	V	Brunisols and some Regosols	well to rapidly drained	< 20 cm	sandy loam to loamy sand	variable	low	low	poor	soil depth limit salvage potential	3,352	6
Water	Water	N/A	N/A	N/A	N/A	N/A	not classified		unsuitable	N/A	8,946	16
Total											56,340	100

Table 7.4-6. Local Soil Parent Materials, their Weathering Class and Acid Deposition Critical Loads

Surficial Deposit	Weathering Class	Acid Buffering Capacity	Critical Load eq/ha/year
Bedrock	2	low	200-500
Weathered bedrock	2	low	200-500
Colluvial	2	low	200-500
Eolian	1	very low	< 200
Fluvial	1	very low	< 200
Glaciofluvial	1	very low	< 200
Glaciolacustrine	2	low	200-500
Glaciomarine	2	low	200-500
Lacustrine	2	low	200-500
Marine	2	low	200-500
Morainal	2	low	200-500
Organic	1	very low	< 200

The concentrations of elements considered as plant macro nutrients (nitrogen, phosphorus, potassium, calcium, and magnesium) could increase in the soil in several areas of the LSA. Predicted yearly rates of nitrogen deposition in the LSA (resulting mainly from diesel engine emissions) are discussed in detail in the Air Quality effects assessment (Volume 4, Section 2). Detailed discussion of the predicted levels of potential nutrient deposition in various parts of the LSA, including maps, is also provided in the Air Quality effects assessment (Volume 4, Section 2).

Atmospheric nitrogen deposition of 5 to 10 kg N/ha/year has been suggested as the critical load for ombrotrophic bogs and alpine heath ecosystems (Bobbink and Roelofs 1995; Bobbink et al 2010; Tomassen et al 2003). Higher deposition levels are expected to lead to significant environmental changes. Studies conducted in the alpine ecosystems of Colorado (Baron et al. 2000) suggest, however, that even small increases in atmospheric nitrogen deposition (2 to 3 kg N/ha/year) lead to measurable changes in terrestrial and wetland ecosystem properties. Studies of Arctic heath vegetation (Gordon, Wynn, and Woodin 2001) show that small additions of phosphorus (1 to 5 kg P/ha/year) sustained for several years can alter species composition and increase ecosystem sensitivity to nitrogen addition.

Several ecosystems in the LSA characterized by low and very low productivity (including rock outcrops, Betula-Ledum-Lichen, Eriophorum Tussock Meadow and Dryas Herb assemblages), are particularly sensitive to eutrophication (Table 7.4-7). These ecosystems are characterized by very poor to poor nutrient regimes and they often provide unique habitat for rare species of lichens, mosses, and vascular plants. While no studies of ecosystem response to soil eutrophication have been conducted in the LSA, it is likely that these ecosystem types would respond negatively to annual deposition levels exceeding 5 kg of nitrogen or phosphorus per ha. A full list of ecosystems in the LSA classified according to their expected sensitivity to eutrophication is provided in Table 7.4-7. Distribution of listed ecosystems is shown in Figure 7.4-4.

