GAHCHO KUÉ PROJECT

ENVIRONMENTAL IMPACT STATEMENT

SECTION 11.6

SUBJECT OF NOTE: PERMAFROST, GROUNDWATER AND HYDROGEOLOGY

December 2010 **09-1365-1004**

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11.6 SUBJECT OF NOTE: PERMAFROST, GROUNDWATER, AND HYDROGEOLOGY

11.6.1 Introduction

11.6.1.1 Context

This section of the environmental impact statement (EIS) for the Gahcho Kué Project (Project) consists solely of the Subject of Note: Permafrost, Groundwater, and Hydrogeology. In the *Terms of Reference for the Gahcho Kué Environmental Impact Statement* (Terms of Reference) issued on October 5, 2007, the Gahcho Kué Panel (2007) identified the need for this subject of note, because of the following concern:

> *"Limited baseline information creates uncertainty about any impacts on permafrost or ground water movements. The dewatering of the lake, the excavation of large pits, and the re-filling of these pits with waste rock, processed kimberlite, and contaminated mine water was noted to have great potential to disrupt or change permafrost distribution and ground water flow."*

As required by the Terms of Reference, the EIS must examine potential effects to permafrost, groundwater, and hydrogeology within this subject of note, understanding that the material presented herein overlaps with that presented in the following key lines of inquiry and subjects of note:

- Key Line of Inquiry: Water Quality and Fish in Kennady Lake (Section 8);
- Key Line of Inquiry: Long-term Biophysical Effects, Closure, and Reclamation (Section 10);
- Subject of Note: Mine Rock and Processed Kimberlite Storage (Section 11.5); and
- Subject of Note: Climate Change Impacts (Section 11.13).

Pursuant to the Terms of Reference, this subject of note (i.e., Permafrost, Groundwater, and Hydrogeology) contains information pertaining to the following topics:

- the potential of the Project to disrupt or change permafrost distribution and groundwater flow; and

- effects related to accumulation of permafrost into on-site infrastructure and proposed mitigative strategies.

Although the Terms of Reference also specify that this subject of note is to include an analysis of the feasibility of sequestering materials in the mined out pits over the long term, an evaluation of this topic requires consideration of the quality of the combined surface water / groundwater flow that is used to initially fill the relevant portions of the backfilled pits. It also requires consideration of wind-driven and density-driven mixing conditions in Kennady Lake after refilling. As these items for consideration involve environmental components beyond permafrost, groundwater and hydrogeology, the hydrogeologic and groundwater inputs that are relevant to the evaluation of this topic are presented herein, but the overall analysis of this topic is outlined in Section 8 of this EIS (i.e., Key Line of Inquiry: Water Quality and Fish in Kennady Lake).

11.6.1.2 Purpose and Scope

The purpose of the Subject of Note: Permafrost, Groundwater and Hydrogeology is to meet the final Terms of Reference for the EIS issued by the Gahcho Kué Panel (2007). The terms of reference requirements for this subject of note are shown in Table 11.6-1, which also includes related requirements from other sections of the Terms of Reference. The entire Terms of Reference document is included in Section 1, Appendix 1.I of this EIS.

The Terms of Reference indicate that a “substantive analysis” of effects to permafrost is required. The term “substantive analysis” has been interpreted to mean that potential effects to permafrost were to be examined to the extent required to support the overall conclusions of the EIS, with respect to potential impacts to values components, such as water quality and fish in Kennady Lake.

As outlined in Sections 8, 9 and 10, the assessment of potential effects to valued components has been completed to date without consideration of permafrost development within mine facilities, such as the Fine Processed Kimberlite Containment (PKC) Facility, Coarse Processed Kimberlite (PK) Pile, and mine rock piles. In other words, the mitigative effects associated with permafrost development in mine facilities, in terms of reduced seepage rates, has so far been ignored. Consequently, a detailed evaluation and assessment of permafrost has not yet been required to support the overall conclusions of the EIS, with respect to potential impacts to values components, and the scope of the permafrost assessment is generally qualitative in nature. Similarly, changes to permafrost are not expected to affect the integrity of project infrastructure, because their integrity is not dependant on, will not be negatively affected by the development of permafrost.

