CUMBERLAND
RESOURCES LTD.

MEADOWBANK GOLD PROJECT

BASELINE PHYSICAL ECOSYSTEM REPORT

JANUARY 2005

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LIST OF ABBREVIATIONS

Ag .... Silver
Al .... Aluminum
AMEC .... AMEC Americas Ltd.
ARD .... Acid Rock Drainage
As .... Arsenic
BGC .... BGC Engineering Inc.
CCME .... Canadian Council of Ministers for the Environment
Cd .... Cadmium
CEQG .... Canadian Environmental Quality Guidelines
CN .... Cyanide
Cr .... Chromium
Cumberland .... Cumberland Resources Ltd.
Cu .... Copper
F .... Fluorine
Fe .... Iron
Golder .... Golder Associates Ltd.
Hg .... Mercury
IF .... Iron formation rock
INAC .... Indian and Northern Affairs Canada
IPCC .... Intergovernmental Panel on Climate Change
IV .... Intermediate volcanic
ML .... Metal leaching
MMER .... Canadian Metal Mining Effluent Regulations
Mo .... Molybdenum
Ni .... Nickel
NO_2 .... Nitrite
NPR .... Neutralization Potential
PAG .... Potential for Acid Generation
Pb .... Lead
PEL .... Probable effects limit
QTZ .... Quartzite
ROM .... Run-of-mine
Se .... Selenium
Tl .... Thallium
U .... Uranium
UM .... Ultramafic rock
Zn .... Zinc

DESCRIPTION OF SUPPORTING DOCUMENTATION

Cumberland Resources Ltd. (Cumberland) is proposing to develop a mine on the Meadowbank property. The property is located in the Kivalliq region approximately 70 km north of the Hamlet of Baker Lake on Inuit-owned surface lands. Cumberland has been actively exploring the Meadowbank area since 1995. Engineering, environmental baseline studies, and community consultations have paralleled these exploration programs and have been integrated to form the basis of current project design.

1. The Meadowbank project is subject to the environmental review and related licensing and permitting processes established by Part 5 of the Nunavut Land Claims Agreement. To complete an environmental impact assessment (EIA) for the Meadowbank Gold project, Cumberland followed the steps listed below:

2. Determined the VECs (air quality, noise, water quality, surface water quantity and distribution, permafrost, fish populations, fish habitat, ungulates, predatory mammals, small mammals, raptors, waterbirds, and other breeding birds) and VSECs (employment, training and business opportunities; traditional ways of life; individual and community wellness; infrastructure and social services; and sites of heritage significance) based on discussions with stakeholders, public meetings, traditional knowledge, and the experience of other mines in the north.

3. Conducted baseline studies for each VEC and compared / contrasted the results with the information gained through traditional knowledge studies (see Column 1 on the following page for a list of baseline reports).

4. Used the baseline and traditional knowledge studies to determine the key potential project interactions and impacts for each VEC (see Column 2 for a list of EIA reports).

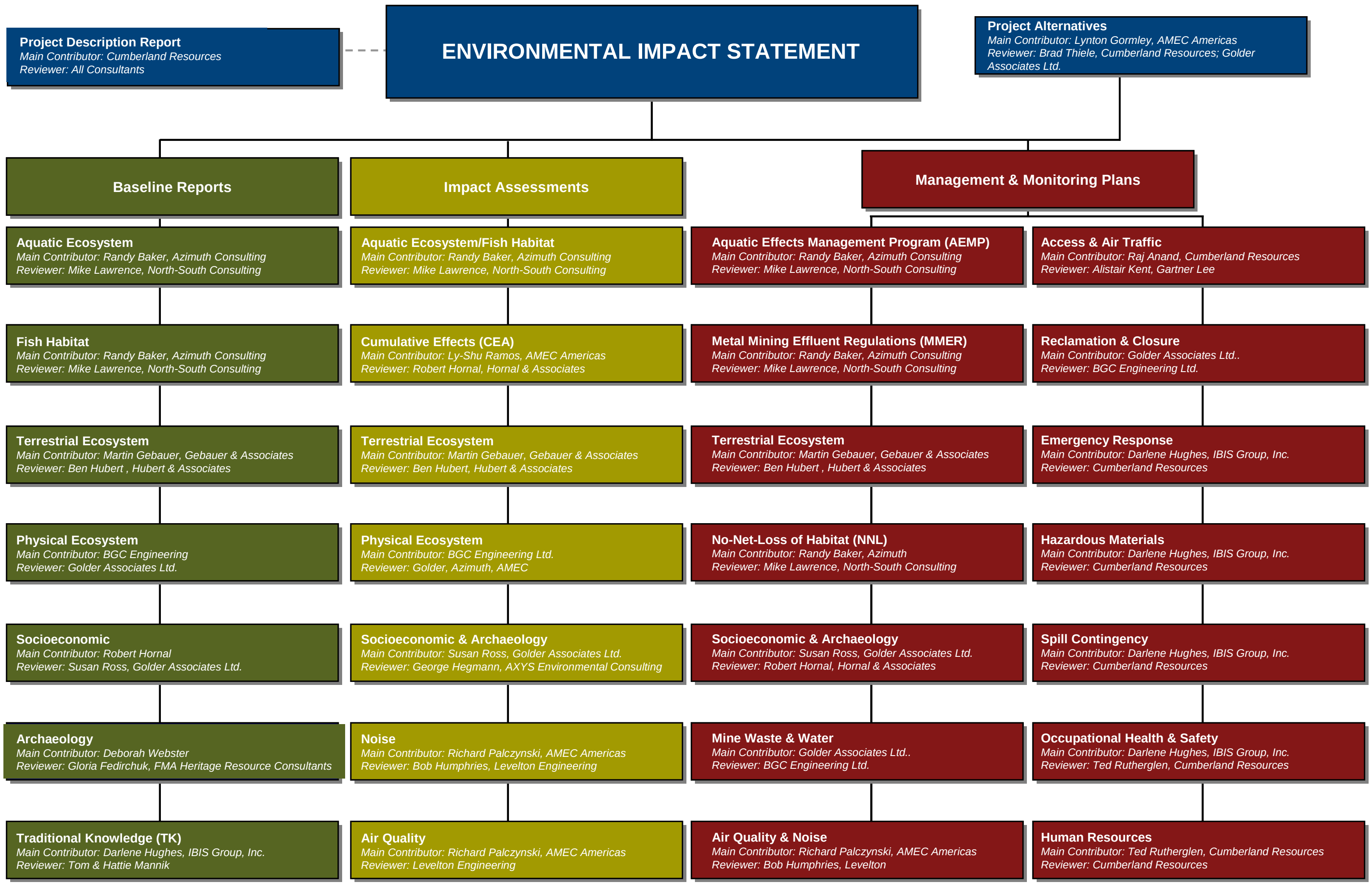
5. Developed preliminary mitigation strategies for key potential interactions and proposed contingency plans to mitigate unforeseen impacts by applying the precautionary principle (see Column 3 for a list of management plans).

6. Developed long-term monitoring programs to identify residual effects and areas in which mitigation measures are non-compliant and require further refinement. These mitigation and monitoring procedures will be integrated into all stages of project development and will assist in identifying how natural changes in the environment can be distinguished from project-related impacts (monitoring plans are also included in Column 3).

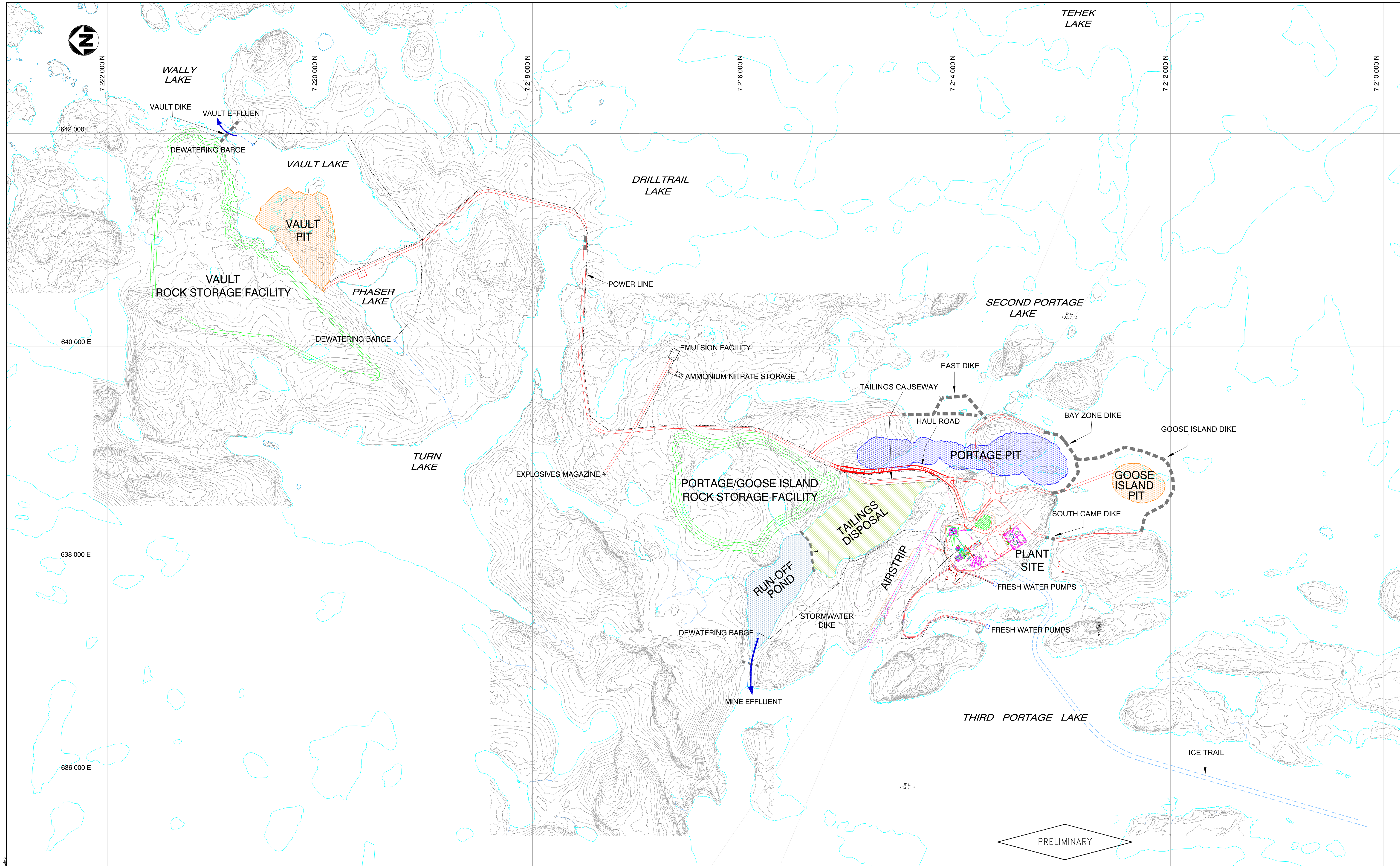
7. Produce and submit an EIS report to NIRB.

As shown on the following page, this report is part of a documentation series that has been produced during this six-stage EIA process.

EIA DOCUMENTATION ORGANIZATION CHART



PROJECT LOCATION MAP



Datum: UTM NAD83 Zone 14

Proposed Mine Site Layout

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Meadowbank Gold Project

SECTION 1 • INTRODUCTION

The Meadowbank Gold project is located within a Low Arctic ecoclimate, one of the coldest and driest regions of Canada. The topography of the area is of generally low relief with an elevation range of 70 m. The surficial geology is dominated by discontinuous thin veneers of organic material, till, and/or weathered parent material overlying undulating to hummocky bedrock. Block fields of weathered rock interspersed with thin veneers of moraine or organics are common.

The underlying bedrock consists of IF, IV, and UM rocks, with QTZ in some areas. Two main faults, the Bay Zone Fault and the Second Portage Fault, are present. The sheared and faulted stratigraphic contacts and overall foliation orientations will dip at steep angles to the west at the western and eastern margins of the Third Portage and Goose Island deposits, while they dip at shallower angles through the central portion and north end of the Third Portage deposit, the Connector Zone and the North Portage deposit. The sheared stratigraphic contacts and overall foliation orientations at the Vault deposit will dip to the south and southeast at shallow angles

The observed periglacial geomorphic processes are typical of areas underlain by continuous permafrost, although their expression is subdued by the relatively thin cover of overburden and the relatively dry site conditions. Terrain features and geomorphic processes associated with excess ground ice and generally wet conditions exist in limited areas commonly associated with low-lying bogs and areas of poor drainage. Colluvial aprons at the toe of steep rocky bluffs indicate that frost action on exposed bedrock and the resultant rockfall and rock displacement are active processes, although rare within the project area. In general, the geomorphology and soils observed within the area do not present any features or processes that prohibit the development of the proposed mine.

Continuous permafrost to depths of 550 m underlies most of the Meadowbank project area. Based on the current site thermistor instrumentation, the depth of the active layer in the project area ranges from about 1.3 m in areas of shallow overburden and away from the influence of lakes, up to 4 m adjacent to lakes, and up to 6.5 m beneath the stream connecting Third Portage and Second Portage lakes. Taliks extending through the permafrost will exist beneath circular lakes having a minimum diameter of 570 m, and elongate lakes having a minimum width of 320 m. Based on this, Second Portage Lake and Third Portage Lake will have taliks extending through the permafrost. The talik beneath Vault Lake is considered to be isolated.

The shallow groundwater flow regime at the Meadowbank project has little to no hydraulic connection with the groundwater regime located below the deep permafrost. On a regional scale, deep groundwater in the Meadowbank project area will flow either to the northwest or to the southeast from Third Portage Lake. This is due to the project being located near the drainage divide between the Black River Basin, which flows north and northwest to the Arctic Ocean, and the Thelon River Basin, which flows east to southeast towards Hudson Bay. The northwest portion of Second Portage Lake, however, is a discharge zone with water flowing upwards from the deep groundwater regime. This is due to large and higher elevation lakes located to the east of Second Portage Lake.

The groundwater velocity towards the northwest portion of Second Portage Lake is estimated to be approximately 0.50 m per year. The groundwater velocity away from Third Portage Lake towards the northwest is estimated to be approximately 0.50 m per year. The velocity of the groundwater flow to the southeast from Third Portage Lake and from the southeast portion of Second Portage Lake is estimated to be approximately 0.30 m per year. These flows will be higher along specific features such as the Second Portage Lake Fault where these are hydraulically connected to lakes down-gradient of Second Portage Lake.

SECTION 2 • GEOLOGY

2.1 REGIONAL GEOLOGY

The Meadowbank project is located in the Canadian Shield, the largest physiographic region of Canada. The Shield hosts the largest area of Archean rocks (>2.5 billion years old) in the world, including the oldest rocks, dated at 4 billion years. All rock units at the project site are of Archean age.

2.2 SURFICIAL GEOLOGY

Laterally extensive deposits of glacial till cover the project area. In general terms, the till can be described as a silty sand/gravel till, with between about 30% and 40% fines (silt and clay). The material also contains up to boulder-sized particles.

The material that has been recovered from beneath the lakes during geotechnical drilling along the proposed dike alignments is generally described as cobbles and gravel with traces of sand, silt, and clay. Locally, samples of sand and clayey sand have also been obtained.

2.3 BEDROCK GEOLOGY

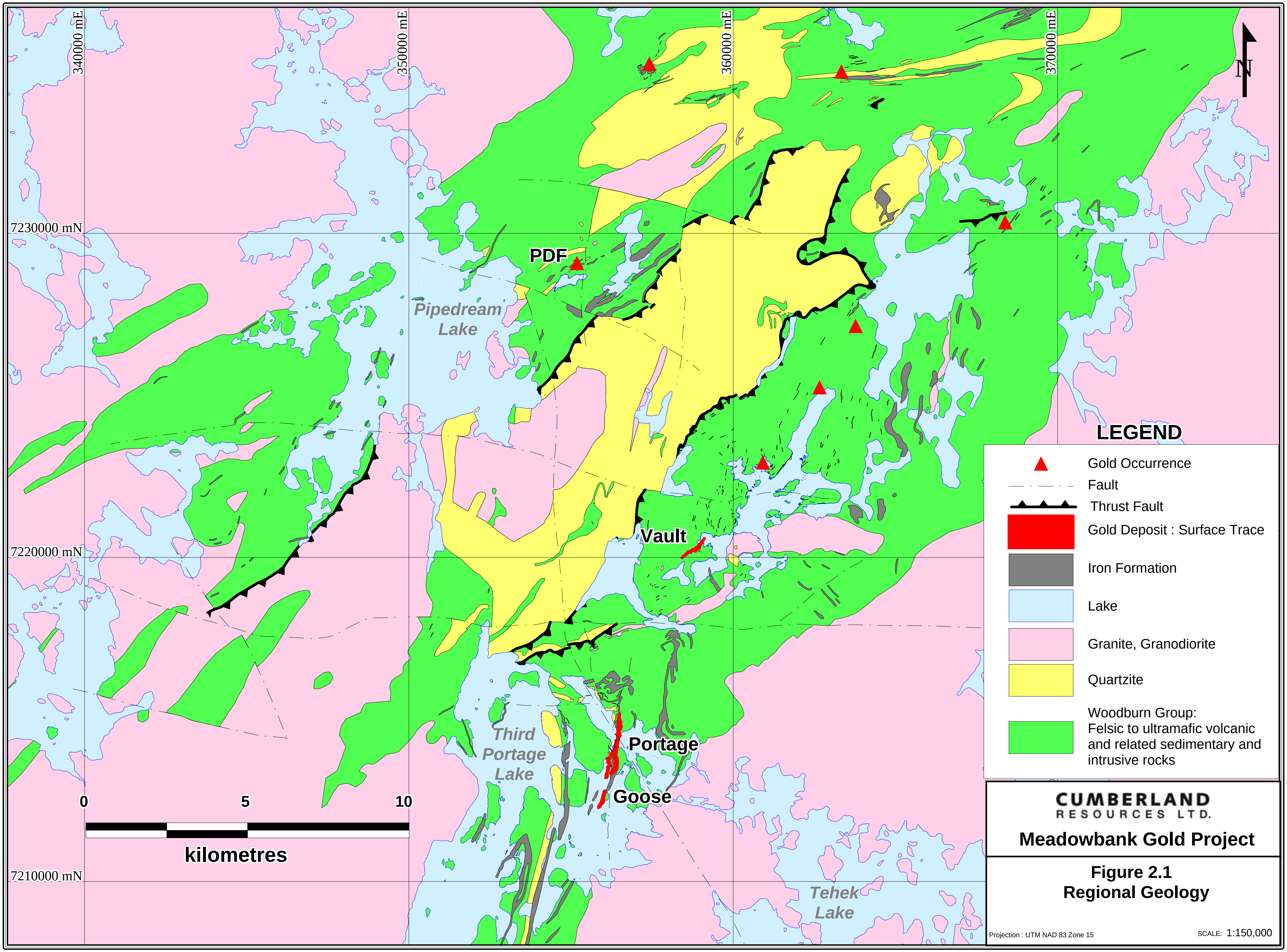
The Meadowbank project is underlain by a sequence of Archaean greenstone (ultramafic and mafic flow sequences) and metasedimentary rocks that have undergone polyphase deformation resulting in the superposition of at least two major structural events. Enclosed within the greenstone are volcaniclastic sediments, felsic-to-intermediate flows and tuffs, sediments (greywackes), and oxide iron formations. The sequence also contains sericite schists, which are believed to be altered felsic flows or dykes. The ultramafic rocks are variably altered, containing serpentinite, chlorite, actinolite, and talc. The ore in the Vault deposit is hosted in intermediate volcanic rocks. The ore in the Portage deposit is hosted in iron formation rocks.

The regional geology of the Meadowbank area and contours showing the approximate thickness of overburden (till) are shown on Figure 2.1.