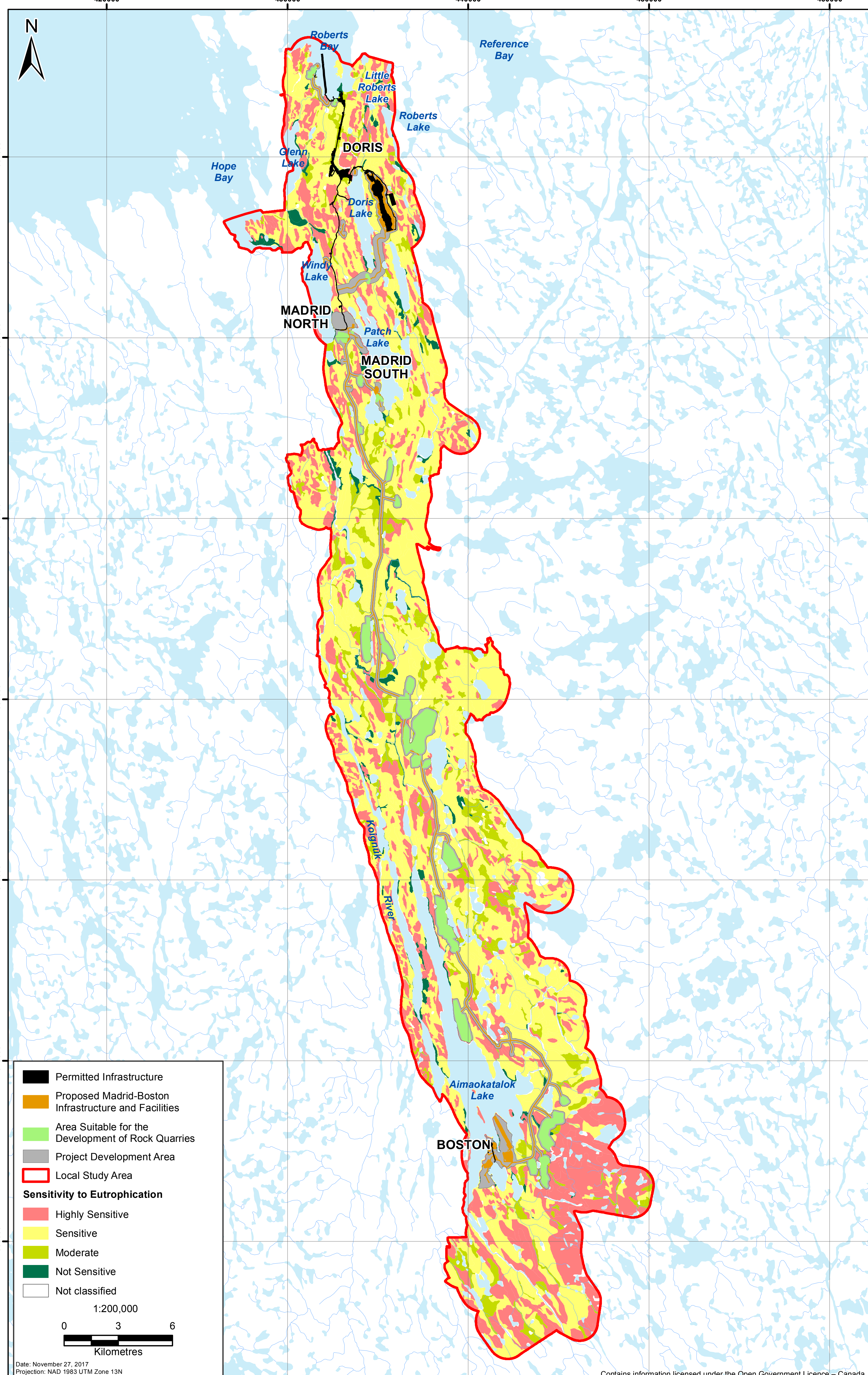
Rock outcrop ecosystem is typically associated with SMU-R (bedrock) and SMU-V (very thin eolian or morainal veneers). Betula-Ledum-Lichen ecosystem usually develops on SMU-R, SMU-V and SMU-M1 (rapidly to moderately well-drained morainal deposits over permafrost). Eriophorum Tussock Meadows are typically associated with SMU-M1 and Dryas Herb assemblages with SMU-V. Distribution of listed SMUs is shown on full-size soil maps in Appendix V4-7A.

Table 7.4-7. Ecosystems Sensitive to Eutrophication within the LSA

Ecosystem Description	Map Code	Sensitivity to Eutrophication	LSA (ha)	Percent
Barren	BA	Sensitive	5.8	0.0%
Beach	BE	Sensitive	20.9	0.0%
Blockfield	BI	Highly Sensitive	979.1	1.7%
Betula-Ledum-Lichen	BL	Highly Sensitive	7,075.8	12.6%
Betula-Moss	BM	Highly Sensitive	1,708.4	3.0%
Dry Carex-Lichen	CL	Highly Sensitive	527.1	0.9%
Dryas Herb Mat	DH	Sensitive	4,344.8	7.7%
Dry Willow	DW	Sensitive	1,243.8	2.2%
Emergent Marsh	EM	Moderate	751.1	1.3%
Exposed Soil	ES	Sensitive	77.5	0.1%
Low Bench Floodplain	FP	Sensitive	122.8	0.2%
Lakes and Ponds	LA	Not classified	8,214.6	14.6%
Marine Backshore	MB	Highly Sensitive	17.7	0.0%
Mine Spoils	MS	Sensitive	3.3	0.0%
Ponds	PD	Not classified	16.9	0.0%
Polygonal Ground	PG	Sensitive	10.6	0.0%
River	RI	Not classified	2,569.3	4.6%
Rock Outcrop	RO	Highly Sensitive	797.6	1.4%
Riparian Willow	RW	Not Sensitive	3,280.4	5.8%
Dwarf Shrub-Heath	SH	Not Sensitive	19.6	0.0%
Salt Water	SW	Not classified	1,229.5	2.2%
Eriophorum Tussock Meadow	TM	Sensitive	741.8	1.3%
Wet Meadow	WM	Moderate	741.1	1.3%
Total Area			**15,630.1**	