Table 11.6-1 Terms of Reference Pertaining to Permafrost, Groundwater and Hydrogeology

Final Terms of Reference Requirements		Applicable EIS Sub-section
Section	**Description**	
Permafrost		
3.1.3 Existing Environment: Permafrost	describe the distribution, thickness, and lateral extent on the surface	11.6.2.1, Annex D
	describe permafrost processes, features, and stability, including a description of the active layer	11.6.2.1, Annex D
	describe the extent, locations, and dimensions of taliks, including any connections between taliks in terms of groundwater movement	11.6.2.1, 11.6.2.2.3, 11.6.2.2.5, Annex D
	describe the interfaces between frozen and unfrozen ground (including frequency and length of segments)	11.6.2.1, Annex D
	describe permafrost conditions beneath or around Kennady Lake	11.6.2.1, 8.3.3.2, Annex D
5.2.5 Biophysical Subjects of Note: Permafrost, Groundwater, and Hydrogeology	include a discussion of the potential impacts for accumulation of permafrost into on-site infrastructure and proposed mitigative measures	11.6.3.1, 11.6.4.1
4.1.2 Water Quality and Fish in Kennady Lake	description of maintenance procedures for long-term frozen conditions of potentially reactive waste rock and barren kimberlite, including the incorporation of frozen conditions under climate change parameters	11.5, 11.6.3, 11.13
	long-term monitoring plan of thermal conditions of frozen waste rock and process kimberlite piles	11.6.3.4
	confidence in predictions from long-term modelling that has been conducted for permafrost issues, particularly effects of the pits on the thermal regime, and a verification that a robust monitoring program will be in place	11.6.3
4.1.4 Long Term Biophysical Effects, Closure and Reclamation	demonstration of the long-term physical stability including long-term maintenance of frozen conditions both within and under waste rock and processed kimberlite storage facilities; if long-term waste storage is solely reliant on frozen conditions, stability of frozen conditions in climate change scenarios must be included	11.5, 11.6.3, 11.13
7 (Table 7-3) Water Issues	remaining water issues pertaining to permafrost include:	
	- effects of permafrost freeze back on exposed lake bed	11.6.3.1.2
	- adequacy of permafrost monitoring and data to appropriately model mine components	11.6.3.4
	- problems with freeze-back of processed kimberlite	11.5, 11.6
	- implications of climate change on reclaimed mine components	11.13
7 (Table 7-4) Other Issues	remaining issues pertaining to physical stability:	
	- impacts from changing permafrost	11.5, 11.6.3

Table 11.6-1 Terms of Reference Pertaining to Permafrost, Groundwater and Hydrogeology (continued)

Final Terms of Reference Requirements		Applicable EIS Sub-section
Section	**Description**	
Groundwater and Hydrogeology		
3.1.3 Existing Environment: Water Quality and Quantity	describe existing groundwater resources in the Project area, including quality and quantity, flow patterns, recharge and discharge areas, and interactions with surface water	11.6.2.2, Annex G
5.2.5 Biophysical Subjects of Note: Permafrost, Groundwater, and Hydrogeology	provide a detailed analysis of the feasibility of sequestering contaminants in the mined out pits over the long-term	11.6.4, 11.5
4.1.2 Water Quality and Fish in Kennady Lake	hydrogeological dynamics of the lake bottom under freezing conditions, in particular the potential for highly concentrated deep groundwater to be expelled into the remaining ponds during freeze-up, as well as an assessment of changes in the thermal regime of the lake bottom and the extent of freezing	11.6.3
	interactions between groundwater and submerged processed kimberlite and waste rock, including the possibility of the pits being a long-term contamination source	11.6.4
	potential interaction between groundwater and the open pits, as well as between groundwater and submerged waste rock or kimberlite, including the possibility of the pits being a long-term contamination source	11.6.4, 8.6.2
	relationship between taliks and groundwater flows in the Project area, particularly the potential for taliks to act as a pathway for contaminants, including the distribution of taliks in the Project area and any connection or interactions between taliks of different lakes	11.6.4, 8.3.4
7 (Table 7-3) Water Issues	remaining water issues pertaining to groundwater/hydrogeology include:	
	- impacts of pits on movement and quality of groundwater	11.6.4
	- interaction between groundwater and submerged waste	11.6.4
	- relationships between taliks and groundwater flow regime	11.6.2
	- short-term and long-term impacts on groundwater flow	11.6.4
	- management of groundwater flows by De Beers	11.6.4

Table 11.6-1 Terms of Reference Pertaining to Permafrost, Groundwater and Hydrogeology (continued)