2.4 MEADOWBANK SITE BEDROCK LITHOLOGY, MORPHOLOGY & STRUCTURES

The three main rock types composing the Portage, Goose Island, and Vault deposits are iron formation (IF), intermediate volcanic (IV), and ultramafic volcanic (UM), while a fourth, less common rock type, quartzite (QTZ), may form portions of the upper west pit wall of the Goose Island and Portage deposits. The ultramafic volcanic rock may be serpentinized. Where this occurs, the area may be considerably weaker than non-serpentinized ultramafic rock.

Faults are suspected in the Meadowbank project area, based on strong lineament trends through bedrock exposures. Two main faults have been encountered in geotechnical drilling completed to date (Figure 2.2 and Table 2.1).


340000 mE
350000 mE
360000 mE
370000 mE
7230000 mN
7220000 mN
7210000 mN
N
PDF
Pipedream Lake
Vault
Third Portage Lake
Portage
Goose
Tehek Lake
0
5
10
kilometres
LEGEND
Gold Occurrence
Fault
Thrust Fault
Gold Deposit : Surface Trace
Iron Formation
Lake
Granite, Granodiorite
Quartzite
Woodburn Group:
Felsic to ultramafic volcanic and related sedimentary and intrusive rocks
CUMBERLAND RESOURCES LTD.
Meadowbank Gold Project
Figure 2.1
Regional Geology
Projection : UTM NAD 83 Zone 15
SCALE: 1:150,000

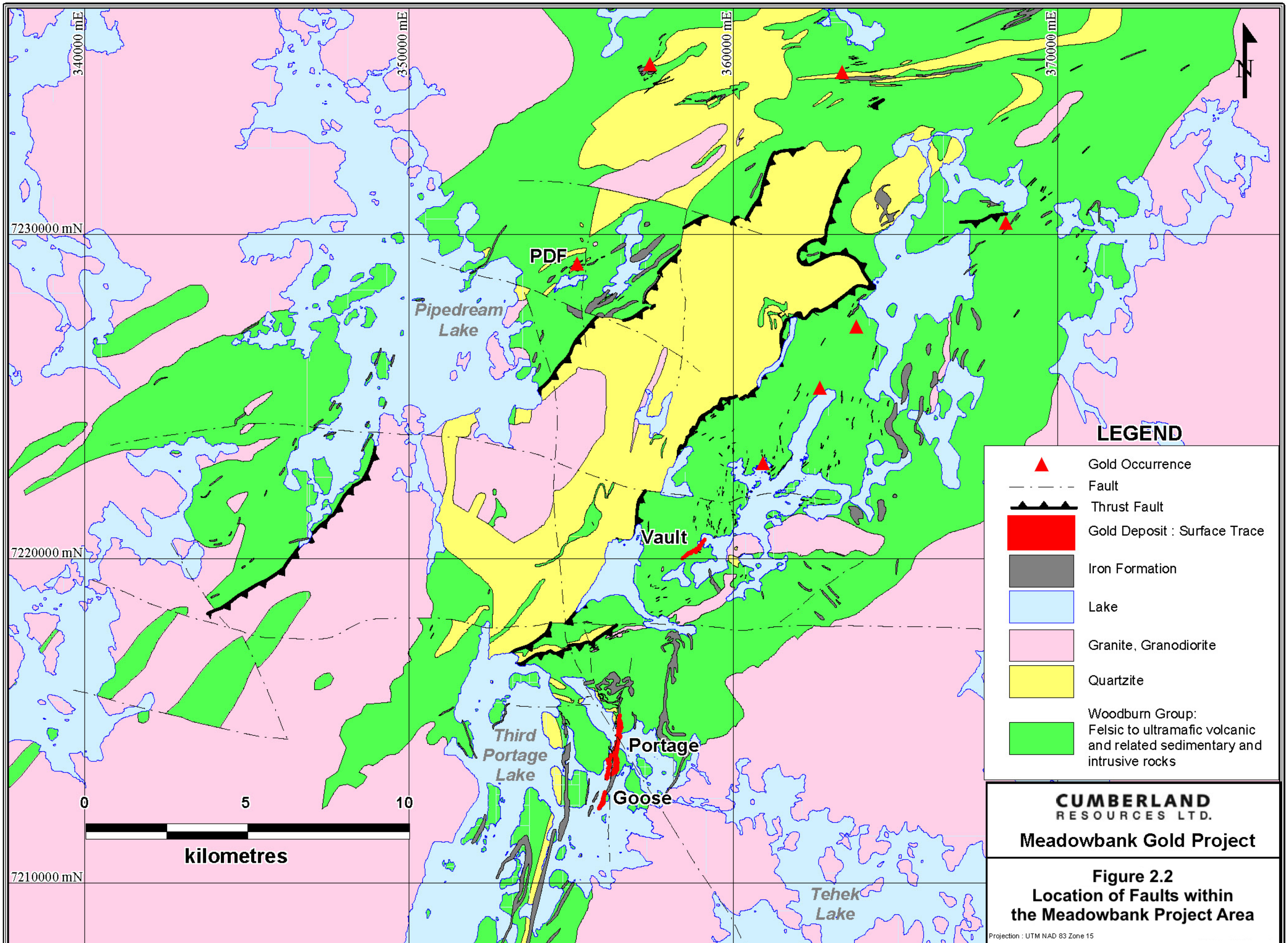


Figure 2.2
Location of Faults within the Meadowbank Project Area

Table 2.1: General Fault Orientations

Fault	Dip	Dip Direction
Bay Fault	70°	270°
Second Portage Lake Fault	70°	235°

To the north of the Third Portage peninsula, the Second Portage Fault trends northwest, parallel to the northwest arm of Second Portage Lake. This fault dips to the southwest at high angles between 60 and 80 degrees. Its projected surface trace would intersect the proposed tailings dike as well as the east dewatering dike.

The Third Portage peninsula is flanked on the west by the north-south trending Bay Zone Fault, which roughly parallels the western shoreline of Third Portage peninsula and extends northward along the western flank of the North Portage deposit and south-southeastward between the eastern shore of the Bay Zone Island and the Third Portage peninsula. A splay trending off the Bay Zone Fault begins south of the narrows separating the Third Portage peninsula from the mainland and trends south along the western side of the Bay Zone Island. Both the Bay Zone Fault and splay dip at high angles between 60 and 80 degrees to the west. Both pass beneath the proposed Bay Zone dike, but whether one or both pass beneath the Goose Island dike is unknown.

The sheared and faulted stratigraphic contacts and general foliation orientations for Third Portage and Goose Island deposits will dip at steep angles (>60°) to the west at the eastern and western margins of these deposits. They will dip at shallower angles (<30°) to the west through the central portion of the Third Portage deposit, at the north end of the Third Portage deposit, through the Connector Zone and at the North Portage deposit. The sheared stratigraphic contacts and overall foliation orientations at the Vault deposit will dip to the south and southeast at inclinations between roughly 20° and 30°. The stratigraphic contacts are considered pervasive structures that will control bench scale and pit wall stability. Although the contact orientations follow the general trend of the overall foliation orientations, the latter may exhibit a high degree of variability on a local scale.

The iron formation, intermediate volcanic, and quartzite are expected to have good rock mass quality, while the ultramafic rock is expected to have fair to good rock mass quality. The overall pit slope configurations will be controlled by the sheared and faulted main stratigraphic contacts. Table 2.2 provides a summary of the main discontinuity properties.

Deposit Geology

Gold mineralization in the ore is closely associated with low levels of sulphide mineralization, dominantly pyrrhotite and pyrite. In the main Third Portage deposit (the Bay Zone, Third Portage, and North Portage deposits) and Goose Island deposit, these sulphides dominantly occur as a replacement of magnetite in the oxide iron formations. They also occur as a fracture fill silica and disseminations in both the iron formation and surrounding volcaniclastic units. The bulk of the gold mineralization is contained within the iron formations, with mineralization occurring in the clastic units representing remobilization and secondary enrichment by gold-bearing fluids. The gold tends to be concentrated along the lower limb and in the hinge areas of a recumbent fold and shows excellent continuity both along strike and down dip through the deposits.

Table 2.2: Summary of Main Discontinuity Properties

Type	Portage & Goose Island Deposts			Valut Deposit		
	Dip	Dip Direction	Average Spacing (m)	Dip	Dip Direction	Average Spacing (m)
Foliation	12-72	255-300	0.5 -1.5	21-23	136-164	0.5-0.8
Orthogonal	76-10	067-121	1.4-12	60-70	333-336	2.8-8.1
CJ1	43-79	201-237	2.5 11.4	83-85	197-209	1.7-7.4
CJ2	36-81	025-068	2.5-8.3	80-82	040-053	
CJ3	65-86	125-148	1.2-9.5	-	-	-
CJ4	58 -73	299-340	1.0-7.0	-	-	-
East-dipping	-	-	-	67-81	086-108	3.7-6.1
South-dipping	-	-	-	45-48	174-198	3.7-6.1
Cross	46-63	002-031	0.4-19.4	73	253	4.4
Cross	62-88	341-350		-	-	-
Cross	26-62	170-191		-	-	-
Flat	-	-	-	10-13	330-335	8.3

In the Vault deposit, pyrite is the dominant sulphide mineral and gold mineralization tends to be concentrated in the volcaniclastic unit. The gold mineralization in the Vault deposit shows excellent continuity both down dip and along strike and remains open at depth and along strike for further expansion.

The Meadowbank deposits are typified by trace levels to absence of an arsenopyrite or base metal sulphides.

SECTION 3 • GEOMORPHOLOGY

The topography of the area is of generally low relief with a range of 70 m between approximately 130 and 200 m above sea level. As expected with a low-lying environment that has experienced past glaciation, the surface drainage is chaotic with no established patterns, although lakes and ponds are abundant, occupying about 20% of the area.

The landscape of the Meadowbank region owes its origin mainly to glacial erosion. Regional ice flow indicators suggest glaciers moved north-northwest across the project area. Large-scale linear flutes exceeding 20 km in length and 250 m in width have been documented (Aylsworth et al, 1989). Property-scale ice flow indicator mapping by the Canada-Nunavut Geoscience Office in 2003 (D. Utting, personal communication) showed glacial striae azimuths consistently trending from north to northwest with a principal orientation of 350° azimuth.

Meadowbank landforms are dominated by hummocky bouldery glacial till plains and scattered boulder till moraines with frequent bedrock outcropping in isolated exposures, elevated plateaus, and elongate ridges. Localized north- to northwest-trending glacial drumlins preserve evidence of regional ice flow. Rare glaciofluvial kames and sinuous eskers form isolated topographic features, with the closest being approximately 26 km to the north.

Block fields of weathered parent material interspersed with thin veneers of till or organics are common at Meadowbank; however, the predominant surficial material is locally derived glacial till. Till thickness, as determined from core and reverse circulation overburden drill holes, ranges up to 12.5 m with an average of less than 3 m. In general, till is unsorted, medium brown, silty, sandy and stony, with between 20% and 40% locally derived volcanic, sedimentary, and lesser granitic clasts. Clast sizes range from granule to boulder with a high proportion in the granule to pebble range.

In most of the channels between the lakes and ponds, coarse-grained soils are common. In some, the finer organic material and sediments have been removed by flow between lakes, leaving a stony pavement. In others, solifluction has brought coarse-grained material into the low-lying areas from adjacent slopes.

Small deposits of deltaic sand and fine gravel flank some streams along Third Portage Lake. Glaciofluvial deposits are volumetrically insignificant. The site was above the last glacial marine transgression, consequently no glaciomarine deposits are known in the area.

SECTION 4 • POTENTIAL FOR GROUND & ROCK INSTABILITY

The observed periglacial geomorphic processes are typical of areas underlain by permafrost, although their expression is subdued by the relatively thin cover of overburden and the relatively dry conditions on-site. Terrain features and geomorphic processes associated with excess ground ice and generally wet conditions exist in limited areas commonly associated with low-lying areas, bogs, and areas of poor drainage. Some of the processes observed at the Meadowbank project include: frost wedging and frost shattering, resulting in blocky colluvial slopes; cryoturbation; solifluction; thaw subsidence; and nivation. Overall, the geomorphology and soils observed within the area do not present any features or processes that prohibit the development of the proposed mine.

4.1 BLOCKY COLLUVIAL SLOPES

Frost wedging and frost shattering occur on exposed bedrock and in coarse-grained block fields. Where steep bluffs are present, the frost action generates rock displacement and rockfall. The result is blocky colluvial deposits or talus at the base of steep bluffs. Although rare within most of the project area, local concentrations of rockfall or rock displacement material occur in the southwestern portion of the area.

The dislodged rocks may also roll or slide on snow to a resting place. This scenario, which is common in permafrost areas, creates subtle rubble ridges known as protalus ramparts. Some of these features are suspected in the Meadowbank area, based on airphoto interpretation.

Most of the colluvial deposits, regardless of their origins, are likely affected by solifluction and, potentially, by frost creep.

4.2 CRYOTURBATION

Frost boils were observed in the field near the proposed plant site and at the southern end of the airstrip. These are typically found in areas of fine-grained soils that are underlain by permafrost and consist of small mounds of soil formed by frost action. The process of freezing the fine-grained soils results in pressurized zones of unfrozen soil confined by frozen soil. The unfrozen zones are sometimes extruded upwards to create the mounds. Where the process repeats itself, the ground surface develops a hummocky micro-relief over time.

4.3 SOLIFLUCTION

Uplift perpendicular to the ground surface during freezing, followed by thaw that allows vertically downward movement, combine to produce net downslope displacement. This combination of freeze-thaw movement of soils has created evidence of solifluction in the form of striped ground and lobate patterns on some of the steeper non-bedrock slopes comprising primarily organic and morainal soils. The downslope movement of these materials is expected to be slow because of the relatively thin active layer, short thaw season, and dry conditions. The magnitude and rate will be governed mainly by slope angle and the amount of soil moisture.

4.4 THAW SUBSIDENCE

Thaw settlement was not readily discernable from the air photos but is expected to occur to a limited extent within the area, as indicated by the presence of patches of muted patterned ground and by evidence of some ground ice recorded in the reverse-circulation drilling data. Thaw consolidation leading to thaw settlement can be expected following disturbance of any insulating organic soil covering thicker (e.g., greater than 2 m thick) and wetter (e.g., standing or near-surface water) mineral soils in low-lying marshy areas. Based on the geomorphology and soils mapping, the susceptible areas are of limited extent within the area.

Although no evidence for rapid mass wasting of slopes through detachment failures or retrogressive thaw slumping was observed on the air photos, evidence for thaw-related slumping was noted at two locations. The first is a failure on the north-facing slopes of a valley situated on the northeastern side of Second Portage Lake. The second occurs at the south end of Turn Lake. Both appear to be of limited extent and are located outside the study area. The likelihood of occurrence of detachment failures and retrogressive thaw slumping within the project area is considered to be low.

4.5 NIVATION

Although it is expected that nivation is an active process in the area, it was not directly observable on the air photos; however, it is known that snow accumulations occur on the south- and east-facing slopes in the lee of the prevailing winds. Where this occurs, it will likely increase the rate of physical weathering of in-situ materials, freezing-induced displacement, and thaw-induced displacement of soils, and generate degraded slope profiles downslope of areas with lingering snowbanks.

4.6 LAKE SHORELINES & BOTTOMS SUBJECT TO DEWATERING

The main deposits at the Meadowbank project are situated adjacent to lakes or trend off-shore and beneath lakes. Consequently, a significant component of the project involves the lowering of lake levels in Second Portage and Vault lakes to allow mining to proceed. The initial drawdown of the lakes will expose lake bottom sediments and till in the lake basin side slopes and lake bottoms. This could result in slumping of sediments on steeper lake basin slopes.

In addition to potential slumping of the sediments during drawdown, the lowering of the lake levels will promote aggradation of the permafrost into the former unfrozen lake bottoms. This will be accompanied by frost penetration, moisture redistribution, and ground ice growth, resulting in freezing-induced displacements of the soils and underlying rock. The development of the active layer will result in seasonal freeze- and thaw-induced displacements, which may be associated with soil erosion and localized instability. As stream channelling develops in the former lake bottom sediments, there will be the potential for high sediment loadings resulting from erosion and localized instability.

The process of lake drawdown will also affect adjacent lowlands as well as lowlands along inflowing streams feeding Second Portage and Vault lakes. The original active layer in these lowlands can be expected to deepen because lowering the water table allows more summer heat into the ground. Where the advancing thaw front at the bottom of the active layer encounters excess ground ice, thaw subsidence can be expected. Where the ground ice is in fine-grained mineral and/or organic soils, subsidence may be accompanied by local slumping and release of high suspended sediment loadings in runoff waters entering the water management areas of Second Portage and Vault lakes.

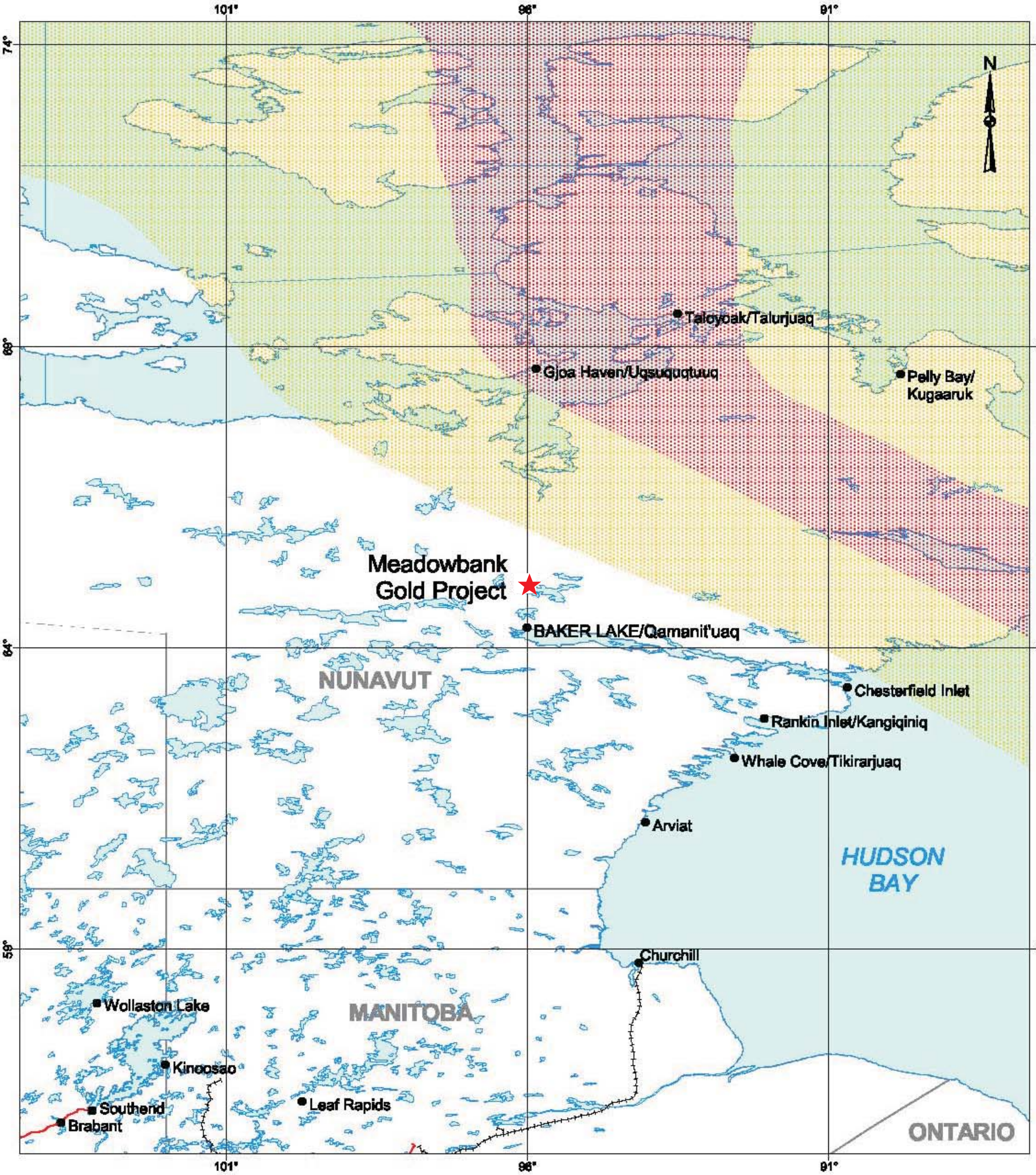
4.7 SEISMICITY

The Meadowbank project is located in an area of low seismicity, as shown in Table 4.1 and Figure 4.1. Low seismicity is considered to correspond to areas where the peak ground acceleration (PGA) for the 1 in 475-year seismic event (10% probability of exceedance in 50 years) is less than 0.04 g (CDA, 1999).