Concentrations of elements considered as plant macro nutrients (nitrogen, phosphorus, potassium, calcium, and magnesium) could increase in the soil in several areas of the LSA. Predicted yearly rates of nitrogen deposition in the LSA (resulting mainly from diesel engine emissions) are discussed in detail in the Air Quality effects assessment (Volume 4, Section 2). In general, the highest rates of nitrate deposition are predicted in the vicinity of the proposed Doris and Boston power plants, air exhaust vents at each underground mine, and the port. Concentrations of nitrogen, phosphorus, and potassium in the soil may also increase in the areas affected by dust deposition (e.g., along the roads and near sites). The predicted maximum annual amount of nitrogen deposited is 4.17 kg/ha/year and that of phosphorus is .0719 kg/ha/year, which suggests that the predicted levels of nutrient deposition will have a minor effect on eutrophication of local oligotrophic ecosystems. Detailed discussion of the predicted levels of potential nutrient deposition in various parts of the LSA, including maps, is provided in the Air Quality effects assessment (Volume 4, Section 2).

Figure 7.4-4
Distribution of Ecosystems Sensitive to Eutrophication in the Local Study Area



7.4.5 Implications to the Project Design Related to Terrain Conditions, in Particular Permafrost, Sensitive Landforms, High Ice-content Soils, Ice Lenses, Thaw-sensitive Slopes, and Talik Zones

In the Arctic, sensitivity of particular deposits to construction and surface disturbance is typically associated with the proximity of competent bedrock to ground surface, depth of active soil layer above permafrost, and annual patterns of groundwater movement through those deposits during the frost-free period. In the LSA, the most prevalent rock type with surface exposure is mafic volcanic basalt with isolated areas dominated by gabbro, felsic volcanics, and granitoids. These rock types are typically competent and exhibit well-defined foliation (Volume 4, Chapter 6). Soil temperatures, active layer thickness, and groundwater movement naturally vary across the LSA in response to microclimatic, topographic, geological, and biological factors such as summer temperatures, snow cover depth, slope aspect, position and gradient, soil permeability and moisture content, thickness of organic soil horizon, and surface vegetation. Within the LSA, the average ground temperature ranges between -10ºC and -6ºC (SRK Consulting 2005). Active layer thickness ranges from 0.5 m to 1.4 m (Volume 4, Section 6, Permafrost).

Sensitivity of local terrain conditions to surficial disturbance is discussed in Section 7.2.3.7 of this document. In general, conditions found in upland terrain polygons dominated by bedrock, very thin eolian or morainal veneers, and morainal deposits associated with very rapidly to well drained bedrock outcrops are considered most resilient to development. Terrain associated with imperfectly to poorly drained Turbic Cryosols developed on glaciomarine, glaciolacustrine, or lacustrine deposits and all organic deposits underlain by shallow permafrost and typically located on valley bottoms are the most sensitive.

Local marine deposits contain ground ice typically ranging from 10 to 30% by volume, but occasionally reaching 50%. The till typically contains low to moderate ice contents ranging from 5 to 25% (Volume 3, Section 3, Project Description – Construction Phase). Overall, 22% of surficial materials located within the LSA are expected to be resilient to development with the remainder classified as 13% moderately sensitive, 14% sensitive, and 35% very sensitive. Water bodies, anthropogenically altered sites, and ice (together 16% of the LSA) were not included in the classification (Table 7.2-5).

Surface disturbance in sensitive terrain can lead to subsidence and considerable (and sometimes irreversible) changes in local hydrology (Jorgenson and Osterkamp 2005; Lantz et al. 2009). Furthermore, while under frozen conditions these soils have sufficient bearing capacity to support infrastructure, under thawing conditions they have much lower strength and, due to high ice content, tend to undergo significant differential settlement (Volume 4, Chapter 6).