Final Terms of Reference Requirements		Applicable EIS Sub-section
Section	Description	
3.2.7 Follow-up Programs	The EIS must include a description of any follow up programs, contingency plans, or adaptive management programs the developer proposes to employ before, during, and after the proposed development, for the purpose of recognizing and managing unpredicted problems. The EIS must explain how the developer proposes to verify impact predictions. The impact statement must also describe what alternative measures will be used in cases were a proposed mitigation measure does not produce the anticipated result.	11.6.3.4, 11.6.4.4
	The EIS must provide a review of relevant research, monitoring and follow up activities since the first diamond mine was permitted in the Slave Geological Province to the extent that the relevant information is publicly available. This review must focus on the verification of impact predictions and the effectiveness of mitigation measures proposed in previous diamond mine environmental impact assessments. In particular the developer must make every reasonable effort to verify and evaluate the effectiveness of any proposed mitigation measures that have been used, or are similar to those used at other diamond mining projects in the Mackenzie Valley.	11.6.4.1, 11.6.4.3

Source: Terms of Reference for the Gahcho Kué Environmental Impact Statement (Gahcho Kué Panel 2007).

Note: This table includes the requirements listed under Section 5.2.5 of the Terms of Reference (Gahcho Kué Panel 2007) and relevant terms from Tables 8.1-1 and 10.1-1.

EIS = environmental impact statement.

11.6.1.3 Study Area

11.6.1.3.1 General Location

The Project is situated north of the East Arm of Great Slave Lake in the Northwest Territories (NWT) at Longitude 63° 26' North and Latitude 109° 12' West. The Project site is about 140 kilometres (km) northeast of the nearest community, Łutselk'e, and 280 km northeast of Yellowknife (Figure 11.1-1). It is located in the Kennady Lake watershed, a small headwater lake within the Lockhart River system, which drains into the East Arm of Great Slave Lake.

11.6.1.3.2 Study Area Selection

To describe the potential of the Project to disrupt or change permafrost distribution and groundwater flow, it is necessary to define appropriate spatial boundaries. The study area for this subject of note was not specified in the final Terms of Reference (Gahcho Kué Panel 2007), but was defined to include the extent of permafrost effects and the influence of the Project on hydrogeology, including deep groundwater. The study area was also defined, recognizing that major local lakes act as the controlling features of the deep groundwater flow and that effects to permafrost can occur over a different spatial extent than those to groundwater and hydrogeology.

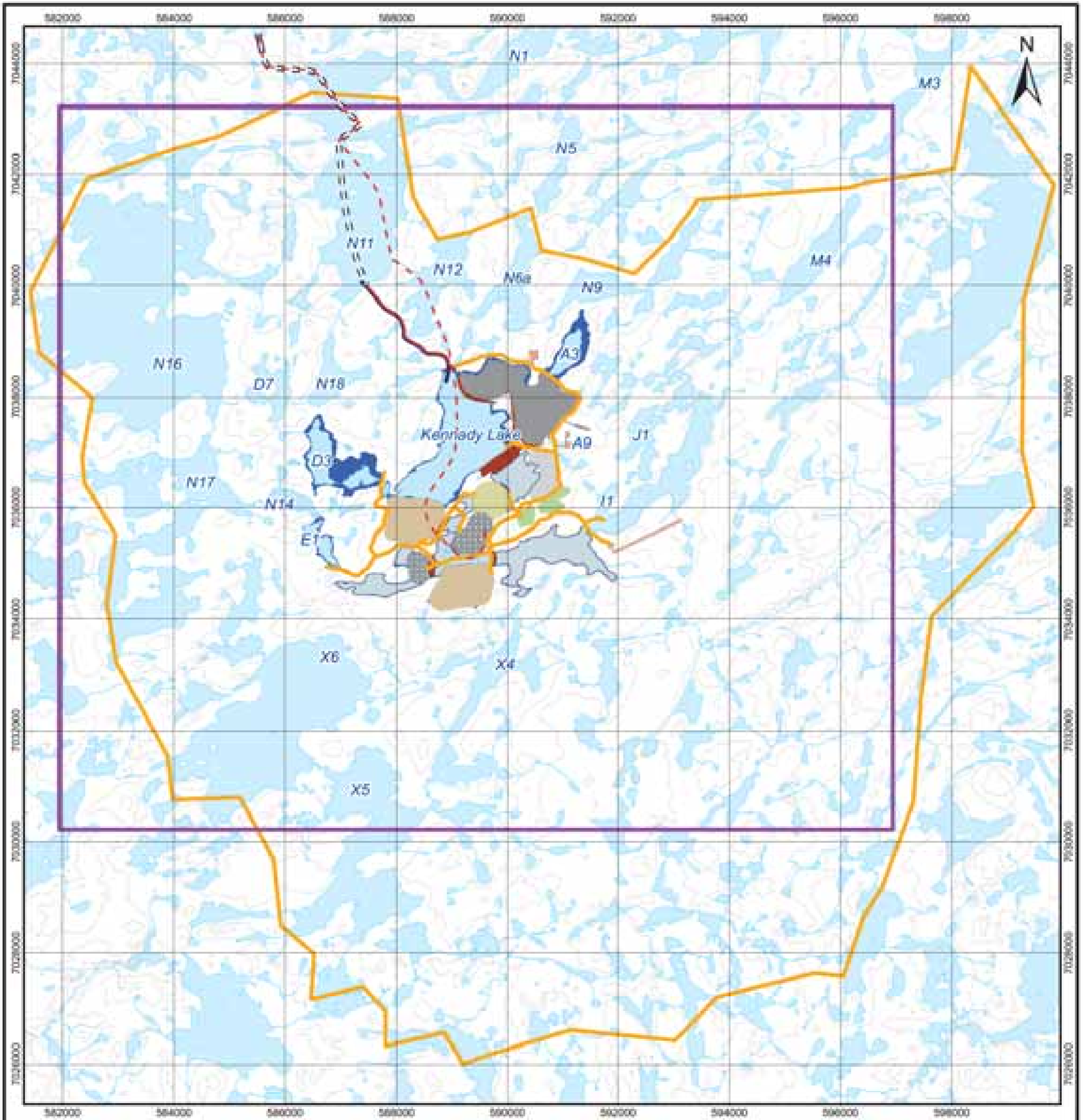
11.6.1.3.3 Permafrost, Groundwater, and Hydrogeology Study Area