Table 4.1: Peak Horizontal Ground Accelerations for Meadowbank Site

Return Period of Seismic Event (years)	Peak Horizontal Ground Acceleration (g)
100	0.018
200	0.025
475	0.034
975	0.044

Source: Seismic Risk Calculation for Meadowbank Project Site, Geological Survey of Canada, Natural Resources Canada, Sidney, BC, July, 2003.



200 0 200 Kilometers

Scale - 1:10,000,000

LEGEND

- Meadowbank Project
- Town/Village

Peak Horizontal Ground Acceleration (g), for 10% probability of exceedance in 50 Year Event

- 0 - 0.039
- 0.04 - 0.079
- 0.08 - 0.109
- Provincial Border
- Water
- Primary Highway
- Railroad

REFERENCE

Base digital data obtained from ESRI Inc.,
DATUM: WGS84 PROJECTION: Geographic

N:\Bur-Graphics\Projects\2003\1413\03-1413-427\GIS\apr\figure-03-2_seismic-zoning.apr (Layout: 8.5x11 Portrait) December 19, 2003

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Meadowbank Gold Project

Figure 4.1
Seismic Zoning Map

SECTION 5 • HYDROLOGY

5.1 LAKE BATHYMETRY

Bathymetric surveys of the lakes adjacent to and overlying the main deposits indicate the lake depths to be extremely variable, ranging from less than 1 m to about 38 m in areas of Second Portage Lake.

Based on bathymetry carried out at the site in 2002 and 2003, Table 5.1 summarizes estimates of total water volume within the Second Portage Lake Arm, Third Portage Lake, and Vault Lake for the areas that will be inside the proposed dewatering dikes. The estimated total volumes of water within the lakes within the project area are summarized in Table 5.2.

Table 5.1: Lake Volumes Inside Dewatering Dikes

Location		Volume (Mm^3)
Second Portage Lake Arm (elevation 133.1 m amsl)	Northwest Basin (run-off pond)	1.6
	Main Basin (Main tailings)	8.6
	East Basin (adjacent to east dike)	2.5
	Total Second Portage Lake Arm within east dewatering dike	12.8
Third Portage Lake – Goose Island Area	Inside Bay Zone dewatering dike	0.4
	Between Bay Zone dike and Goose Island dewatering dikes	2.2
	Total Third Portage Lake – Goose Island Area within dewatering dike	2.6
Vault Lake (elevation 139.4 m amsl)	Total Vault Lake within Vault dewatering dike	2.2

Table 5.2: Estimates of Total Lake Volumes

Lake	Volume (Mn^3)
Second Portage Lake	22.0
Third Portage Lake	228.0
Vault Lake	2.2
Wally Lake	28.1

5.2 SURFACE WATER

5.2.1 Surface Water Quantity

Most streams in the Meadowbank project area are fed from lake outflows and are relatively short, small- to medium-width channels feeding into downstream lakes in a cascading network. Streamflow monitoring of Second Portage Lake outflow and tributary drainages of Third Portage Lake, Drilltrail Lake, and Turn Lake were carried out for the 2002 and 2003 open water seasons. Local data were supplemented by regional data for four Water Survey of Canada stations. Tables 5.3 and 5.4 show details of the regional and site gauging stations, respectively.

Table 5.3: Regional WSC Streamflow Gauging Station

WSC Station Name	WSC Station Number	Drainage Area (km^2)	Gauge Location		Period of Record
Qinguq Creek near Baker Lane	06MA002	432	64° 15' 42"	96° 18' 53"	1969-1978, 1981-1983, 1985-1994
Akkutuak Creek near Baker Lake	06MA004	15	64° 18' 57"	95° 58' 23"	1978-1990
Prince River near Baker Lake	06MA005	2100	64° 18' 08"	95° 45' 31"	1979-1990
Anigaq River below Audra Lake	06MA007	2740	64 12' 48"	96° 35' 14"	1984-1994

.

Table 5.4: Drainage Areas

Monitoring Station	Basin	Land Surface (km^2)	Monitored Lake Surface (km^2)	Other Lakes Surface (km^2)	Other Lakes No.	Total Lake Surface (km^2)	Total Area (km^2)	Ratio of Lake to Total Area
Third Portage Lake	Sub-Basin	49.4	36.0	3.4	55	39.5	88.9	0.444
Turn Lake	Sub-Basin	17.0	2.9	1.5	18	4.4	21.4	0.204
Drilltail Lake	Sub-Basin	66.4	2.0	17.2	107	19.2	85.6	0.224
	Total Basin	83.4	4.9	18.7	125	23.6	107.0	0.221
Second Portage Lake	Sub-Basin	9.8	4.1	0.7	16	4.8	14.6	0.329
	Total Basin	142.6	45.0	22.8	196	67.9	210.5	0.323

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Snowmelt runoff in the region begins in the period from late May to mid-June and the snowmelt peak is often the maximum for the year. Secondary peaks due to rainfall events can occur during the summer and can sometimes exceed snowmelt peaks. Flows typically decline through the late summer and fall, with freeze-up occurring in late September for the smallest streams and in late November for the medium channels. All channels are thought to freeze to the bottom with zero flows over the winter period.

In terms of precipitation, 2002 was a wet year while 2003 was a slightly dry year. The observed project watershed runoff values reflected those conditions. Average runoff depths for the four monitored basins ranged from 130 mm for Third Portage Lake to 206 mm for Drilltraill Lake. The variation in runoff correlates roughly with the relative percentage of lake surface area in each basin. Site runoff data were combined with analysis of available regional streamflow data to estimate long-term average and extreme discharge characteristics for the Meadowbank project area. Table 5.5 summarizes mean monthly runoff from May through October, as a proportion of total annual runoff.

Table 5.5: Estimated Mean Monthly Runoff Depths as Proportion of Annual Depth – Project Basins

Month	Percent of Mean Annual Runoff
May	0%
June	30%
July	40%
August	20%
September	9%
October	1%
Year	100%

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Table 5.6 summarizes the results of frequency analyses of annual runoff for project area basins. Analysis of the available data from the four regional streamflow stations was carried out to develop estimates of flood flows and low flows for the outlets of Turn Lake, Drilltrail Lake, Third Portage Lake, and Second Portage Lake. For these locations and a range of return periods, Table 5.7 summarizes estimated maximum daily discharges and Table 5.8 shows estimated low flows.

Table 5.6: Estimated Annual Runoff Depths - Project Basins

Return Period (Years)	Condition	Estimated Basin Runoff Depth (mm)		
		Drilltrail & Turn	Third Portage	Second Portage
100	Wet	378	238	284
50	Wet	345	217	259
20	Wet	300	189	225
10	Wet	266	168	200
5	Wet	230	145	173
2	Average	175	110	131
5	Dry	135	85.1	101
10	Dry	118	74.3	88.5
20	Dry	105	66.2	78.8
50	Dry	92.6	58.4	69.5
100	Dry	84.8	53.4	63.6

.

Table 5.7: Lake Outlet Flood Discharge Estimates

Lake Outlet Station Name	Basin Area (km^2)	Maximum Daily Discharge (m^3/s)					
		1:2 Year	1:5 Year	1:10 Year	1:20 Year	1:50 Year	1:100 Year
Turn Lake Outlet	21.4	3.9	4.9	5.6	6.3	7.3	7.6
Third Portage Lake Outlet	88.9	12.8	16.3	18.6	20.8	23.8	24.7
Drilltail Lake Outlet	107.0	15.0	19.1	21.7	24.3	27.7	28.8
Second Portage Lake Outlet	210.5	26.2	33.8	38.5	43.0	48.7	50.4

.

Table 5.8: Lake Outlet Low Flow Discharge Estimates – July to September

Lake Outlet Station Name	Basin Area (km^2)	Low Flow Duration	Mean Daily Discharge (m^3/s)					
			1:2 Year	1:5 Year	1:10 Year	1:20 Year	1:50 Year	1:100 Year
Turn Lake Outlet	21.4	7 day	0.026	0.005	0.000	0.000	0.000	0.000
		14 day	0.036	0.007	0.001	0.000	0.000	0.000
		30 day	0.065	0.015	0.004	0.000	0.000	0.000
		60 day	0.150	0.065	0.032	0.006	0.004	0.004
Third Portage Lake Outlet	88.9	7 day	0.147	0.038	0.006	0.002	0.000	0.000
		14 day	0.196	0.053	0.013	0.005	0.003	0.001
		30 day	0.315	0.093	0.033	0.007	0.002	0.001
		60 day	0.621	0.293	0.166	0.050	0.035	0.032
Drilltail Lake Outlet	107.0	7 day	0.184	0.050	0.008	0.003	0.001	0.000
		14 day	0.245	0.069	0.018	0.007	0.004	0.002
		30 day	0.387	0.118	0.044	0.010	0.003	0.002
		60 day	0.747	0.357	0.206	0.066	0.046	0.043
Second Portage Lake Outlet	210.5	7 day	0.422	0.136	0.030	0.012	0.003	0.001
		14 day	0.553	0.182	0.062	0.027	0.014	0.009
		30 day	0.818	0.282	0.127	0.040	0.015	0.011
		60 day	1.470	0.733	0.453	0.182	0.127	0.117

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Surface Water Quality

The Meadowbank project area lakes (Second Portage, Third Portage, and Wally lakes) are ultra-oligotrophic, soft water, nutrient poor and isothermal with neutral pH and high oxygen concentrations year round. Limnological conditions tend to be very stable, with uniform, vertical temperature, oxygen and nutrient distributions with only minor, temporary stratification. Water clarity is extremely high with Secchi depths of 10 m or more, with very low dissolved and suspended solids concentrations. Given the absence of tributary streams, there are no external sources of nutrients or sediment that might contribute to nutrient enrichment. Due to the site's northern latitude and climate, lakes in the area naturally experience long periods of cold temperatures and low light levels during the winter months. Ice covers the lakes for extended periods of time each year and low water temperatures exist year round. The ice-free season is very short, with ice break-up in late-June and ice-up beginning in late September.

Maximum ice thickness is at least 2 m by March/April. Because the lakes are ice covered for most of the year, gas exchange with the atmosphere is limited. Oxygen concentration remains high under the ice, however, because of the low rates of biological activity and decomposition of organic material.

Total and dissolved solids in surface waters were low, typically below laboratory detection (<1 mg/L and <10 mg/L respectively) as was turbidity (<1.1 NTU). Hardness (4.4 to 9.5 mg/L), and dissolved anions (chloride, fluoride, sulphate) were also very low (<0.05 – 0.06 mg/L) and also near detection limits. Surface water had circum-neutral pH (6.6 to 7.7) and low conductivity (5 – 77 µS/cm). Nutrient concentrations (nitrogen, carbon, phosphorus) in the project lakes did not differ appreciably within or between lakes and seasons. Values are very low and equivalent to values typical of ultra-oligotrophic lakes. Nitrogen nutrients (nitrate, nitrite, ammonia, dissolved phosphate) seldom exceeded

0.001 mg/L while dissolved phosphate ranged from <0.001 to 0.003 mg/L. Dissolved organic carbon (DOC) values ranged from 1.4 to 2.3 mg/L over all lakes.

Total and dissolved metals concentrations in surface waters from project lakes were remarkably similar within and between lakes between 1997 and 2002. Total antimony, arsenic, chromium, copper, mercury, and nickel concentrations from project lakes were all below laboratory detection limits and well below CCME (2001) Canadian Water Quality Guidelines (CWQG) for the protection of freshwater aquatic life. The only metals to exceed detection limits were aluminum (0.006 to 0.014 mg/L), cadmium (up to 0.0015 mg/L), lead (up to 0.0012 mg/L), and zinc (0.001 to 0.019 mg/L). Only lead marginally exceeded surface water quality guidelines at a few stations. Dissolved metals concentrations comprised the vast majority of total metals concentrations where results exceeded detection limits, indicating that nearly all metals are dissolved and not associated with particulates, which is consistent with the low suspended solids concentrations observed.

Average baseline water qualities in Third Portage, Second Portage, and Wally lakes are presented in Table 5.9.

Table 5.9: Average Baseline Water Quality in Third Portage, Second Portage & Wally Lakes

Parameter	Units	Third Portage Lake (N=3)	Second Portage Lake (N=8)	Wally Lake (N=3)
Conventional Parameters				
Hardness	mg/L	5.3	8.9	17.2
pH	pH units	6.8	7.5	7.3
Dissolved Anions				
Total Alkalinity	mg/L	4	7	13
Chloride	mg/L	0.5	0.6	0.7
Fluoride	mg/L	0.07	0.07	0.05
Sulphate	mg/L	1.3	2.8	5.3
Nutrients				
Ammonia Nitrogen	mg/L	0.01	0.02	0.02
Total Kjeldahl Nitrogen	mg/L	0.09	0.08	0.11
Nitrate Nitrogen	mg/L	0.004	0.007	0.024
Nitrite Nitrogen	mg/L	0.001	0.001	0.001
Total Phosphate	mg/L	0.002	0.003	0.003
Total Phosphorus	mg/L	0.002	0.003	0.003
Organic Parameters				
Dissolved Organic Carbon	mg/L	1.4	1.7	2.2
Cyanides				
Total Cyanide	mg/L	0.005	0.005	0.005
Total Metals				
Aluminum	mg/L	0.006	0.007	0.008
Antimony	mg/L	0.0005	0.0005	0.0005
Arsenic	mg/L	0.0005	0.0005	0.0005
Barium	mg/L	0.02	0.02	0.02
Beryllium	mg/L	0.001	0.001	0.001
Boron	mg/L	0.1		0.1
Cadmium	mg/L	0.00005	0.00077	0.00005
Calcium	mg/L	1.2	2.3	4.6
Chromium	mg/L	0.001	0.001	0.001
Cobalt	mg/L	0.0003	0.0003	0.0003

Copper	mg/L	0.001	0.001	0.002
Iron	mg/L	0.03	0.03	0.03
Lead	mg/L	0.0006	0.0009	0.0007
Lithium	mg/L	0.005	0.005	0.005
Magnesium	mg/L	0.5	0.8	1.3
Manganese	mg/L	0.001	0.0016	0.0013
Mercury	mg/L	0.00005	0.00005	0.00005
Molybdenum	mg/L	0.001	0.001	0.001
Nickel	mg/L	0.001	0.001	0.001
Potassium	mg/L	2	2	2
Selenium	mg/L	0.001	0.001	0.001
Silver	mg/L	0.00002	0.00002	0.00002
Sodium	mg/L	2	2	2
Thallium	mg/L	0.0002	0.0002	0.0002
Tin	mg/L	0.0006	0.0005	0.0005
Titanium	mg/L	0.01	0.01	0.01
Uranium	mg/L	0.0002	0.0002	0.0002
Vanadium	mg/L	0.03	0.03	0.03
Zinc	mg/L	0.005	0.005	0.013

Note: N = number of samples used to calculate average values

5.3 CLIMATE

The project is within a Low Arctic ecoclimate, one of the coldest and driest regions of Canada. Climate data have been collected at the Meadowbank Camp since 1997. Long-term climate characteristics at Meadowbank were estimated based on site data and long-term data from the Meteorological Service of Canada climate station at Baker Lake. Table 5.10 summarizes precipitation data from the Meadowbank site. The annual precipitation at the site generally falls as rain between June and September, and generally as snow between October and May. Snowfall might, however, occur at any time of year. Table 5.11 summarizes mean monthly climate data collected from the site since 1997.

The dominant wind direction is from the northwest. Wind speeds of greater than 100 km/h have been reported at the site. Estimates of wave heights on Third Portage Lake during one such event were approximately 0.6 m to 0.9 m (2 to 3 ft), based on personal communication with Cumberland site personnel during 2002.

Table 5.10: Annual Precipitation Data 1998 to 2002

Year	Recorded Precipitation (mm)
1998	177.1
1999	190.2
2000	100.5
2001	84.1
2002	146.7

Source: Meadowbank Gold Property – Project Description Report, 2003.

Table 5.11: Summary of Monthly Climate Data

	Mean Monthly					
Month	**Maximum Air Temperature (°C)**	**Minimum Air Temperature (°C)**	**Minimum Relative Humidity (%)**	**Maximum Relative Humidity (%)**	**Wind Speed (km/h)**	**Soil Temperature[1] (°C)**
January	-28.2	-34.9	67.8	76.8	17.1	-24.7
February	-27.9	-35.2	66.6	76.3	16.1	-28.2
March	-21.7	-29.7	69.3	81.9	16.9	-24.4
April	-12.7	-22.1	71.4	90.3	17.1	-17.6
May	-2.3	-9.3	75.7	97.4	19.0	-7.4
June	7.8	0.0	61.7	96.8	16.3	1.9
July	17.2	7.6	47.2	94.0	14.9	11.0
August	13.6	6.7	58.5	97.7	18.3	9.6
September	5.8	1.1	69.6	98.3	18.7	3.7
October	-4.8	-10.6	82.4	97.0	21.1	-2.9
November	-14.5	-21.5	80.8	90.9	17.4	-12.1
December	-22.3	-28.9	74.0	83.4	18.1	-19.2

Note: 1. Mean soil temperature is reported by AMEC to be measured at a depth between 0.2 m and 0.3 m below ground surface, but should be confirmed. Installation details such as slope aspect, surficial cover, site drainage, and annual snow cover are not available.

5.4 CURRENT CLIMATE CONDITIONS

Meadowbank is, on average, about 0.6°C cooler than Baker Lake. Based on long-term Baker Lake data from 1946 to 2003, the mean annual air temperature for Meadowbank is estimated to be about -12.8°C. Monthly mean temperatures are above freezing for June through September, but day-to-day temperatures can drop below zero in any month of the year. Mean monthly temperatures, rainfall, snowfall, and total precipitation are summarized in Table 5.12.

Table 5.12: Estimated Average Monthly Temperature & Precipitation – Meadowbank Site

Month	**Mean Temperature (°C)**	**Average Precipitation (mm)**			**Lake Evaporation (mm)**
		Rainfall	**Snowfall**	**Total**	
January	-33.7	0	11.3	11.4	0
February	-33.4	0.1	10.5	10.6	0
March	-28.3	0	14.5	14.6	0
April	-18.6	0.8	17.1	17.8	0
May	-7.1	6.2	11.2	17.4	0
June	3.3	18.2	3.8	22.1	7.8
July	10.3	37.7	0	37.8	98.1
August	8.9	40.3	0.9	41.2	103.0
September	2.1	30.4	8.9	39.3	49.4
October	-8.1	6.8	30.7	37.5	0.1
November	-20.7	0.2	23.3	23.6	0
December	-28.6	0	14.8	14.8	0

Note: Rounding of monthly averages has occurred. Temperatures and precipitation were estimated based on site data (1997 to 2003) and adjusted Baker Lake data (1946 to 2003). Lake Evaporation based on site data.