Development of the Project is expected to interact with local terrain conditions (in particular with the permafrost environment) where changes to ground thermal conditions associated with excavations, landfilling, quarrying or surficial traffic are proposed. Infrastructure that may interact include the underground mines, quarries, tailings impoundment areas, waste rock storage areas, and landfills. In consideration of local terrain conditions, a number of recommendations regarding Project infrastructure development have been proposed. For example, bedrock foundations will be required for critical structures such as fuel storage facilities, mills and powerhouses. Where possible, construction of infrastructure located outside of the areas where competent bedrock could be exposed will be preceded by placement of at least 1-m-thick bulk rock fill and construction under thawed conditions will be avoided. Overburden and organic material will not be stripped prior to infrastructure construction. Permafrost aggradation (upward expansion) is expected to occur within and beneath earth-filled infrastructure, including the landfills and roadbed pads. Waste rock piles will be constructed on 1-m-thick, geochemically suitable rock material pads placed directly on permafrost soils, with no excavation of vegetation or organic material. It is expected that permafrost soils will remain frozen and thus provide suitable foundations for waste rock piles. During Operation, stability of waste rock stockpiles will be monitored and at Closure all material will be used for backfilling of the underground mine. A summary of permafrost characteristics and typical overburden and borrow material properties in the LSA followed by a discussion of geotechnical design principles for the proposed infrastructure are provided in the SRK geotechnical report (Volume 4, Chapter 6).

7.5 REFERENCES

Abboud, S. A. and L. W. Turchenek. 2009. *Site-Specific Critical Loads of Acid Deposition on Soils in the Edmonton 83H East Map Sheet, Alberta*. ISBN: 978-0-7785-8121-5 Alberta Research Council, Edmonton, AB.

Aherne, J. 2008. *Calculating critical loads of acid deposition for forest soils in Alberta: Critical Load, Exceedance and Limitations*. PN 1408. Trent University and Canadian Council of Ministers of the Environment.

Banci, V. and R. Spicker. 2015. *Inuit Traditional Knowledge for TMAC Resources Inc. Proposed Hope Bay Project. Naonaiyaotit Traditional Knowledge Project (NTKP)*. Kitikmeot Inuit Association, Lands and Environment department, Kugluktuk, NU.

Banerjee, I. and B. C. McDonalds. 1975. *Nature of esker sedimentation In Glaciofluvial and glaciolacustrine sedimentation*. Ed. J. A. V. a. M. B.C. 123-54. Society of Economic Paleontologists and Mineralogists Special Publication.

Baron, J. S., H. M. Rueth, A. M. Wolfe, K. R. Nydick, E. J. Allstott, J. T. Minear, and B. Moraska. 2000. Ecosystem Responses to Nitrogen Deposition in the Colorado Front Range. *Ecosystems,* 3 (4): 352-68.

BC MELP and BC MOF. 1998. *Field Manual for Describing Terrestrial Ecosystems*. Land Management Handbook No. 25. British Columbia Ministry of Environment Lands and Parks and British Columbia Ministry of Forests Research Branch: Victoria, BC.

Binkley, D., C. T. Driscoll, H. L. Allan, P. Schoeneberger, and D. McAvoy. 1989. *Acidic deposition and forest soils: context and case studies of the southeastern United States*. Springer-Verlag, New York, NY.

Blaser, P., M. Zysset, S. Zimmermann, and J. Luster. 1999. Soil Acidification in Southern Switzerland between 1987 and 1997: A Case Study Based on the Critical Load Concept. *Environmental Science and Technology,* 33 (14): 2383–89.

Bobbink, R., K. Hicks, J. Galloway, T. Spranger, R. Alkemade, M. Ashmore, M. Bustamante, S. Cinderby, E. Davidson, F. Dentener, B. Emmett, J.-W. Erisman, M. Fenn, F. Gilliam, A. Nordin, L. Pardo, and W. De Vries. 2010. Global assessment of nitrogen deposition effects on terrestrial plant diversity: a synthesis. *Ecological Applications,* 20: 30-59.

Bobbink, R. and L. Lamers. 2002. Effects of increased nitrogen deposition. *Air pollution and plant life,* 2: 201-35.

Bobbink, R., and J. G. M. Roelofs. 1995. Nitrogen critical loads for natural and semi-natural ecosystems: the empirical approach. *Water Air Soil Pollut*. 85:2413–2418.

Bowman, W. D. and H. Steltzer. 1998. Positive Feedbacks to Anthropogenic Nitrogen Deposition in Rocky Mountain Alpine Tundra. *Ambio,* 27 (7): 514-17.