The study area for the Subject of Note: Permafrost, Groundwater, and Hydrogeology consists of the 222 square kilometre (km^2) regional hydrogeology study area used for the baseline and the permafrost study area, both of which are shown in Figure 11.6-1 .

11.6.1.4 Content

Section 11.6 provides details of the impact analysis and assessment related to permafrost, groundwater and hydrogeology. The headings in Section 11.6 are arranged according to the sequence of steps in the assessment. The following briefly describes the content under each heading of this subject of note:

- **Existing Environment** summarizes baseline information relevant to permafrost, groundwater and hydrogeology, beginning with a description of the general environmental setting in which the Project occurs, followed by baseline methods and results for permafrost, and baseline methods and results for hydrogeology and groundwater (Section 11.6.2).



LEGEND

- Baseline Winter Access Road
- Proposed Winter Access Road
- Watercourse
- Waterbody
- Contour (10m interval)
- Groundwater and Hydrogeology Study Area
- Permafrost Study Area

Project Footprint

- Service Road
- Site Road
- Water Pipeline
- Airstrip
- Back-filled Pit
- Building
- Coarse PK Pile
- De-watered Lake Bed
- Dyke or Berm
- Fine PK Containment Facility
- Flooded Area
- Mine Rock Pile
- Open Pit
- Plant Site
- Water

NOTES

Base data source: National Topographic Base Data (NTDB) 1:50,000
PKC = Processed Kimberlite Containment
SW = Southwest

GAHCHO KUÉ PROJECT

Permafrost, Groundwater and Hydrogeology Study Area

PROJECTION: UTM Zone 12	DATUM: NAD83	DE BEERS CANADA	
Scale: 1:100,000 1,000 500 0 1,000 Metres			
FILE No: SON-11.5-001-GIS		DATE: December 9, 2010	
JOB NO: 09-1365-1004	REVISION NO: 2	**Figure 11.6-1**	
OFFICE: GOLD-CAL	DRAWN: CW	CHECK: DC	