The prevailing winds at Meadowbank for both the winter and summer months are from the northwest. A maximum daily wind gust of 83 km/h was recorded on 21 May 2002.

Meadowbank total annual rainfall averaged 85% of the Baker Lake total for the common period of record. The estimated mean annual rainfall, snowfall, and precipitation for Meadowbank are 144.0 mm, 148.8 mm, and 292.8 mm, respectively. Annual wet year and dry year extremes of rainfall, snowfall, and total precipitation were estimated using frequency analyses (see Table 5.13. Preliminary estimates of short duration rainfall intensity-duration-frequency values were developed based on the Hydrological Atlas of Canada and are shown in Table 5.14.

Table 5.13: Estimates of Extreme Annual Rainfall, Snowfall, & Total Precipitation at Meadowbank Camp

Return Period (Years)	Condition	Rainfall (mm)	Snowfall (cm)	Total Precipitation (mm)
100	Wet	245	265	452
50	Wet	232	252	433
25	Wet	218	237	411
10	Wet	195	212	376
5	Wet	175	189	343
2	Average	139	145	285
5	Dry	108	104	233
10	Dry	93.6	84.4	208
25	Dry	79.2	64.6	183
50	Dry	70.4	52.4	168
100	Dry	62.9	41.8	155

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Table 5.14: Estimates of Rainfall Intensity-Duration-Frequency Statistics Meadowbank Project

Duration	Return Period (Years)					
	2	5	10	25	50	100
5 min	2.0	2.3	2.6	2.9	3.1	3.3
10 min	2.5	3.0	3.5	4.0	4.3	4.7
15 min	3.1	3.7	4.4	4.9	5.3	5.7
30 min	4.1	5.0	6.1	7.0	7.6	8.1
1 hour	6.0	7.0	9.0	10.0	11.0	11.5
2 hours	7.3	9.1	11.9	13.8	15.2	16.5
6 hours	11.4	14.6	20.1	23.8	26.4	28.9
12 hours	15.1	19.8	28.0	33.6	37.5	41.2
24 hours	22.6	32.2	38.6	46.7	52.7	58.7

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Lake evaporation was estimated from daily Class A evaporation pan measurements taken at the Meadowbank Camp over the 2002 and 2003 seasons. Pan evaporation was converted to lake evaporation with a pan coefficient calculated using Environment Canada's methodology. The average annual small lake evaporation depth for the Meadowbank region was estimated to be 258.4 mm. Evapotranspiration was estimated to be relatively small in comparison to lake evaporation, with a value from about 20 to 40 mm estimated from water balance considerations.

Snow surveys were conducted at Meadowbank in May 2003, and snow water equivalent values (SWE) weighted by terrain types and distributions were developed for each monitored watershed. The average pre-melt SWE for the four watersheds was 115 mm. Sublimation of snow occurs over the winter period during suspension and re-distribution of fallen snow by the wind. Comparing average pre-melt SWE with cumulative winter snowfall, sublimation was estimated to have been about 18 mm.

Solar radiation and wind speed and direction have been measured at the Meadowbank Camp since 1997. The prevailing winds at Meadowbank (1997 to 2003 data) for both the winter and summer months were from the northwest. A maximum daily wind gust of 83 km/h was recorded on 21 May 2002.

5.5 PROJECTED CLIMATE CHANGE

According to the Intergovernmental Panel on Climate Change (IPCC, 2001a), the global mean surface air temperature is projected to increase by 1.4 to 5.8°C from 1990 to 2100. These projected temperatures are amplified at high latitudes.

For the Canadian Arctic, temperatures are expected to increase by 3°C to 4°C by 2050 (Natural Resources Canada, 2004), rising 5°C to 7°C across the mainland by 2100. Marine areas such as Hudson Bay and the Arctic Ocean may see a 1 to 2°C increase in the summer and a 10°C or greater increase in winter temperatures (IPCC, 2001b; Maxwell, 1997). Woo et al (1992) suggest an increase of 4°C for the permafrost zone, with a greater increase of 4 to 10°C in the winter, particularly around the Arctic Ocean and Hudson Bay due to sea ice pattern changes.

Snow and ice surfaces have a high albedo, which means they reflect much of the incoming solar radiation. As a result, large snow and ice surfaces absorb roughly three times less incoming solar radiation than non-snow and ice areas. Any decrease in snow- and ice-covered areas that is expected with global warming means more incoming solar radiation would be absorbed, causing a possible further increase in temperatures. Precipitation in the Arctic is expected to increase 0 to 25%, particularly in the summer and autumn months (Maxwell, 1997; IPCC, 2001a). Woo et al (1992) show an increase in precipitation in the eastern Keewatin. On this basis, no additional increase in temperatures is forecast based on decreased snow cover.

By the middle of the 21^{st} century, sufficient temperature change is predicted to cause near-surface permafrost to be reduced by 12% to 15% once equilibrium conditions become established under the new temperatures. The predicted increase in active layer thickness of 15% to 30% will reach equilibrium relatively much faster (IPCC, 2001a).

IPCC 2001 states that global sea level rise will be within 9 to 88 cm by 2100 (IPCC, 2001b). This figure is based on global mean temperature changes and uncertainties in model parameters for land ice, permafrost, and sediment deposition. Regional differences in sea level will depend on average sea level and regional geological adjustments. According to Natural Resources Canada (2001), global sea level rise is expected to be between 0.5 and 2.0 m in the next 100 years; however, most areas in the Arctic are still rebounding from the most recent glacial period and an increase in global sea level may not have a large effect on the area.

A report, “Implications of Global Warming and the Precautionary Principle in Northern Mine Design and Closure” (BGC, 2003), was prepared for Indian and Northern Affairs Canada, and provides guidance relevant to mine design in Nunavut.

This report suggests that globally the average temperature may increase by about 2°C by 2100 due to global warming. The report also states that the increase may be double the global average for sites located at 50°N, and may be 3.5 times greater for sites located at 80°N.

These estimates suggest that the average annual temperature for the Meadowbank property, located at around 65°N, may increase by approximately 5.5°C by 2100.

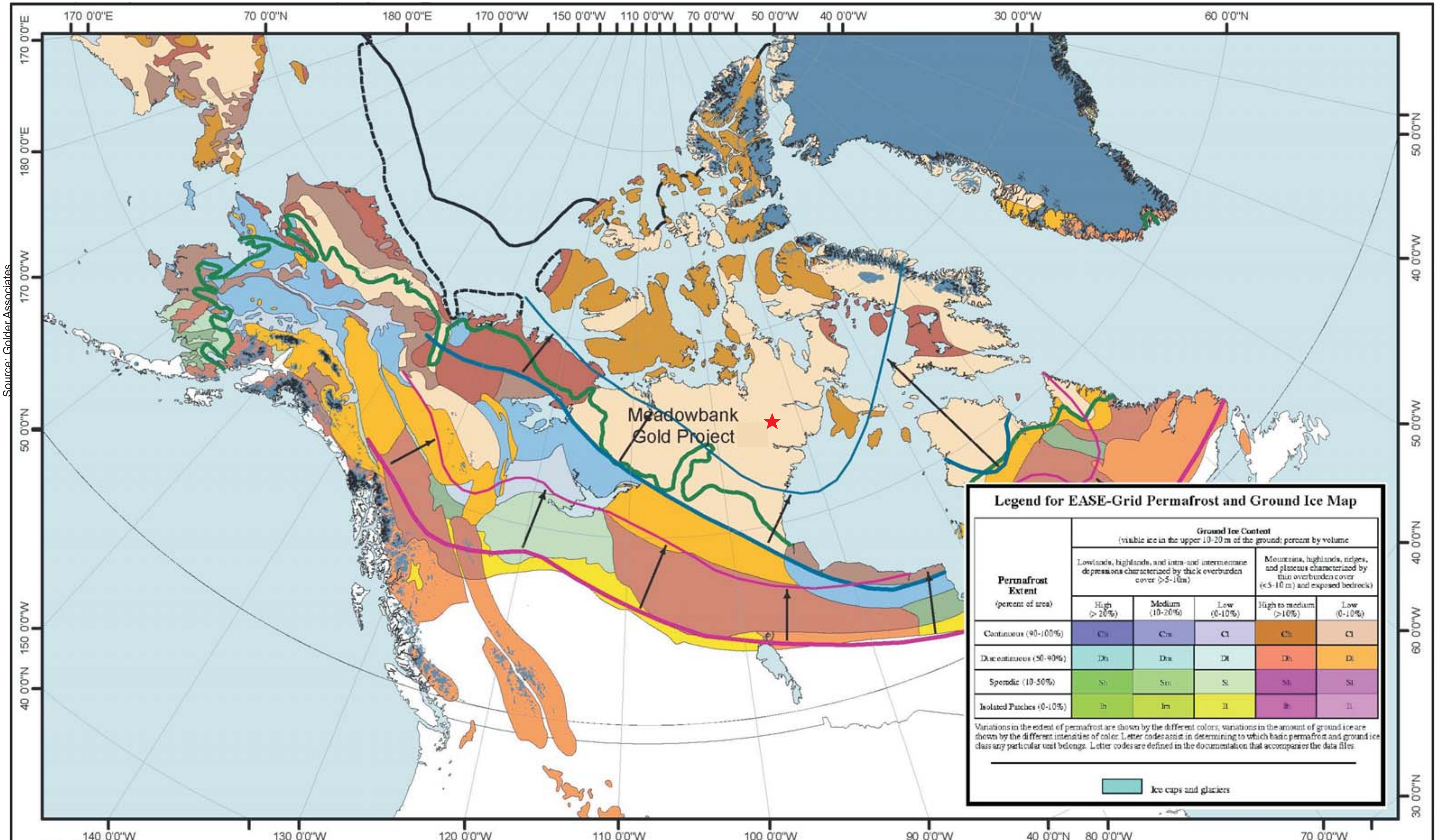
Studies indicate that the boundaries of discontinuous and continuous permafrost are expected to move northward due to global warming (Woo et al, 1992; Figure 5.1). Predictions based on a warming of 4°C to 5°C over the next 50 years (approximately double the rate predicted above) suggests that the Meadowbank property would remain within the zone of continuous permafrost under this scenario, but the active layer thickness would be expected to increase, and the total thickness of permafrost may slowly reduce in time.

5.6 PERMAFROST

The Meadowbank project area is in the area of continuous permafrost as shown on Figure 5.1. Taliks (areas of unfrozen ground) are expected where water depth is greater than about 2 m to 2.5 m. Based on thermal studies and measurements of ground temperatures carried out to date, the depth of permafrost at the site is estimated to be in the order of 550 m, depending on the proximity to lakes. The depth of the active layer ranges from about 1.3 m in areas with shallow overburden, up to about 4 m adjacent to lakes. The depth of permafrost and of the active layer will vary based on proximity to lakes, overburden thickness, vegetation, climatic conditions, and slope direction.

Based on ground conductivity surveys and compilation of regional data, the ground ice content is expected to be low. Locally on land, ice lenses and ice wedges are present, as indicated by ground conductivity, and by permafrost features such as frost mounds. These areas of local ground ice are generally associated with low-lying areas of poor drainage.

A talik (zone of permanently unfrozen ground) exists below Second Portage Arm, and is expected to extend to the base of the permafrost. Thermistors have been installed in boreholes at the locations shown in Figure 5.2, and the inferred thermal regime beneath the Second Portage Arm based on measurements from these instruments is shown in Figure 5.3.



LEGEND

- Treeline
- Sea-ice Edge Limit
- Subsea Permafrost Limit
- Southern boundary of discontinuous permafrost - Present
- Southern boundary of discontinuous permafrost - Predicted
- Southern boundary of continuous permafrost - Present
- Southern boundary of continuous permafrost - Predicted
- Predicted movement of permafrost boundaries

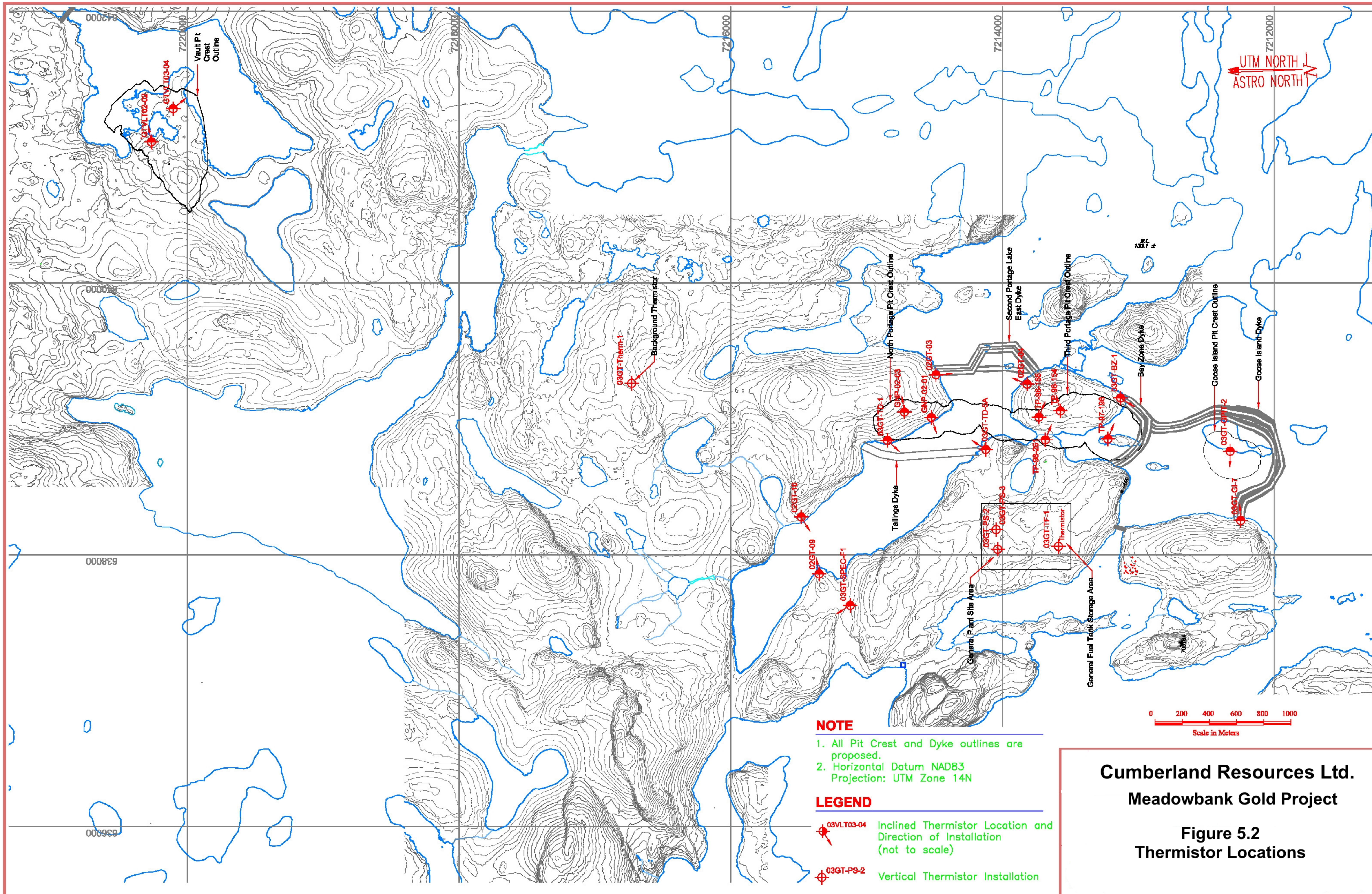
REFERENCE

Brown, J., O.J. Ferrians Jr., J.A. Heginbottom, and E.S. Melnikov. 1998. Circum-Arctic Map of Permafrost and Ground-Ice Conditions. Boulder, CO: National Snow and Ice Data Center/World Data Center for Glaciology. Digital Media.
Predicted permafrost boundaries based on Woo et al., 1992.
PROJECTION: Lambert Azimuthal Equal Area

CUMBERLAND RESOURCES LTD.

Meadowbank Gold Project

Figure 5.1
Permafrost Map of Canada



NOTE

1. All Pit Crest and Dyke outlines are proposed.
2. Horizontal Datum NAD83
   Projection: UTM Zone 14N

LEGEND

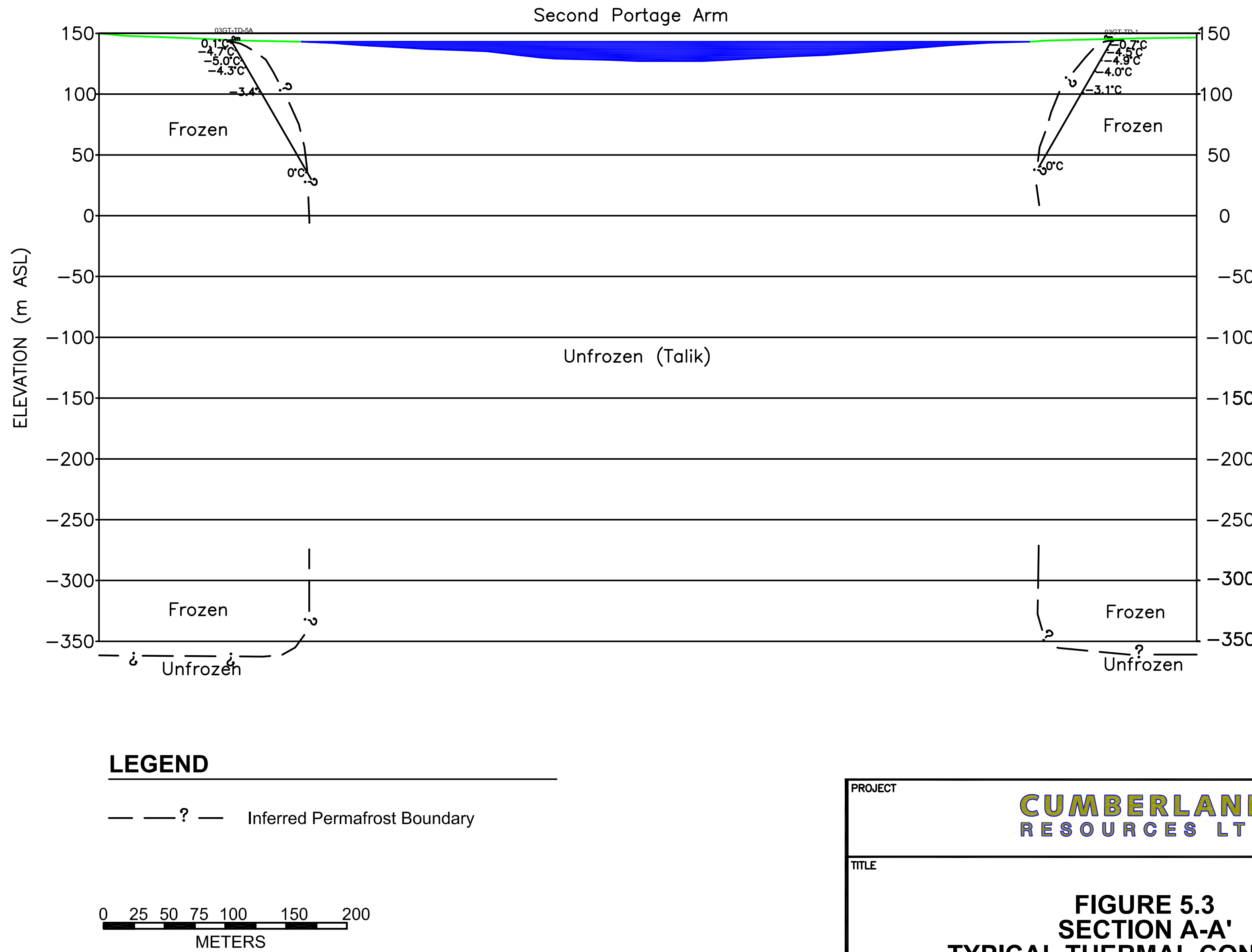
03VLT03-04 — Inclined Thermistor Location and Direction of Installation (not to scale)

03GT-PS-2 — Vertical Thermistor Installation

Cumberland Resources Ltd.