Daigle, P. 2010. A summary of the environmental impacts of roads, management responses, and research gaps: A literature review. *BC Journal of Ecosystems and Management* 10(3):65–89. www.forrex.org/publications/jem/ISS52/vol10_no3_art8.pdf

Dallimore, S. R. and J. L. Davis. 1992. *Ground penetrating radar investigations of massive ground ice*. Geological Survey of Canada:

Dallimore, S. R. and D. A. Wolfe. 1988. *Massive ground ice associated with glaciofluvial sediments, Richards Island, N.W.T., Canada*. Fifth International Conference on Permafrost. Trondheim, Norway.

De Schrijver, A., P. De Frenne, E. Ampoorter, L. Van Nevel, A. Demey, K. Wuyts, and K. Verheyen. 2011. Cumulative nitrogen input drives species loss in terrestrial ecosystems. *Global Ecology and Biogeography,* 20 (6): 803-16.

Environment Canada. 2015. *Canadian Climate Normals or Averages 1981-2010.* http://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html.

ERM Rescan. 2014. *Back River Project: Cumulative Permafrost Baseline Data Report (2007 to May 2014).* Prepared for Sabina Gold & Silver Corp. by Rescan Environmental Services Ltd., an ERM company.

Fenn, M. E., J. S. Baron, A. E. B., H. M. Rueth, K. R. Nydick, L. Geiser, W. D. Bowman, J. O. Sickman, T. Meixner, D. W. Johnson, and P. Neitlich. 2003. Ecological Effects of Nitrogen Deposition in the Western United States. *BioScience,* 53 (4): 404-20.

Fernandez, I. J., L. E. Rustad, S. A. Norton, J. S. Kahl, and B. J. Cosby. 2003. Experimental Acidification Causes Soil Base-Cation Depletion at the Bear Brook Watershed in Maine. *Soil Science Society of America Journal,* 67 (6): 1909-19.

Foster, N. W. 1989. Acidic deposition: what is fact, what is speculation, what is needed? *Water, Air, and Soil Pollution*, 48: 299-306.

Galloway, J. N. 1995. Acid deposition: Perspectives in time and space. *Water, Air, and Soil Pollution,* 85 (1): 15-24.

Golder Associates. 2005. *Doris North Project: Air quality assessment methods.* Report prepared for Miramar Hope bay Ltd.

Gordon, C., J. M. Wynn, and S. J. Woodin. 2001. Impacts of increased nitrogen supply on high Arctic heath: the importance of bryophytes and phosphorus availability. *New Phytologist,* 149 (3): 461–71.

Gowan, R. J. and S. R. Dallimore. 1990. *Ground ice associated with granular deposits in the Tuktoyaktuk coastlands area, N.W.T. Permafrost Canada.* The Fifth Canadian Permafrost Conference. National Research Council Canada.

Greaver, T. L., T. J. Sullivan, J. D. Herrick, M. C. Barber, J. S. Baron, B. J. Cosby, M. E. Deerhake, R. L. Dennis, J.-J. B. Dubois, C. L. Goodale, A. T. Herlihy, G. B. Lawrence, L. Liu, J. A. Lynch, and K. J. Novak. 2012. Ecological effects of nitrogen and sulfur air pollution in the US: what do we know? *Frontiers in Ecology and the Environment,* 10 (7): 365-72.

Grosse, G., J. Harden, M. Turetsky, A. D. McGuire, P. Camill, C. Tarnocai, S. Frolking, E. A. G. Schuur, T. Jorgenson, S. Marchenko, V. Romanovsky, K. P. Wickland, N. French, M. Waldrop, L. Bourgeau-Chavez, and R. G. Striegl. 2011. Vulnerability of high-latitude soil organic carbon in North America to disturbance. *Journal of Geophysical Research*, 116: 1-23.

Heij, G. J. and T. Schneider. 1991. *Acidification Research in The Netherlands.* Amsterdam: Elsevier.

Hornung, M., K. R. Bull, M. Cresser, J. Hall, S. J. Langan, P. Loveland, and C. Smith. 1995. An empirical map of critical loads of acidity for soils in Great Britain. *Environmental Pollution,* 90 301-10.

Howes, D. E. and E. Kenk. 1997. *Terrain Classification System for British Columbia.* Version 2. BC Ministry of Environment: Victoria, BC.

Huddart, D. and T. Stott. 2010. *Earth Environments: Past, Present and Future*. Wiley and Sons.

Jorgenson, M. T. and T. E. Osterkamp. 2005. Response of boreal ecosystems to varying modes of permafrost degradation. *Canadian Journal of Forestry Research,* 35: 2100–11.