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- **Pathway Analyses** identifies all the potential pathways by which the Project could affect permafrost, groundwater and hydrogeology, and provides a screening level assessment of each identified pathway after applying environmental design features and other mitigation measures that are expected to reduce or eliminate potential effects (Section 11.6.3.1 and 11.6.4.1).
- **Effects on Permafrost** presents the results of the analysis of effects of the Project on permafrost (Section 11.6.3.1).
- **Effects on Groundwater** presents the results of the analysis of effects of the Project on groundwater, including those associated with the mine pits, mine rock piles, Coarse PK Pile and Fine PKC Facility (Section 11.6.4.1).
- **Residual Effects Summary** summarizes the residual effects on permafrost and groundwater that are predicted to remain after mitigation to eliminate or reduce negative effects has been incorporated into the Project design (Section 11.6.3.2 and 11.6.4.2).
- **Uncertainty** discusses sources of uncertainty surrounding the predictions of effects related to permafrost, groundwater and hydrogeology (Section 11.6.3.3 and 11.6.4.3).
- **Monitoring and Follow-up** describes recommended monitoring programs, contingency plans and adaptive management strategies related to permafrost, groundwater and hydrogeology (Section 11.6.3.4 and 11.6.4.4).
- **References** lists all documents and other material cited in the text in Section 11.6.5.
- **Glossary** explains the meaning of scientific, technical, or other uncommon terms. In addition, acronyms and abbreviated units are defined in Section 11.6.5.

Residual effects on permafrost, groundwater and hydrogeology are not classified, because they are not valued components. Changes (effects) to permafrost, groundwater and hydrogeology conditions represent potential pathways for effects on valued components, which are assessed in other sections of the EIS. For example, the development of the open pits may result in decreased groundwater discharge to surrounding lakes, but this potential change is not an impact that can be classified. Instead, it is the effect this change may have on surface water quality (a valued component) that is classified. In other words, it is the end use or ecological system affected by the change that is classified, and impacts are classified in the specific sections of the EIS that contain an evaluation of these end uses or ecological systems (e.g., impacts to water quality in Kennady Lake are classified in Section 8). As a result, potential effects to permafrost, groundwater and hydrogeology are assessed in this subject of note and a summary of residual effects is presented. However, the predicted effects are not classified.

11.6.2 Existing Environment

11.6.2.1 Permafrost

Evaluation of the existing permafrost conditions included several stages: aerial photograph interpretation for permafrost mapping, evaluation of data from the geotechnical drill program, a field reconnaissance program to confirm the aerial photograph interpretation, and calculations of the active layer (seasonal frost penetration) thickness and mean annual soil temperatures. The calculations were carried out to supplement available data on the thickness of the active layer and mean annual soil temperature, which were obtained from the geotechnical drill program.

The Project area is located within the Continuous Permafrost Zone (Heginbottom and Dubreuil 1995). Permafrost extends over approximately 90 to 95 percent (%) of the on-land Project area. The thickness of the permafrost was measured in three deep boreholes (MPV-04-153, MPV-04-162, and MPV-04-165) located within the study area. At these three locations, the thickness of the permafrost was estimated to be 120, 150 and 310 m respectively. The first two boreholes were drilled on islands within Kennady Lake at a distance of about 45 to 70 m from the shoreline. The warming effect of Kennady Lake results in the reduced permafrost thickness at these locations. The permafrost thickness of about 310 m encountered in borehole MPV-04-165 is considered as a typical permafrost thickness for climate conditions of the Project area that are not influenced by lake taliks (Brown 1970).

Results of field investigations undertaken by AMEC Earth & Environmental (AMEC) in summer 2004 suggest that taliks (i.e., patches of unfrozen ground surrounded by permafrost) limited in depth could be encountered within isolated areas of glaciofluvial deposits treed with spruce, willow and high polar birch. Taliks can be also encountered beneath numerous lakes in the study area. Depending on the size and age of the lake, sub-aquatic taliks may either be limited in depth (open to the top talik or closed talik) or penetrate through the entire permafrost thickness (through talik – open to both, top and unfrozen layers beneath the permafrost). A through or open talik exists beneath Kennady Lake where water is deeper than 2 metres (m).

The majority of the study area includes glacial veneer over bedrock. Based on Thermistor temperature measurements, mean annual permafrost temperatures over the Project site range from -0.5 to -2.5 degrees Celsius (°C). The highest temperature in this range (-0.5°C) corresponds to places with dense polar birch vegetation, while the lowest temperature in this range (-2.5°C) were typically encountered within glacial veneers or blankets with minimum snow cover.

Wet areas within peat bogs and peat veneers have mean annual temperatures ranging from about -1.0 to -1.5°C. The slightly warmer temperatures are mainly due to the low thermal resistance of saturated moss. Slightly cooler annual permafrost temperatures in the range of about -1.5°C could be encountered either in well-drained peat bogs and peat veneers due to the insulating effect of the moss in summer time. Cooler temperatures can also be expected at the summits of eskers and bedrock outcrops where there is minimal snow cover (low insulating effect of snow in winter time).