Meadowbank Gold Project

Figure 5.2
Thermistor Locations



PROJECT

CUMBERLAND RESOURCES LTD.

TITLE

FIGURE 5.3
SECTION A-A'
TYPICAL THERMAL CONDITION
BELOW SECOND PORTAGE ARM

Source: Golder Associates drawing P031413427−03−5.dwg

5.7 IN-SITU GEOTHERMAL CONDITIONS

Geothermal studies at the site were initiated during the 1996 summer exploration-drilling program with the installation of two thermistor cables in exploration boreholes drilled on Third Portage Peninsula. To date, 22 thermistor cables have been installed to characterize and monitor the thermal conditions and permafrost. The thermistors have been located to characterize the thermal regime both inland away from the influence of deep lakes as well as adjacent to lakes (Figure 5.2).

Thermistors installations were categorized according to their location: deposit thermistors, dike thermistors, site thermistors, background thermistors, and specific feature thermistors.

Deposit thermistors were installed at the Goose Island, Third Portage, North Portage, and Vault deposits. Their purpose was to characterize the deposit-specific permafrost conditions.

Dike thermistors were installed at several of the abutment areas of the proposed dewatering dikes and tailings dike. These are Goose Island dike, Bay Zone dike, Second Portage Lake (east) dike, and Tailings dike. The purpose of these installations was to characterize the permafrost in dike abutments.

Site thermistors were installed at the plant site and fuel tank farm locations. Two thermistor cables were installed at the proposed plant site and one in the area of the proposed fuel tank storage area. These have not yet reached thermal equilibrium.

A background thermistor was installed to provide data relating to the regional thermal regime. The location was determined based on a minimum distance of 500 m from lakes to reduce their influence on measured ground temperatures. The thermistor is located approximately midway between the Third Portage and Vault deposits.

A specific feature thermistor was installed in a geotechnical borehole to investigate an east-west linear feature on the strip of land separating Second and Third Portage lakes. The borehole encountered a fault at a down-hole depth of approximately 87 m. The thermistor was installed to provide information relating to the thermal conditions near this structure, as well as additional information relating to the thermal regime at the site.

The data collected from site thermistors that were installed in 1996 and 1997 indicate there are no significant variations in the permafrost thermal regime to the depths recorded by these installations for the period of seven years over which monitoring was carried out. Based on this information, the permafrost thermal regime at the site appears to be at steady state. On-going monitoring of the existing thermistors will enable comparison with the current baseline data.

5.8 IN-SITU PERMAFROST & GROUND ICE CONDITIONS

The Meadowbank project area is located well within the zone of continuous permafrost. Permafrost depths are estimated to be between 450 and 550 m, depending on proximity to lakes, slope, aspect, and other site-specific conditions.

The measured active layer depth (a seasonally thawed layer) in the project area currently ranges from about 1.3 m in areas of shallow overburden and away from the influence of lakes up to 4 m adjacent to lakes, and up to 6.5 m beneath the streams connecting Third Portage and Second Portage lakes.

The ground ice content of permafrost soil and rock in the region is expected to be between 0% and 10% (dry permafrost) based on regional scale compilation data (International Permafrost Association, 1997). Electromagnetic surveys (EM31) in specific areas of the project site indicated that, in general, the majority of the areas covered by the survey are underlain by dry permafrost (upland areas). There is little evidence of ground ice, patterned ground, thermokarst, frost mounds, cryoturbation, and other landforms diagnostic of excess ground ice. Excess ground ice is, however, expected in limited areas such as lowlands that are characterized by marshy and poorly drained conditions, commonly with patterned ground evidence.

5.9 GEOTHERMAL MODELING OF ROCK STORAGE FACILITIES

Thermal models were developed for the Portage rock storage facility and the Second Portage Lake tailings storage facility. These were calibrated against in situ ground temperature measurements to demonstrate that the models could indeed predict current conditions. This routine approach is taken to demonstrate the validity of numerical models before they are used for design and performance predictions. For the purposes of this baseline report, the model calibrations enable a broader description of the existing ground thermal regime. Input data for the modeling were selected based on available site climate, permafrost data, and published data.

Description of Calibration Modelling

Thermal modeling was carried out using TEMP/W (Version 5). TEMP/W is a commercially available one- and two-dimesional geothermal modeling software package produced by GeoSlope International.

The calibration model was assigned a stratigraphy comprising 1 m of ice-poor glacial till overlaying bedrock.

The average air temperature at Meadowbank is estimated to be about -12.8°C. Mean monthly soil temperatures were measured at an estimated depth of 0.2 to 0.3 m and can be seen in Table 5.15. It is pointed out, however, that the depths of soil temperature measurements were not recorded when the instruments were installed by Cumberland personnel; hence, the above values are based solely on anecdotal information. Several ground surface temperature functions were considered as shown in Table 5.16 with GST No. 3 being the preferred. Based on the Meadowbank site climate station, the thaw season begins about day 150 of the year (30 May) and ends about day 270 of the year (27 September).

The bottom profile of Second Portage Inlet Arm was assigned a constant boundary condition of 4°C to simulate the influence of the lakes surrounding thermistors TP96-154 and TP96-155 (see Figure 5.4). The models were calibrated using a two-dimensional transient analysis and comparing the results to thermistor data for TP96-154, TP96-155, and a background thermistor. The transient model was run to simulate a period of 11 years, and the resulting temperature profiles in the 11th year were compared to the thermistor data.

Table 5.15: Mean Monthly Soil Temperature at Meadowbank Site

Month	Days per Month	Temperature (°C)
January	31	-24.7
February	28	-28.2
March	31	-24.4
April	30	-17.6
May	31	-7.4
June	30	1.9
July	31	11
August	31	9.6
September	30	4
October	31	-2.9
November	30	-12.1
December	31	-19.2

Note: Mean soil temperature is reported by AMEC to be measured at a depth between 0.2 m and 0.3 m below ground surface but should be confirmed. Installation details such as slope aspect, surficial cover, site drainage and annual snow cover are not available.

Table 5.16: Ground Surface Temperature Functions for Model Calibration

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Air Temp	-31.6	-31.7	-25.5	-17.2	-5.6	3.8	12.4	9.9	3.3	-7.6	-18	-25.6	-11.1
GST No. 1	-24.7	-28.2	-24.4	-17.6	-7.4	1.9	11	9.6	4.0	-2.9	-12.1.	-19.2	-9.2
GST No. 2	-20.2	-17.9	-16.2	-12.3	-4.6	0.3	7.2	6.8	1.8	-4.9	-9.6	-15.0	-7.1
GST No. 3	-22.5	-23.1	-20.3	-15.0	-6.0	1.1	9.1	8.2	2.9	-3.9	-10.9	-17.1	-8.1

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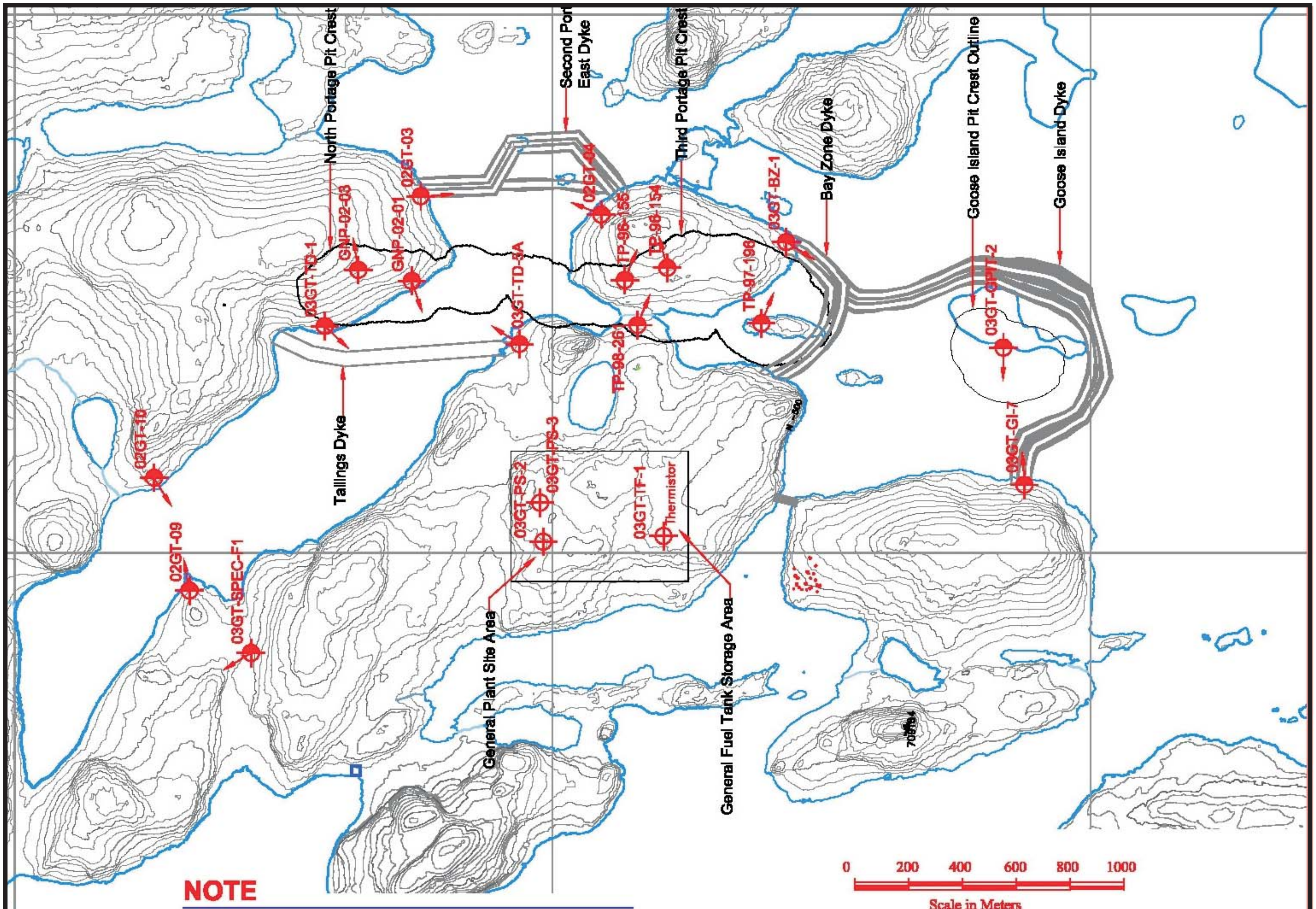
Calibration Modelling Results

Figure 5.5 represents a dike thermistor, located approximately 30 m away from the nearest lake. The measured data, thermistor 02GT-10, are on a 49º shoreward-sloping angle, while the model is vertical in orientation, which may account for the warmer temperatures seen in the measured values.

In Figure 5.6, the measured data are from deposit thermistor TP96-154, which is on a 60º angle sloping away from the nearest shoreline. The measured temperatures are taken at a distance of 150 m from the nearest lake, while the predicted values represent a location 300 m from the nearest lake. Although the background thermistor 03GT-Therm-1 is located 500 m from the nearest lake, thermistor TP96-154 has a more complete record and was therefore used in comparison with the model results. The larger distance from a body of water represented in the model may account for the cooler temperatures displayed in the graph.

In the foregoing discussion, minor differences between the model results and the monitoring data are attributed to proximity of the thermistors to lakes. Differences between time-steps for the model output and the actual monitoring dates, as well as differences in assumed and actual soil conditions at the ground surface where the thermistors are located, can also affect how closely the model reproduces the measured ground temperatures.



NOTE

1. All Pit Crest and Dyke outlines are proposed.
2. Horizontal Datum NAD83
   Projection: UTM Zone 14N

LEGEND

03VLT03-04 — Inclined Thermistor Location and Direction of Installation (not to scale)

03GT-PS-2 — Vertical Thermistor Installation

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Figure 5.4
Thermistor Locations

Figure 5.5
Model Temperature Prediction 30 m from nearest lake
02GT-10

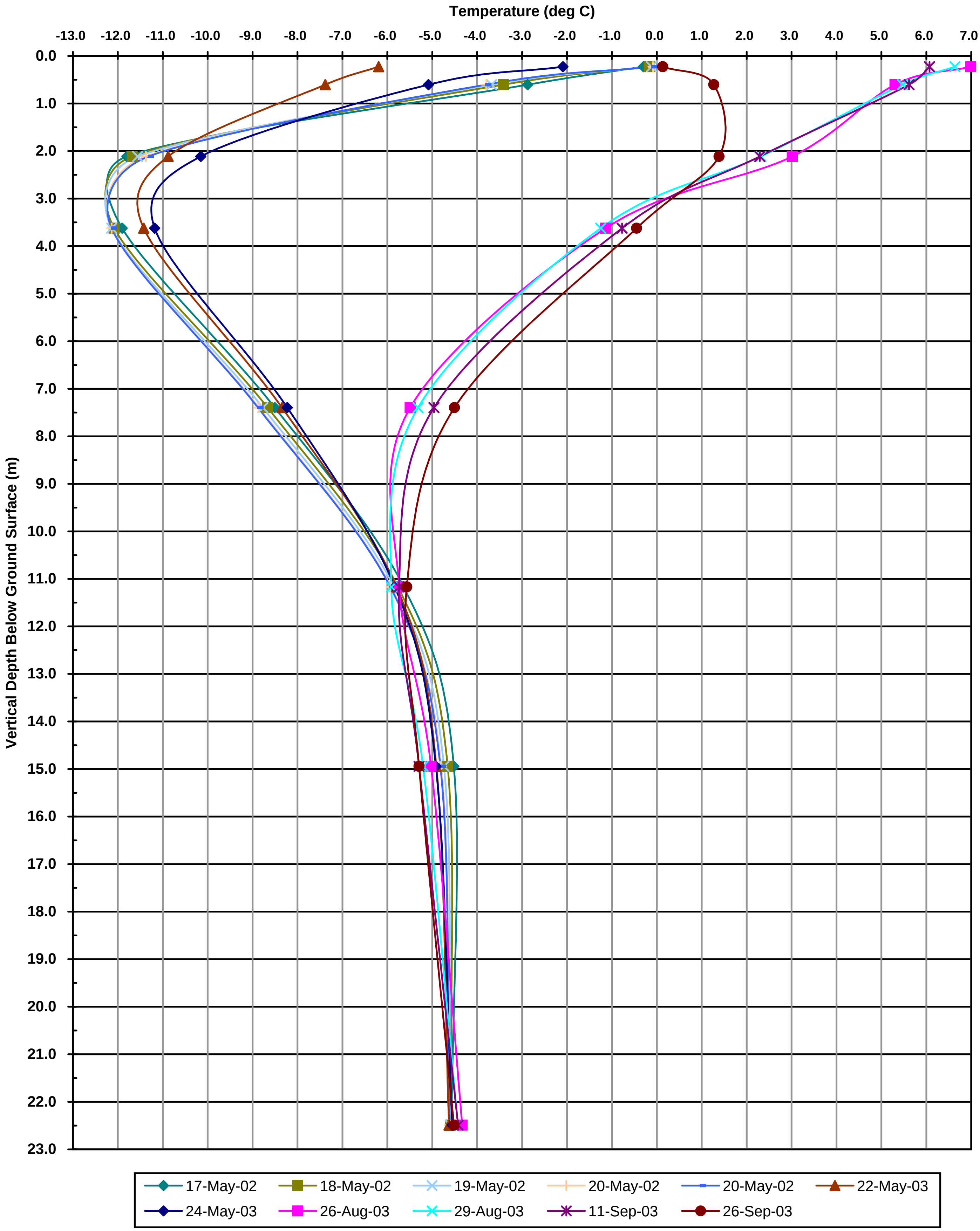
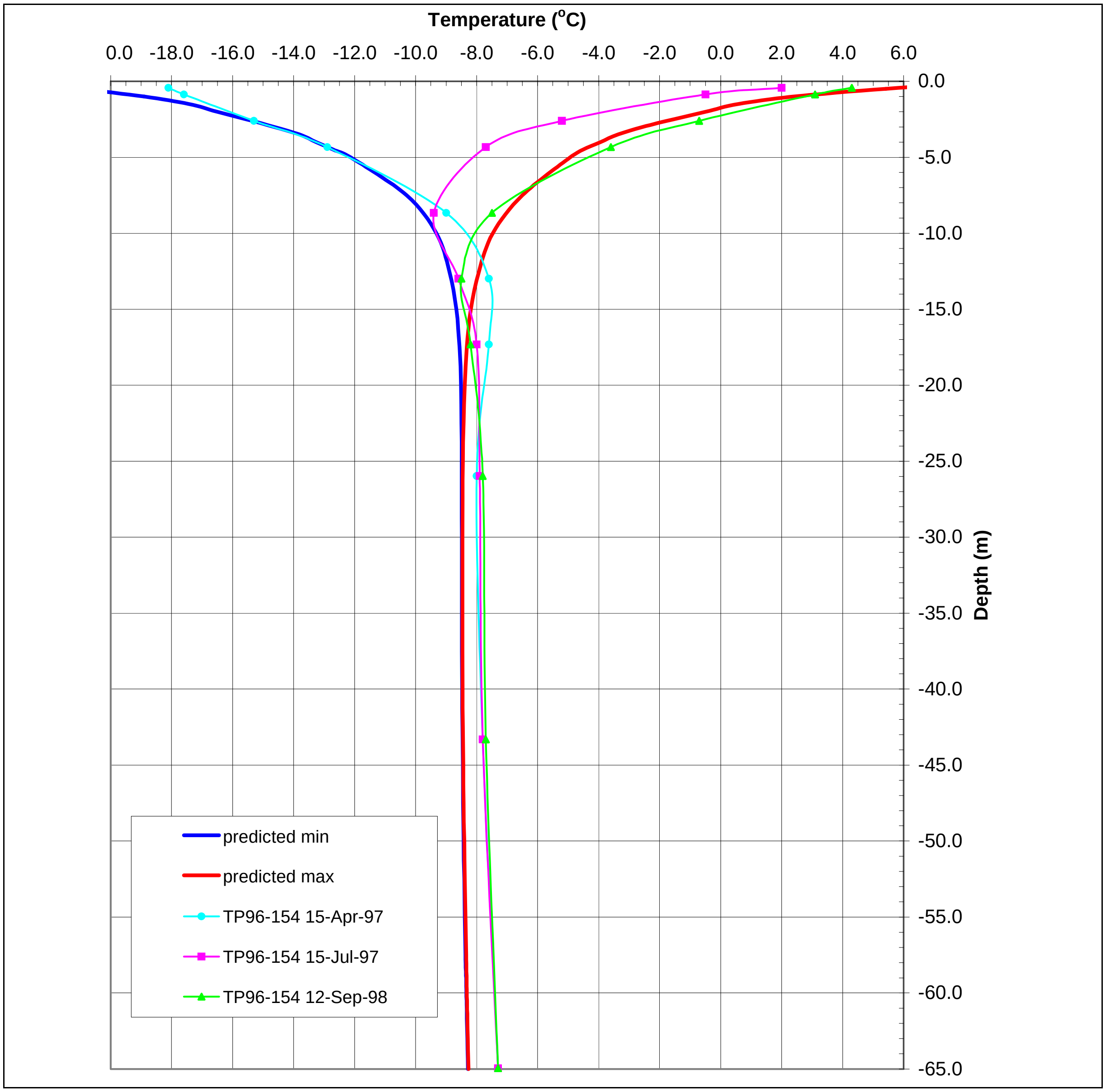


Figure 5.6: Model Temperature Predictions 300 m from Nearest Lake



Model Predictions

The following presents the model predictions of permafrost both on-land and beneath Second Portage Lake. These results are based on the input parameters used for the calibration exercise described above, but the stratigraphy was varied to reflect the variable site conditions.