Kerr, D.E., Knight, R.D., Kyer, T. (2000). Till geochemistry, Rideout Island and Elu Inlet map areas, Nunavut (76O N/2; 77A SW/4). Geological Survey of Canada, Open File 3863, 92 p

Lantz, T. C., S. V. Kokelj, S. E. Gergel, and G. R. Henry. 2009. Relative impacts of disturbance and temperature: persistent changes in microenvironment and vegetation in retrogressive thaw slumps. *Global Change Biology,* 15: 1664-75.

Liu, Y., G. Shi, L. Mao, G. Cheng, S. Jiang, X. Ma, L. An, G. Du, N. Collins Johnson, and H. Feng. 2012. Direct and indirect influences of 8 yr of nitrogen and phosphorus fertilization on Glomeromycota in an alpine meadow ecosystem. *New Phytologist*, 194 (2): 523–35.

Macumber, L. A., L. A. Neville, J. M. Galloway, R. T. Petterson, H. Falck, G. Swindles, C. Crann, I. Clark, P. Gammon, and E. Madsen. 2011. *Paleoclimatological assessment of the Northwest Territories and implications for the long term viability of the Tibbit to Contwoyto winter road, part II: March 2010 field season results.*

Moorman, B. J. and F. A. Michel. 2003. *Burial of glacier ice by deltaic deposition.* M. Phillips, S. M. Springman, and L. Arenson, Eds. Permafrost: 8th International Conference. Zurich: Balkema.

Nilsson, S. I. and P. Grennfelt. 1988. *Critical Loads for Sulphur and Nitrogen.* NORD 1988:97. Nordic Council of Ministers. Copenhagen, Denmark. 418 pp.

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.

Prest, V. K. 1970. Quaternary geology of Canada. In *Geology and Economic Minerals of Canada*. Ed RÿJ W Douglas, Geological Survey of Canada, Economic Geology Report, No 1 pp 675-764 Department of Energy, Mines and Resources Canada.

Racine, C. H. and G. M. Ahlstrand. 1991. Thaw response of tussock-shrub tundra to experimental all terrain vehicle disturbance in south-central Alaska. *Arctic,* 44: 31-37.

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

Reuss, J. O., B. J. Cosby, and R. F. Wright. 1987. Chemical processes governing soil and water acidification. *Nature,* 329: 27-32.

Robinson, S. D., B. J. Moorman, A. S. Judge, and S. R. Dallimore. 2003. *The characterization of massive ground ice at Yaya Lake, Northwest Territories using radar stratigraphy techniques.* Paper 93-1B.

SENES Consultants Limited. 2013. *West Kitikemeot Slave Study: State of Knowledge Report – 2007 Update.*

Shur, Y. L. and M. T. Jorgenson. 2007. Patterns of permafrost formation and degradation in relation to climate and ecosystems. *Permafrost Periglacial Processes,* 18 (1): 7–19.

Sonesson, M. 1985. *Research in Arctic life and earth sciences: present knowledge and future perspectives.* Naturvetenskapliga forskningsrådet. Abisko, Sweden.

SRK Consulting. 2005. *Groundwater Assessment, Doris North Project, Hope Bay, Nunavut, Canada.* Report prepared by SRK Consulting (Canada) Inc. for Miramar Hope Bay Limited.

Tomassen, H. B. M., A. J. P. Smolders, L. P. M. Lamers, and J. G. M. Roelofs. 2003. Stimulated growth of Betula pubescens and Molinia caerulea on ombrotrophic bogs: role of high levels of atmospheric nitrogen deposition. *J. Ecol.* 91:357–370.

Turetsky, M. R., R. K. Wieder, D. H. Vitt, R. J. Evans, and K. D. Scott. 2007. The disappearance of relict permafrost in boreal North America: Effects on peatland carbon storage and fluxes. *Global Change Biology,* 13 (9): 1922–34.

Walter, K. M., S. A. Zimov, J. P. Chanton, D. Verbyla, and F. S. Chapin III. 2006. Methane bubbling from Siberian thaw lakes as a positive feedback to climate warming. *Nature,* 443: 71-75.

Watmough S.A. . 2002. A dendrochemical survey of sugar maple in south-central Ontario. *Water, Air and Soil Pollution,* 136 (165-187).

Wolfe, S. A., M. M. Burgess, M. Douma, C. Hyde, and S. Robinson. 1997. *Geological and geotechnical investigations of ground ice in glaciofluvial deposits, Slave Geological Province, NWT.*