Predicted Active Layer Thickness in Various Soils & Rock

The active-layer thicknesses were determined for scenarios where the top 5 m of the numerical model composed one material type. The predicted active-layer thicknesses, based on geothermal modeling of the rock storage facilities, are as follows:

- bedrock: 2.6 m
- ice-poor glacial till: 1.4 m
- ice-rich sediments: 0.7 m
- rockfill: 1.3 m.

The results give an indication as to the influence of variable surficial geology and ground ice conditions across the project site on the ground thermal regime. They should also assist with placement of thermistor beads for optimum resolution of the ground thermal regime at future installation sites.

Depth of Zero Mean Annual Ground Temperature Change

The model results and mathematical solutions based on the site monitoring data for both locations have similar zero annual amplitude depths and temperatures, as seen in Table 5.17.

Taliks beneath Lakes

On the basis of geothermal modelling calibrated to in situ ground temperature measurements, round lakes that do not freeze to the bottom in winter and have a diameter in the order of 570 m or greater will have a talik (an area of unfrozen ground) that extends through the permafrost down to the deep groundwater regime nearby permafrost depth. In addition, elongated lakes that do not freeze to the bottom in winter and have a width in the order of 320 m or greater will have a similar talik. Based on these analyses, the taliks beneath Third Portage Lake and Second Portage Lake are expected to extend down to the deep groundwater regime. The talik beneath Vault Lake is not expected to extend to the deep groundwater flow regime because this lake is relatively shallow and much of it freezes to the bottom in winter.

Lake-ice thickness is estimated to be around 1.5 to 2.0 m thick during mid- to late-spring, depending on site-specific conditions of water depth and exposure. Consequently, where water depth is greater than about 2 to 2.5 m, taliks are to be expected.

Table 5.17: Measured Thermistors & Model Details

Borehole	Location	Length (m)	Depth (m)	Distance from Nearest Lake (m)	Inclination	Drilling Direction (with respect to shoreline)	Depth of Zero Annual Amplitude (m)	Zero Amplitude Temperature (°C)	Extrapolated Mean Annual Surface Temperature (°C)	Geothermal Gradient (°C/m)	Vertical Depth of Active Layer (m)
Measured TP96-154	Third Portage Depost	75.0	65.0	150	60°	Away	20-30	-8.0	-8.5	0.018	2.5
Measured TP96-155	Third Portage Depost	75.0	65.0	150	60°	Away	20-30	-7.0	-8.0	0.025	2.6
Model for 300 m	Model at 300 m (with GST No. 3)	65.0	65.0	300	Vertical	Vertical	20-30	-8.5	-8.5	0.020	2.0
Measured 02GT-10	West Dyke North Abutment	30.0	22.5	37	49°	Towards	20-25	-5.5	N/A	N/A	3.0
Model for 30 m	Model at 30 m (with GST No. 3)	65.0	65.0	30	Vertical	Vertical	20-33	-5.2	-	-	2.0
Background Thermistor 03GT-Therm-1	Between Third Portage and Vault Deposits	150.0	150.0	500	Vertical	Vertical	Insufficient Data	Insufficient Data	-9.5	0.017	2.1

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5.10 HYDROGEOLOGY

In areas of continuous permafrost there are two groundwater flow regimes: a shallow groundwater regime located in the active layer near the ground surface and a deep groundwater regime beneath the permafrost.

Current & Projected Groundwater Use

Groundwater sources from either the active layer or the deep groundwater regime below the permafrost are not presently utilised for drinking water. This is likely due to the presence of deep permafrost, the seasonal nature of the active layer and the availability of many good quality surface drinking water sources near the project site. Furthermore, it is unlikely that the groundwater in the shallow active layer would be utilised in the future because of its seasonal nature and low yields. Deep groundwater may be utilised in the future, but the likelihood of this is considered low because there are abundant sources of good quality surface water.

Hydrostratigraphy & Groundwater Flow

The following provides a discussion of the shallow and deep groundwater regimes at the Meadowbank project based on the hydrogeological and thermal field investigations.

Shallow Groundwater Flow Regime

The hydraulic conductivity of the till overburden was characterised by falling head tests and was found to be between 3×10^{-4} and 1×10^{-7} m/s.

From late spring to late summer, when temperatures are above 0 degrees Celsius, the active layer thaws, creating the shallow groundwater regime. Within the active layer, the water table is expected to be a subdued replica of the topographic surface. Groundwater gradients, or the slope of the groundwater table, are similar to topographic gradients. Locally, groundwater in the active layer flows to local depressions and ponds that drain to Second and Third Portage lakes or flows directly to Second and Third Portage lakes.

Permafrost reduces the hydraulic conductivity of the rock by at least one to two orders of magnitude (Anderson and Morgenstern, 1973; Burt and Williams, 1976). Consequently, permafrost in the rock at Meadowbank will result in very low permeability compared to that of the unfrozen rock. The shallow groundwater flow regime therefore has negligible hydraulic connection with the groundwater regime located below the deep permafrost except where taliks exist beneath large water bodies.

Deep Groundwater Flow Regime

In areas of continuous permafrost, the deep groundwater regime is connected by taliks located beneath large lakes. Taliks exist beneath lakes that do not freeze to the bottom in winter. If a lake is large enough, the talik extends down to the deep groundwater regime. At Meadowbank, analyses have predicted that open taliks extending to the deep groundwater regime will occur beneath lakes that do not freeze to the bottom in winter, when the diameter is in the order of 570 m or greater for round lakes, or the width is at least 320 m for elongated lakes. Based on these analyses, open taliks exist beneath Third and Second Portage lakes, including Second Portage Arm. These analyses also suggest that the talik beneath Vault Lake does not extend to the deep groundwater flow regime because this lake is relatively shallow and much of the lake freezes to the bottom in winter.

The elevation of the water levels in lakes that have open taliks provides the driving force (hydraulic head) for the deep groundwater flow. The presence of the thick and low permeability permafrost beneath land located between large lakes results in negligible recharge to the deep groundwater flow from these areas. Smaller lakes have isolated, or closed, taliks that do not extend down to the deep groundwater regime and thus do not influence the groundwater flow in the deep regime. Consequently, recharge to the deep groundwater flow regime is limited to the open taliks beneath large lakes. Generally, groundwater will flow from higher elevation lakes to lakes located at lower elevations. This concept is illustrated in Figure 5.7 (overleaf)

The hydrogeological characteristics of the unfrozen bedrock were investigated by hydraulic conductivity testing within geotechnical boreholes. The field studies were located within the Portage area of the Meadowbank project as follows:

- Third Portage Deposit
- North Portage Deposit
- Goose Island Deposit
- Second Portage Lake.

No hydraulic conductivity testing was undertaken at the Vault deposit area as the deposit is underlain by permafrost.

There does not appear to be discernable difference in the hydraulic conductivity of the various rock types. Ultramafic rocks at a given depth have similar hydraulic conductivity to those of the intermediate volcanics at the same depth. The hydraulic conductivity of the shallow exfoliated and weathered bedrock, regardless of rock type, is generally higher than the deeper less fractured rock. Average hydraulic conductivities, calculated as a geometric mean of packer tests conducted within 30 m depth intervals are summarized in Table 5.18. At greater depths, it is expected that hydraulic conductivity values would be less than the Table 5.18 values.

Table 5.18: Variation in Hydraulic Conductivity with Depth

Depth below Ground (m)	**K (m/s)**
0-30	$6x10^{-7}$
30-60	$3x10^{-7}$
60-90	$1x10^{-8}$
90-120	$2x10^{-8}$
120-150	$2x10^{-8}$

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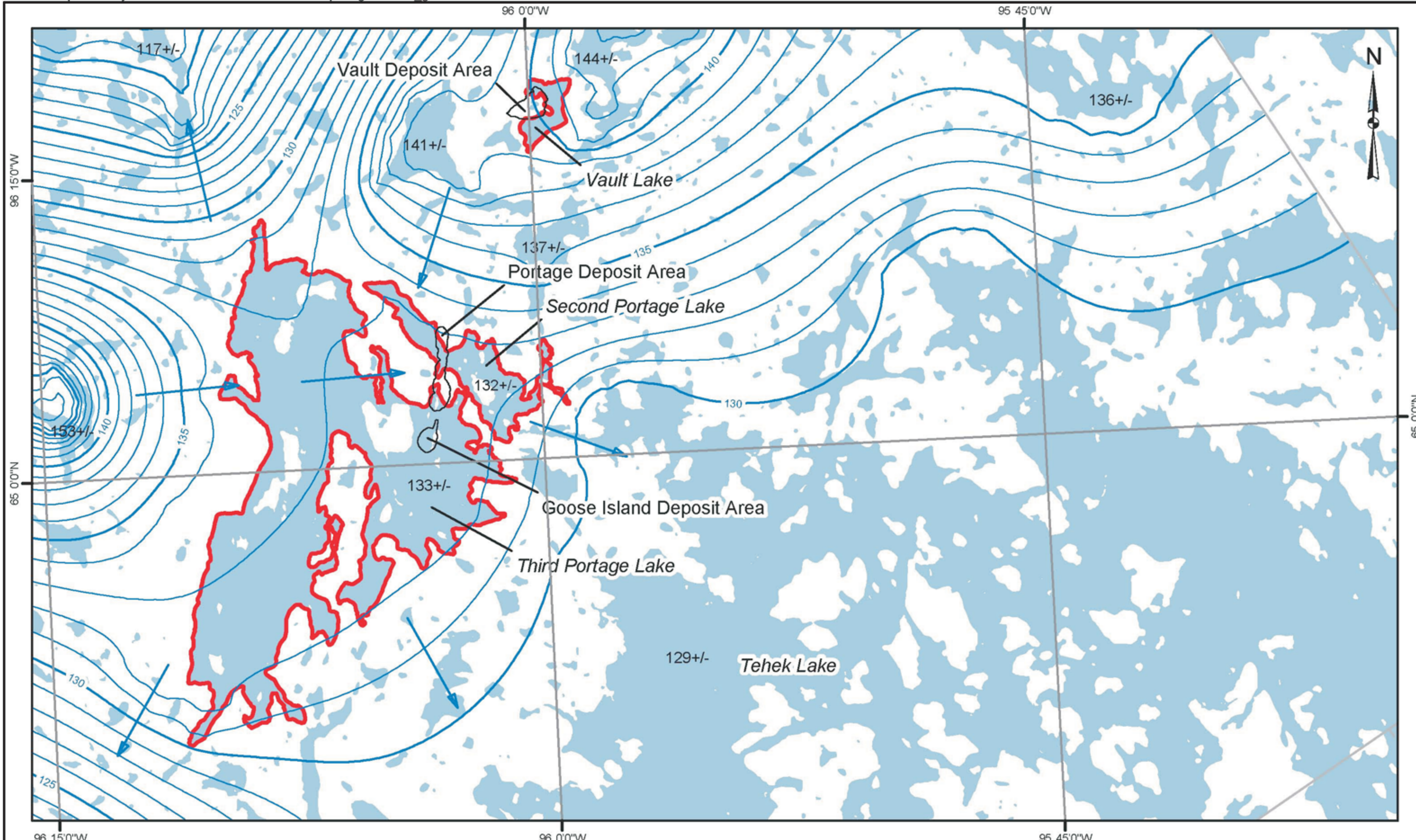

LEGEND

- Proposed Open Pit Crest
- Inferred Groundwater Contour (1 m interval)
- Inferred Groundwater Contour (5 m interval)
- Inferred Groundwater Flow Line
- 133 Waterbody (elevation in masl)

REFERENCE

District of Keewatin, Northwest Territories, Department of Energy, Mines and Resources, Mapsheets 66A/16, 56E/04, 66H/01, 56D/13
Datum: NAD83 Projection: UTM Zone 14

NOTE

Water levels vary annually and may differ from recently surveyed elevations.

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Figure 5.7
Groundwater Flow from Higher Elevation Lakes to Lower Elevation Lakes

Two main faults are present in the Portage Deposit area. These are the Bay Zone Fault and an associated splay, and the Second Portage Fault. The hydraulic conductivities of the fractured rock zone associated with the Bay Zone Fault and fault splay were similar to those of the less fractured rock, while the hydraulic conductivity of the fractured rock zone associated with the Second Portage Fault at a depth of 75 m was generally higher and approximately 5×10^{-6} m/s. The Bay Fault and associated splay trend in a roughly north-south direction along the western margin of the Third Portage Deposit. The Second Portage Fault trends to the northwest roughly parallel to the orientation of the Second Portage Lake.

The driving force or hydraulic head for the deep groundwater regime is the water levels in large lakes with taliks that extend down to the deep groundwater regime. The Meadowbank project is located close to the surface water divide between the Back River basin, which flows north and northwest towards the Arctic Ocean, and the Thelon River basin, which flows east to southeast into Hudson Bay. Consequently, on a regional scale groundwater from the northwestern side of Third Portage Lake would flow in a northwest direction, and from the southeast end of Third Portage and Second Portage Lakes in a southeast direction. On a local scale, groundwater flows from a higher elevation lake located to the east to the northwest portion of Second Portage Lake (Second Portage Arm). Figure 5.8 presents the likely baseline groundwater flow directions in the deep groundwater regime near the Meadowbank project.

Groundwater Flow

The estimated rate of groundwater flow in the Meadowbank area is shown in Table 5.19. Groundwater flow from Second Portage Lake to Tehek Lake is predicted to be approximately 0.1 m^3/day. Groundwater flow from Third Portage Lake into Second Portage Lake is predicted to be around 0.4 m^3/day. Groundwater is expected to flow into Second Portage Lake from a lake located to the northwest of Second Portage Lake at 0.2 m^3/day, while groundwater is expected to flow to Second Portage Lake from Turn Lake at 3.8 m^3/day.

The groundwater velocity towards the northwest portion of Second Portage Lake is estimated to be approximately 0.50 m per year. The groundwater velocity away from Third Portage Lake towards the northwest is estimated to be approximately 0.50 m per year, while the velocity of the groundwater flow to the southeast from Third Portage Lake and from the southeast portion of Second Portage Lake is estimated to be approximately 0.30 m per year. The groundwater flow directions, gradients and velocities are shown in Table 5.20.

The Meadowbank project is located close to the surface water divide between the Black River basin, which flows north to northwest towards the Arctic Ocean, and the Thelon River basin, which flows east to southeast into Hudson Bay. On a regional scale, groundwater flows in a northwest direction from the northwestern end of Third Portage Lake and in a southeast direction from the southeast end of Third Portage and Second Portage lakes. On a local scale, the northwest portion of Second Portage Lake has the lowest water level in the area and consequently forms a discharge zone (groundwater flows from high elevation water levels to lower elevation water levels) with groundwater flowing from a higher elevation lake located to the east, through the deep groundwater flow system and then up into the lake.

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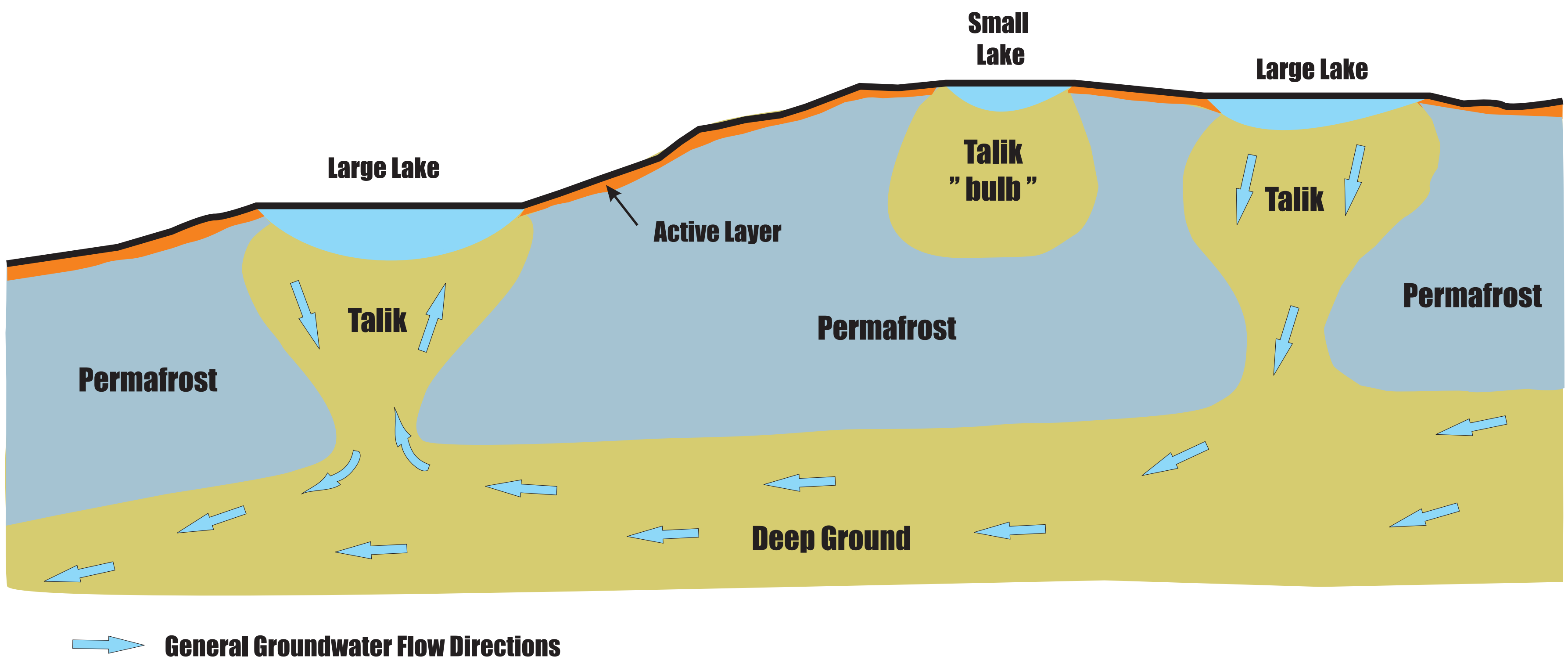

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Figure 5.8
Likely Baseline Groundwater Flow Directions In The Deep Groundwater Regime

Table 5.19: Estimated Groundwater Flux

	Flux (m^3/day)
Second Portage Lake to Tehek Lake	0.1
Third Portage Lake to Second Portage Lake	0.4
A lake located northwest of Second Portage Lake to Second Portage Lake	0.2
A lake (Turn Lake) located northeast of Second Portage Lake to Second Portage Lake	3.8

Table 5.20: Hydraulic Gradient & Velocity

Location	**Direction of Groundwater Flow**	**Approximate Hydraulic Gradient**	**Approximate Velocity (m/year)**
Northwest Portion of Third Portage Lake	NW away from lake	0.004	0.50
Southeast portion of Third and Second Portage Lakes	SE away from lakes	0.002	0.30
Northwest portion of Second Portage Lake	SW towards lake	0.004	0.50

Groundwater Quality

Groundwater baseline data were collected from four monitoring wells located within the 3 main rock types in the area of the Goose Island and Portage deposits (namely the Iron Formation (IF), Intermediate Volcanic (IV) and Ultramafic (UM) lithologies), and from the talik underlying the proposed tailings storage facility area at Second Portage Lake . No wells were installed in the Vault area, as it lies within continuous permafrost. Difficulties experienced in developing the well installed into the talik under the proposed tailings area (MW03-04), and inconsistent water quality results in water samples taken from the well, suggests that samples collected from this well may not be representative of the actual groundwater chemistry in that area.

Table 5.21 presents a summary of groundwater quality results for each lithology, as compared against CWQG for the protection of freshwater aquatic life, and MMER guidelines. No samples reported MMER exceedances, although some samples reported exceedances to CWQG. Concentrations of total metals generally exceeded those of dissolved metals for all wells.

Table 5.21: Summary of Groundwater Quality

Monitoring Well	**Lithology**	**Location**	**Groundwater Quality >CEQG, >MMER**	**Rock Leachate Quality (Static & Kinetic Tests)[2] >CEQG, >MMER**
MW03-01 (duplicate)	UM	Goose Island	dissolved Cd; total As, Ag, Cd, Cr, Cu, Fe, Pb, Zn.	dissolved *As*, Cr, Cu
MW03-02	IF	Goose Island	dissolved Al, Cr, Cu, F, Fe; total Cu, Fe.	*pH*, dissolved Al, As, Cd, Cu, F, Fe, Ni, Pb, *Zn*
MW03-03	Portage IV	North Portage	dissolved F	
MW03-04	Portage IV	Second Portage Lake	dissolved Al, As, Cu, F, Fe, Pb.[1]	[3]dissolved Al, As, Cu

Notes: 1. Total metals not analyzed.

A trilinear Piper plot (Figure 5.9) was developed to show general trends in the major ion chemistry of groundwater for the different lithologies). Lake water was also shown for comparison. Lake water demonstrated a fairly consistent chemical signature, while the chemistry of groundwater demonstrate distinct signatures for each lithology, all plotting away from the lake water signature.

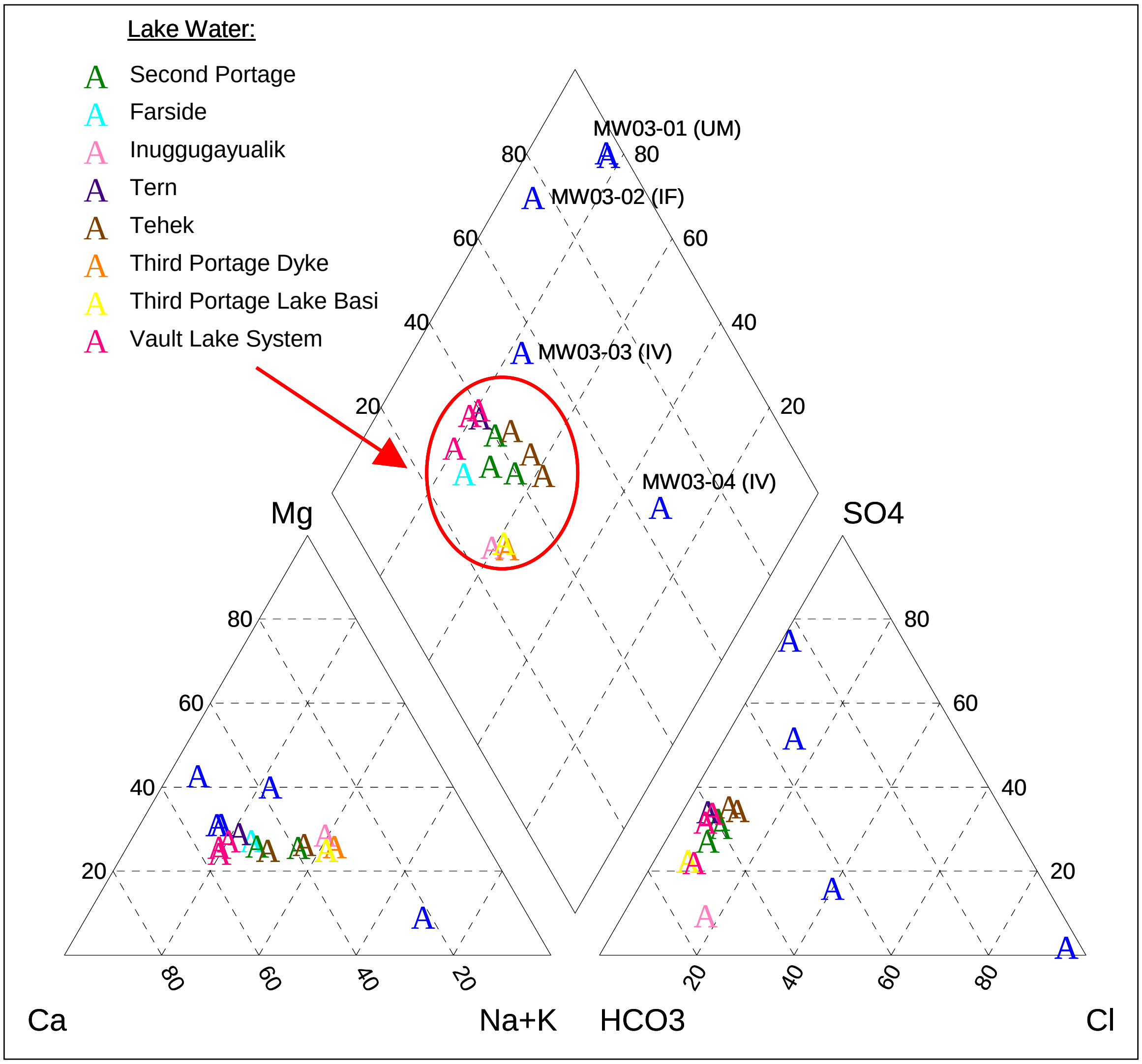
Table 5.22 also presents a summary of leachate results for each lithology based on static and kinetic tests. In comparison with groundwater quality, rock leachates obtained from static and kinetic tests generated a greater number of dissolved constituent exceedances of CEQG and MMER. This is likely an artefact of the rock leaching test methodology, which accelerates rock weathering. Groundwater quality is nevertheless generally consistent with rock leachate characteristics, with the majority of constituents present in rock leachate also present in the groundwater of the corresponding lithology.

Groundwater Salinity & Freezing Point Depression

Based on data from other sites in the Canadian Shield it is expected that the salinity of the groundwater will increase with depth. Water samples collected from monitoring wells installed in the talik beneath Second Portage Lake and Third Portage Lake to depths of up to 175 m have chloride concentrations up to 626 mg/L and TDS values up to 800 mg/L. Water samples collected from a number of large lakes in the area have chloride concentrations of less than 1 mg/L. By comparison, seawater has chloride concentrations of approximately 19,000 mg/L.

The maximum increase in the rate of TDS or chloride concentrations with depth that have been observed in the Canadian Shield by Frape and Fritz (1997) would result in a chloride concentration of around 2000 mg/L at 550 m depth, which is the estimated maximum depth of permafrost at the site. This is equivalent to a salinity of approximately four, and would result in an approximate 0.1°C depression of the freezing point. This in turn would represent an approximate 1% reduction in the thickness of permafrost due to the hydrochemical talik. Consequently, there is not expected to be a depression of the freezing point within the permafrost for the existing conditions. Freezing point depression is not considered in the characterization of the shallow or deep groundwater flow regime.

Figure 5.9: Trilinear Plot of Lake & Groundwater Samples



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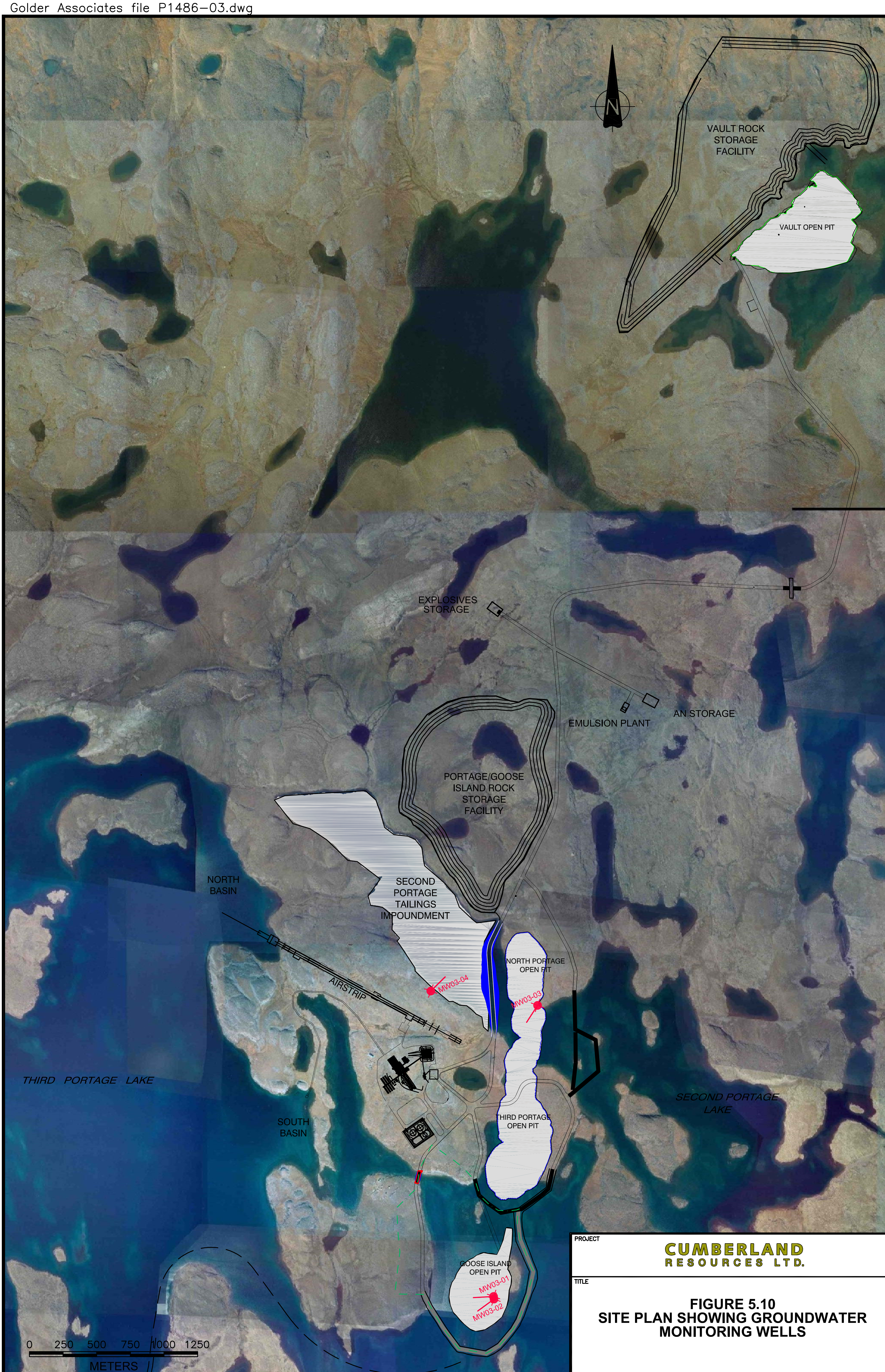

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FIGURE 5.10
SITE PLAN SHOWING GROUNDWATER MONITORING WELLS

Table 5.22: Groundwater Quality Results

		Canadian Water Quality Guideline for the Protection of Aquatic Life (CEQG)	Metal Mine Effluent Regualtion[6] (MMER)	MW03-01 UM Goose Island 9755-2	MW03-02 IF Goose Island 9756-03	MW03-03 IV North Portage 9756-02	MW03-04[7] IV Second Portage Lake 9756-01	Method Dectectior Limit
Field Parameters								
Depth of Screen Midpoint (m)				150	143	111	169	-
pH (s.u.)		**6.5-9.0**	6.0-9.5	7.36	7.68	8.63	7.67	-
Conductivity (µS/cm)				1855	660	350	370-450	-
Redox (mV)				-	8.2	79.9	-	-
Alkalinity (mg/L as $CaCO_3$)				19 - 22	96-100	87	-	-
Laboratory Parameters								
Calculated TDS (mg/L)				793	500	254	154	-
pH (s.u.)		**6.5-9.0**	6.0-9.5	7.24	7.04	7.83	-	-
Total Alkalinity $CaCO_3$ (mg/L)				30	103	93.8	-	1
Bicarbonate Alalinity HCO_3 (mg/L)				36.6	125	114	-	0.5
Dissolved Sulphate SO_4 (mg/L)				15.6	263	26.6	63.8	0.5
Hardness $CaCO_3$ (mg/L)				262*	290	136	53	1
Hardness (Total) $CaCO_3$ (mg/L)				318*	316	114	-	1
Total Metals (mg/L)								
Aluminum[1]	Al			4.16	1.07	0.018	-	0.005
Arsenic	As	**0.005**	0.5	<0.001	0.002	0.004	-	0.001
Cadmium[3]	Cd	**0.000017**		**0.00024**	<0.0002***	<0.0002***	-	0.0002
Calcium	Ca			72	68.3	28	-	0.05
Chromium[2]	Cr	**0.001/0.0089**		**0.049**	0.003	<0.001	-	0.001
Cobalt	Co			0.004	0.004	<0.001	-	0.001
Copper[3]	Cu	**0.002-0.004**	0.3	**0.044**	**0.004**	<0.001	-	0.001
Iron	Fe	**0.3**		**6.05**	**2.96**	<0.05	-	0.05
Lead[3]	Pb	**0.001-0.007**	0.2	**0.013**	0.002	0.001	-	0.001
Magnesium	Mg			33.2	35.2	18	-	0.05

Table 5.22 – Continued

		Canadian Water Quality Guideline for the Protection of Aquatic Life (CEQG)	Metal Mine Effluent Regualtion[6] (MMER)	MW03-01 UM Goose Island 9755-2	MW03-02 IF Goose Island 9756-03	MW03-03 IV North Portage 9756-02	MW03-04[7] IV Second Portage Lake 9756-01	Method Dectection Limit
Manganese	Mn			0.073	1.04	0.11	-	0.001
Mercury	Hg	**0.0001**		-	<0.00002	<0.00002	-	0.00002
Molybedenum	Mb	**0.073**		<0.0005	0.022	0.056	-	0.0005
Nickel[3]	Ni	**0.025-0.15**	**0.5**	0.056	0.008	0.003	-	0.001
Potassium	K			7.31	5.94	3.51	-	0.01
Seleniuum	Se	**0.001**		<0.001	<0.001	<0.001	-	0.001
Silver	Ag	**0.0001**		**0.0064**	<0.0001	<0.0001	-	0.0001
Sodium	Na			**22**	6.81	17.6	-	0.05
Thalium	Tl	**0.008**		<0.0001	<0.0001	<0.0001	-	0.0001
Zinc	Zn	**0.03**	**0.5**	**0.063**	0.014	<0.005	-	0.005
Dissolved Metals (mg/L)								
Aluminum[1]	Al	**0.005-0.1**		0.051	0.47	0.018	**0.72**	0.005
Cadmium[3]	Cd	**0.000017**		**0.00007**	<0.0002**	<0.0002**	<0.0002**	0.0002
Calcium	Ca			65.6	63.1	26.3	15	0.05
Chromium[2]	Cr	**0.001/0.0089**		<0.001	**0.001**	<0.001	<0.001	0.001
Cobalt	Co			0.001	0.004	<0.001	0.003	0.001
Copper[3]	Cu	**0.002-0.004**	0.3	0.002	**0.004**	<0.001	**0.006**	0.001
Iron	Fe	**0.3**		<0.5	**1.19**	<0.05	**0.55**	0.05
Lead[3]	Pb	**0.001-0.007**	0.2	<0.001	0.001	<0.001	**0.006**	0.001
Magnesium	Mg			23.4	32.1	17.1	3.81	0.05
Manganese	Mn			0.06	0.96	0.1	0.049	0.001
Mercury	Hg	**0.0001**		-	<0.00002	<0.00002	<0.00002	0.00002
Molybdenum	Mo	**0.073**		<0.0005	0.018	0.052	0.024	0.0005
Nickle[3]	Ni	**0.025-0.15**	0.5	0.006	0.007	0.003	0.003	0.001
Potassium	K			5.71	5.36	3.33	5.44	0.01
Selenium	Se	**0.001**		<0.001	<0.001	<0.001	<0.001	0.001

Table 5.22 – Continued

		Canadian Water Quality Guideline for the Protection of Aquatic Life (CEQG)	Metal Mine Effluent Regualtion[6] (MMER)	MW03-01 UM Goose Island 9755-2	MW03-02 IF Goose Island 9756-03	MW03-03 IV North Portage 9756-02	MW03-04[7] IV Second Portage Lake 9756-01	Method Dectectior Limit
Silver	Ag	**0.0001**		<0.0001	<0.0001	<0.0001	<0.0001	0.0001
Sodium	Na			20	6.29	16.5	52.9	0.05
Thallim	Ti	**0.0008**		<0.0001	<0.0001	<0.0001	<0.0001	0.0001
Zinc	Zn	**0.03**	0.5	0.006	0.012	<0.005	0.022	0.005
Dissolved Anions (mg/L)								
Dissolved Floride[4]	F	**0.12**		<0.05	**0.35**	**0.46**	**0.34**	0.05
Dissolved Chloride	Cl			626	5.4	50.4	13.4	0.2
Nutrients (mg/L)								
Total Phosphate	PO4			110	190	70	-	-

Notes: **1.** Freshwater Aquatic Life Guideline is pH, calcium and DOC dependent. Exceedances identified apply pH criterion. **2.** Freshwater Aquatic Life Guideline for chromium depends on valence of chromium ion (Cr(III) = 0.0089 mg/L, Cr(VI) = 0.001 mg/L). **3.** Freshwater Aquatic Life Guideline is hardness dependent. **4.** Freshwater Aquatic Life Guideline listed for inorganic fluorides. **5.** CEQG (2002 update) Freshwater Guidelines and Criteria are based on total metal concentrations, except for aluminum (dissolved aluminum criterion).

SECTION 6 • BEDROCK & TAILINGS GEOCHEMISTRY

A mine site materials geochemical characterization program was developed to chemically characterize rock at the mine site, and define the nature and magnitude of impacts that may result from the interaction between mine materials and the environment during mine operation and after cessation of mining, with emphasis on the generation of acid rock drainage (ARD), metal leaching (ML), and non-metal constituents.

The geochemical characteristics of bedrock in the area of the proposed open pits as well as in the area of planned mine infrastructure away from the ore deposits (i.e., in the region of buildings, plant site, and airstrip) were determined. Tailing material, produced from processed ore from the pits, and overburden were also characterized. Materials were characterized using static tests, which identified bulk chemistry and potential to generate acidic drainage and leach constituents to the environment. The long-term weathering behaviour of selected pit rock and tailings samples was also characterized with respect to ARD potential and leachate chemistry based on results of kinetic testing to date. Some of these results are considered interim as testing of some material is ongoing. The aqueous chemistry of tailing decant and surface water ponded in mineralized exploration trenches was also characterized.

6.1 MATERIAL SAMPLING

The major rock types to be disturbed during construction and mining are grouped into three lithological units, IF, IV, and UM rocks. These lithologies represent 22%, 23%, and 53%, respectively, of the waste rock that will be generated from all open pits during mine life. Each is represented in the chemical characterization program (Table 6.1). A quartzite unit (QTZ) also occurs in localized areas of the southern pits (i.e., in the upper portions of the west pit wall), but will generate a significantly lower quantity of waste (~1%). This unit was included in the static testing program but not in the kinetic testing program.

Table 6.1: Pit Rock Lithology & Sample Distribution

Rock Type	Estimated Quantity of Pit Rock Generated (10^6 tonnes)			Lithological Distribution of Pit Rock (%)	Number of Samples Analyzed (Static Tests)	Sample Distribution (%)
	Goose/Portage	Vault	Total			
IV	27	54	81	53.3	87	53
IF	34	-	34	22.4	31	19
UM	35	-	35	23.0	39	24
QTZ	2	-	2	1.3	7	4
Total	**98**	**54**	**152**	**100**	**164**	**100**

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Processed ore samples from each of the three pits were represented in the chemical characterization program and samples of the Third Portage deposit were considered to be representative of North Portage (Table 6.2).

Table 6.2: Proportion of Tailings from Each Deposit & Sample Distribution

Deposit	**Estimated Quantity of Ore Mined (10^6 tonnes)**	**Proportion of Tailings in Impoundment at Closure (%)**	**Number of Tailings Samples Analyzed (Static Testing)**
Goose Island	1.7	8	5
Portages	11.5	53	5
Vault	8.5	39	5
Total	**21.7**	**100**	**15**

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6.2 SCOPE OF MINE SITE MATERIALS CHARACTERIZATION PROGRAM

Static Testing

The static test data are derived from studies conducted between 1996 and 2003. Static testing was conducted on 15 rock samples from mine site infrastructure, 164 drill core samples representing pit rock (including low grade ore and older, weathered samples), and 15 tailing solids of ores from each deposit. Other samples collected for water chemistry analysis included 11 tailing decant water samples and 4 trench water samples.

Mine infrastructure was characterized by 10 surface rock (grab) samples collected along the proposed airstrip alignment, 3 drill core samples, and 1 surface grab sample collected from the plant site area, and 1 drill core sample collected from the tank farm area.

Pit rock samples were obtained from exploration drill core specifically for ARD and ML testing to determine the spatial and compositional variability of each rock unit to be disturbed. Analysis of a relatively old drill core that had been exposed to climatic conditions on-site for 11 to 12 years was conducted to document the effects of weathering on the chemical characteristics of pit rock.

Tailing solids and decant water samples were obtained from the metallurgical program, which focused on the processing characteristics of representative ore samples from each deposit.

Kinetic Testing

Kinetic testing was completed on representative samples of each of the three principal lithologies that will be disturbed during mining and on all flotation-circuit tailings generated from each deposit.

The pit rock sample selection focused on representing the average and higher concentration ranges of constituents having environmental interest. Lithological representation was addressed by considering the volume of waste to be generated from each lithology, the variance of constituents of interest for each lithology, and the potential impact from these constituents on water quality. The 12 pit rock samples selected for kinetic testing include 6 IV, 4 IF, and 2 UM rock samples.

6.3 SAMPLING & ANALYTICAL METHODOLOGY

Two comparative criteria were used: acid rock drainage potential, and metal leaching potential.

Acid Rock Drainage Potential

Guidelines presented by INAC (1992) for northern mine sites were applied in the classification of acid generation potential for the Meadowbank project, with the neutralization potential ratio (NPR) as the principal indicator of ARD potential considered.

Metal Leaching Potential

Metal concentrations in leachate generated by static and kinetic tests were compared to the Canadian Council of Ministers of the Environment's (CCME) Canadian Environmental Quality Guidelines (CEQGs) (updated 2002) for the protection of freshwater aquatic life, and to the Canadian Metal Mining Effluent Regulations (MMER, 2002). Short-term (static) leaching tests are considered initial screening tools in the identification of potential constituents of concern and do not necessarily infer non-compliance of mine drainage chemistry.

6.4 CHEMICAL CHARACTERIZATION OF MINE SITE MATERIALS

Surficial Rock Away from Mineral Deposits

Rock located in mine site infrastructure areas, away from the deposits, consists exclusively of IV.

All of these samples had no Potential for Acid Generation (non-PAG), with 14 samples containing no detectable sulphur and one plant site rock sample having low (0.16 %) total sulphur content. The latter represents a slightly mineralized zone of limited extent in the plant site area. All samples have excess carbonate neutralization capacity. Mine area IV rock had higher median calcium (4 times) and magnesium (1.5 times) contents than Portage/Goose IV pit rock, possibly owing to silicification associated with mineralization. Pit Rocks

Portage & Goose Areas

Table 6.3 presents a summary of geochemical characteristics of Portage and Goose Island pit rock that will be removed from the pits, reporting either as construction material or to the Portage rock storage area. The summary includes the three major lithologies (IF, IV, and UM) present in the Portage and Goose Island pits as well as a fourth but less common rock type present in these southern deposits (QTZ). The characteristics of each lithologic unit are described below.

Table 6.3: Summary of Geochemistry Considerations

Open Pit	Material Type	Potential for ARD	Potential for ML	Restrictions for Storage or use in Construction
All Pits	Overburden	None	Low	None
	Tailings	High	High	Requires measures to control ARD
Portage & Goose	Ultramafic & Mafic Volcanic	None	Low	May require collection and treatment of drainage
	Intermediate Volcanics	Variable (none to moderate)	Moderate	Requires measures to control ARD
	Iron Formation	High	High	Requires measures to control ARD
	Quartzite	High	Low	Co-disposal with ultramafic/mafic volcanic or cap/water cover
Vault	Intermediate Volcanics	Low	Variable (low to moderate)	May require collection and treatment of drainage

Ultramafic

The predominant minerals in UM rock include talc, chlorite, and iron-rich carbonate minerals (mostly iron-rich dolomite, some siderite and calcite). These minerals provide UM rock with a relatively high neutralization potential. Some pyrite and pyrrhotite are present in UM rocks, although sulphide phases are generally sparse in this lithology.

Ultramafic volcanic waste is considered non-PAG, with 95% of samples having a NPR>2. The two UM rock samples kinetically tested contained available, reactive carbonate minerals, generating neutral drainage (pH around 7.6) throughout the testing period and sustained alkalinity in leachates. The bulk of UM rock will not generate ARD. The calculated rate of carbonate depletion in both samples suggests that UM rock can be a long-term source of alkalinity, provided the carbonate minerals remain available (e.g., do not become coated in secondary minerals).

Iron Formation

The characteristic mineral assemblage of IF rock includes quartz, magnetite, chlorite, and amphibole, and generally excludes any carbonate minerals. The principal sulphides present in mineralized IF rocks are pyrrhotite and pyrite, both of which are approximately equal in proportion in the Goose Island deposit, with pyrite content increasing toward the North Portage deposit. Trace arsenopyrite and chalcopyrite are also present.

Eighty-five percent of IF rock is PAG (NPR<2), having a median total sulphur content of 0.8 and low neutralization potential. The non-PAG IF rock also has low neutralization potential but lower total sulphur (<0.1%). All four PAG IF rock samples, including one low grade ore sample, generated acidic drainage (pH less than 5) in the early stages of kinetic testing, and the small amount of alkalinity present in each of these samples was depleted in that time. It is likely that the majority of IF rock will generate acid rock drainage (ARD) and, based on the results of kinetic tests completed to date, onset of acidic conditions can occur after a short period of exposure, possibly within one season given favourable climatic conditions.

Quartzite

All QTZ samples tested are classified as PAG. Considering the median paste pH of 8.2 and low median total sulphur content (0.35%), it is uncertain whether the quartzite's apparent potential to generate ARD would ever be realized. The small quantity of QTZ pit rock excavated during mining should, nonetheless, be considered and managed as PAG material since this lithology contains virtually no neutralization potential. The long-term leachate characteristics of QTZ were not evaluated.

Intermediate Volcanic

IV rock shows a prevalence of quartz and aluminosilicate minerals, mainly muscovite and chlorite, and variable carbonate mineral content mainly as iron-rich dolomite, calcite, and some siderite. Mineralogical observations suggest that carbonate content may increase from Goose Island to North Portage. Pyrite and pyrrhotite are the principal sulphide minerals responsible for the generation of ARD from mineralized IV rocks in the Goose Island and North Portage deposits, with the proportion of pyrite increasing toward the north. Minor sulphide phases also include arsenopyrite and trace amounts of chalcopyrite. No other arsenic or copper-bearing phases were identified in the IV samples observed.

The ARD potential of Portage-Goose IV pit rock is variable, with 35% of waste rock designated as PAG or uncertain. Although the bulk of IV pit rock is non-PAG, portions of this material may generate localized acidic conditions in the waste rock stockpile. No robust operational criterion has been identified to segregate PAG from non-PAG IV rock; however, the static test database indicates that Portage IV samples located away from the ore zones and close to surface[1] have lower sulphide contents (typically below the detection limit of 0.01% total sulphur) and associated higher neutralization potential (non-PAG) compared to IV samples located closer to the ore zone. Further sampling will be conducted during the 2004 field season, targeting surficial IV in Third and North Portage. Sampling will be aimed at verifying this trend so that the use of PAG IV in construction can be avoided.

Three of the four Portage-Goose IV samples tested for long-term weathering behaviour were designated as PAG and one was non-PAG (a surficial sample, representative of material that may be used for construction in the first year of activity, pre-operation). The Portage-Goose non-PAG IV sample generated neutral pH drainage and sustained alkalinity levels throughout the testing period. The buffering capacity was calculated to be available to neutralize acidity generated by the oxidation of sulphides but, for the sample tested at least, should not be considered as a long-term source of alkalinity.

Two of the three Portage-Goose PAG IV samples generated acidic drainage in the early stages of testing. One sample never generated ARD in 50 weeks of testing and continued to sustain alkalinity levels. Based on mineral depletion calculations, this sample should generate acidic drainage in time but after a relatively long lag period, potentially longer than the projected 10-year mine life. Although

[1] To a depth equivalent to the first year of pre-production, to an elevation of approximately 105 m.

only a portion of the PAG IV rock is readily reactive, it is expected that all PAG IV rock could generate ARD in the future if provided sufficient time and favourable conditions.

Vault Area

The Vault deposit is hosted almost exclusively in IV rock. Although generally similar to Goose Island and Portage IV, the principal difference is the higher carbonate content of Vault IV (primarily as dolomite with some calcite), which provides more readily available neutralization than aluminosilicate minerals. Over 90% of sulphides at Vault consist of pyrite, while the rest include pyrrhotite, minor arsenopyrite and trace chalcopyrite. No other arsenic or copper-bearing phases were identified in the samples tested.

Twenty five percent of Vault IV waste rock is designated as PAG. Although 75% of waste rock is non-PAG, portions of this material may generate localized acidic conditions in the Vault rock stockpile, given favourable conditions. The bulk of the pile is not expected to constitute a source of ARD.

The long-term leachate characteristics of the non-PAG Vault IV sample included neutral pH drainage and sustained alkalinity levels throughout the 20-cycle testing period. The buffering capacity of this sample from dolomite and/or calcite is calculated to be available to neutralize acidity generated by the oxidation of sulphides.

Tailings

The tailing samples tested for geochemical characteristics were generated from a laboratory-scale processing circuit that included flotation and cyanidation of a sulphide concentrate, which differs from the whole-ore leaching circuit that is currently being considered. Nonetheless, results of this testing program are considered representative of the long-term leaching characteristics of whole-ore tailings. Table 6.4 presents a summary of geochemical characteristics of tailings from each deposit.

Table 6.4: Summary of Tailings Chemistry

Lithology		**Portages**	**Goose Island**	**Vault**
% of Total Tailings		53	8	39
ARD		PAG	PAG	PAG
Short-Term (static) Leachate Quality	>CCME	pH, F, Ni, Zn	pH, Al, Fe, Ni, NO_2, Zn	pH, F
	>MMER	pH, Ni	pH, Ni	n.e.
Kinetic Test Leachate Quality	>CCME	pH, Ag, Al, As, Cd, Cr, Cu, F, Fe, Ni, Pb, Se, Zn	pH, Ag, Al, As, Cd, Cr, Cu, F, Fe, Hg, Ni, Tl, Zn	Cd, Cr, Zn
	>MMER	pH, Cu, Ni, Zn	pH, Cu, Ni, Zn	n.e.

Note: n.a.: not analyzed. n.e.: no exceedances

Mineralogical analysis identified abundant carbonates in all tailing streams from Vault, consisting of dolomite with minor calcite, which imparts a greater neutralization capacity compared to tailings from Third Portage and Goose Island. Third Portage tailings were found to have minor carbonates whereas the three Goose samples observed had no discernible carbonate grains.

All concentrate and combined tailings (a recombination of 20% concentrate and 80% flotation tailings, similar in proportion to the produced streams) from each deposit along with Portage and Goose Island flotation tailings are PAG, whereas the Vault flotation tailings are non-PAG. All Goose Island and Third Portage tailing streams (concentrate, combined, and flotation tailings) generated ARD within a relatively short period of time after initiation of kinetic testing. These tailings have low buffering capacity provided mainly by aluminosilicate minerals (as compared to predominantly carbonate in Vault tailings), and have a larger proportion of more reactive pyrrhotite than the Vault tailings.

All Vault tailing leachates remained alkaline during the 20 to 40 week testing period. These tailings have ample buffering capacity provided by carbonate minerals (dolomite and some calcite) and can constitute a long-term source of alkalinity, provided the neutralizing minerals remain available and are not coated by secondary minerals. Depletion calculations suggest that Vault tailings will eventually generate ARD but after a slightly longer lag period than the current testing period (4 to 15 years under laboratory conditions, likely much longer under actual site conditions).

Considering the proportion of each deposit that will generate tailings and that all tailings will report to the same impoundment, the bulk tailing material is expected to be PAG. The tailing management strategy will require measures to prevent or minimize ARD.

SECTION 7 • REFERENCES

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APPENDIX A

Glossary

The following terms in this section are taken from the Government of British Columbia (1994b), the National Research Council of Canada (1988), Pidwirny (1999-2004), Tarbuck et al (1996), Trenhaile (1998) and WordRefernce.com.

Acidic – Any substance with a pH below 7.

Active Layer – The zone above the permafrost that thaws in the summer and freezes in the winter.

Aggrade – To build up the floor or slope of a stream by deposition.

Alkaline **–** A substance with a pH greater than 7

Alluvium **–**Sediment deposited by streams and consisting largely of sand, silt and clay**.**

Azimuth – A system that measures direction clockwise from North over 360°.

Block Field – A surficial layer of angular shattered rock formed in periglacial environments.

Brackish – Slightly briny or salty water

Clast – an individual element, grain or fragment of a sediment or rock, produced by the weathering of a larger rock mass.

Colluvium – Loose, weathered material brought to the foot of a cliff or some other slope by gravity.

Cryoturbation – Churning and heaving of the ground and subsoil by frost action.

Discharge Area – An area where groundwater and water in the unsaturated zone is released to the ground surface, to surface water or to the atmosphere.

Drumlin – a streamlined mound of glacial drift, rounded or elongated in the direction of the original flow of ice.

Esker – A winding ridge made of sand and gravel deposited by a melting glacier.

Evaporation – The process by which a liquid becomes a gas.

Evapotranspiration – The combined effect of evaporation and transpiration.

Fault – A Fracture zone in which there has been movement or displacement of rocks, relative to each other, on either side.

Felsenmeer – The flat or gently sloping veneer rock fragments on moderate slopes above the timberline.

Flutes – A streamlined groove or ridge parallel to the direction of ice movement, formed in newly deposited till or older drift.

Foliation – A parallel and banded structure within a metamorphic rock.

Frost Action – The process of alternate freezing and thawing of moisture in soil, rock and other materials and the resulting effects on materials and on structures placed on or in the ground.

Frost Boil – a small mound of fresh soil material formed by frost action.

Frost Creep – The downslope displacement that occurs when a soil expands normal to the ground surface and settles in a vertical direction during the freeze-thaw cycle**.**

Frost Heave **–** The upward and outward movement of the ground surface caused by the formation of ice in the soil.

Frost Jacking – The collective upward displacement of objects embedded in the ground caused by frost action.

Frost Mound – Any mound-shaped landform produced by ground freezing combined with groundwater movement or the mitigation of soil moisture.

Frost Shattering – The mechanical disintegration, splitting, or breakup of a rock or soil caused by the pressure exerted by freezing water in cracks or pores, or along bedding planes.

Frost Sorting – The sorting of soil particles by frost action.

Frost Wedging – A process of physical weathering in which water freezes in a crack and exerts force on the rock causing further rupture.

Gelifluction – The movement of soil material over the permafrost layer and the formation of lobe-shaped features.

Glaciofluvial – The processes, sediments, and landforms associated with glacial meltwater streams.

Glaciomarine – The processes, sediments, and landforms associated with meltwater streams in contact with the sea.

Ground Ice – A term used to describe all bodies of ice in the ground surface of the permafrost layer.

Hummock – A mound of broken ice which has been forced upward by pressure.

Hydraulic Conductivity – A measure of the ability of a fluid to flow through the ground, determined by the size and shape of the pore spaces of the various rocks and soils.

Hydraulic Gradient – The slope of the groundwater level or water table.

Hydraulic Head – The pressure exerted by a liquid as a result if the difference in its surface level between two points

Kame – A steep-sided hill composed of sand and gravel originating when sediment collected in openings in inactive glacial ice.

Leachate – Water that carries salts dissolved out of materials through which it has percolated.

Lobe – An isolated tongue-like feature formed by more rapid solifluction on certain sections of a slope showing variations in gradient.

Mass Wasting – The downward movement of large masses of earth material under the direct influence of gravity.

Moraine – A hill of glacial till deposited directly by a glacier.

Nivation – Process where snow patches initiate erosion through physical weathering, meltwater flow, and gelifluction.

Outcrop – An area of exposed bedrock at the Earth's surface with no overlying deposits of soil.

Overburden – Earth overlying a useful deposit of rock or other useful material.

Oxidation – Chemical attachment of free oxygen to other elements and compounds. One of the types of chemical weathering.

Parent Material – The mineral material from which a soil forms.

Patterned Ground – Term used to describe a number of surface features found in periglacial environments. These features can resemble circles, polygons, nets, steps, and stripes. The development of some of these shapes is thought to be the result of freeze-thaw action.

Periglacial – Landforms created by processes associated with intense freeze-thaw action in high latitude areas or near an alpine or continental glacier.

Permeability – The ease of which liquids can pass through a rock or soil.

pH – A numerical measure of the acidity or alkalinity of water ranging from 0 to 14. Neutral waters have pH near 7. Acidic waters have pH less than 7 and alkaline waters have pH greater than 7.

Protalus Rampart – Unsorted, non-stratified, coarse angular rock debris forming arcuate low ridges. Associated with former persistent snowbanks in shaded sites, commonly at base of corrie headwalls

Recharge Area – An area of land where the groundwater moves downward and water infiltrates from the surface into the geological formations below.

Relief – The difference in elevation between high and low points in an area.

Salinity – Concentration of dissolved salts found in a sample of water. Measured as the total amount of dissolved salts in parts per thousand. Seawater has an average salinity of about 34 parts per thousand.

Serpentine – A dark green or brown mineral with a greasy or silky lustre, found in igneous and metamorphic rocks.

Shear – Stress that causes two neighbouring bodies to slide past one another.

Slump – The downward slipping of a mass of rock or unconsolidated material moving as a unit along a curved surface.

Solifluction – The slow, downslope flow of water-saturated materials common to permafrost areas.

Sorted Step – A patterned ground form with a dominantly polygonal outline and a sorted appearance commonly due to a border of stones surrounding a central area of finer material.

Stratification – The arrangement of sediments in layers or strata marked by a change in colour, texture, dimension of particies, and composition.

Stratigraphy – The study of the composition, relative positions and other qualities of rock strata in order to determine their geological history

Striae – Scratches or grooves in a bedrock surface cause by the grinding action of a glacier and its sediment load.

Sublimation – The process where ice changes into water vapor without first becoming liquid.

Subsidence – The lowering or sinking of the Earth's surface.

Tailings – Waste left over after certain processes, such as from an ore-crushing plant.

Talik – An area of permanently unfrozen ground in regions of permafrost.

Thaw Consolidation – The compression resulting from thawing of frozen ground and subsequent drainage of excess water.

Thaw Settlement – Compression of the ground due to thaw consolidation.

Thermistor – (thermal resistor) It is a semiconductor whose resistance varies sharply in a known manner with temperature.

Thermokarst – A landscape dominated by depressions, pits, and caves that is created by the thawing of ground ice in high latitude locations.

Till – Unsorted sediment deposited by a glacier.

Total Dissolved Solids (TDS) – TDS are made up of inorganic salts such as calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates and small amounts of organic matter that are dissolved in water.

Transpiration – The release of water vapour into the air by plants.

Veneer – Any facing material that is applied to a different backing material.