Areas with a mean annual soil temperature above 0°C (up to +1.5°C) could be encountered within the tall shrub terrain along creeks in the glaciofluvial deposits and at lake banks. The occurrence of the positive temperatures is a result of snow accumulation in tall shrubs.

The maximum thickness of the active layer (3.7 to 4.0 m) was estimated to be in exposed bedrock areas. Deep seasonal thaw is a result of low moisture content in bedrock. A deep active layer (in the range of 3.0 to 3.4 m) was also calculated for the eskers. The thickness of the active layer within the moraine veneer and blanket could vary from 2.6 to 3.2 m and 1.6 to 2.5 m, respectively. Glaciofluvial sand and silt deposits have the thinnest active layer thickness (1.0 to 2.0 m) of the mineral soils within the study area. Seasonal frost penetration within the on-land taliks likely does not exceed 1.5 m, due to a thick snow cover within tall shrubs.

Organic soils (peat) are characterized with the shallowest active layers (0.4 to 0.9 m). The main factors that determine a relatively shallow active layer are high moisture content and insulating effect of the moss cover. Within this range, the deepest thaw that would be expected occurs in relatively dry peat bogs (moisture content about 500% by dry weight of peat) while the shallowest thaw is typical for heavy mossy patches of organic veneers.

The mineral soils within the Project area have variable although generally low ice content. No visible ice was observed in the majority of boreholes advanced at the moraine blanket and glaciolacustrine plain. The moisture contents of these materials were in a range of 3 to 20%, by dry weight of solids. Higher ice contents were observed in glaciofluvial deposits. For instance, ice layers, up to 10 millimetres (mm) thick, were encountered in one borehole (MPV-04-206 in the depth interval from 1.8 to 2.9 m, see Annex D, Bedrock Geology, Terrain, Soil, and Permafrost Baseline for details).

Organic deposits were found to be extremely ice rich. It was estimated that volumetric ice content of the peat could be about 40 to 50% (moisture content of peat, defined as weight of water to weight of dry peat, was in a range of about 500 to 800%). Ice layers in peat were up to 3 mm thick, and were horizontal or wavy in shape. The ice layers were alternated with peat layers also several millimetres thick. Numerous ice lenses and pockets, up to 30 mm in size, were also recorded in the peat.

Various earth processes and phenomena were identified during an air photo review and field reconnaissance. Some of the processes are a result of thawing or freezing, while others are a result of specific soil composition, terrain, topography, and origin of deposits.

Stone channels and polygons are considered to be erosional features that result in part from thawing of permafrost. Snow meltwater and runoff have washed out the soil matrix, leaving stony material (cobbles, boulders, and rock fragments) in the form of stone channels and stone polygons. Because the moraine deposits have a stony composition, formation of stone channels and stone polygons are widespread processes within the study area.

Mud boil polygons are encountered in moist to wet cohesive surficial soils. The formation of the mud boil polygons is a process related to frost cracking, followed by freezing of the active layer downward from the ground surface, perpendicular to the frost cracks, and upward from the active layer base. If the freezing soil is saturated or nearly saturated, the soil within the polygon under high pore water pressure bursts through the surficial frozen layer and freezes at the ground surface.

Landforms associated with ice wedges were frequently encountered in organic deposits of the study area. Formation of the ice wedges is a cyclic process of freezing and thawing. Winter cold causes the frozen soil of the active layer to shrink and crack. During warm spring days, water seeps into the cracks, freezes and expands when it is chilled by the still-frozen soil, forming wedges of ice in the soil. Each winter, cracks form again in the same places and each spring, additional water enters and enlarges the ice wedges as the freezing water expands. This cycle of cracking and freezing continues to enlarge the wedges year after year.

Thermokarst depressions and lakes were found occasionally within peat bogs and organic veneers. Formation of the thermokarst features is due to the process of thawing ice-rich permafrost and, finally, accumulation of water in the resulting subsidence. The soil subsidence can lead to formation of large thermokarst lakes, up to several tens of metres in dimension. Thermokarst processes are often accompanied with thermo-erosion, referred to as soil erosion from combined thermal and mechanical activity of running water in permafrost areas, resulting in formation of gullies.

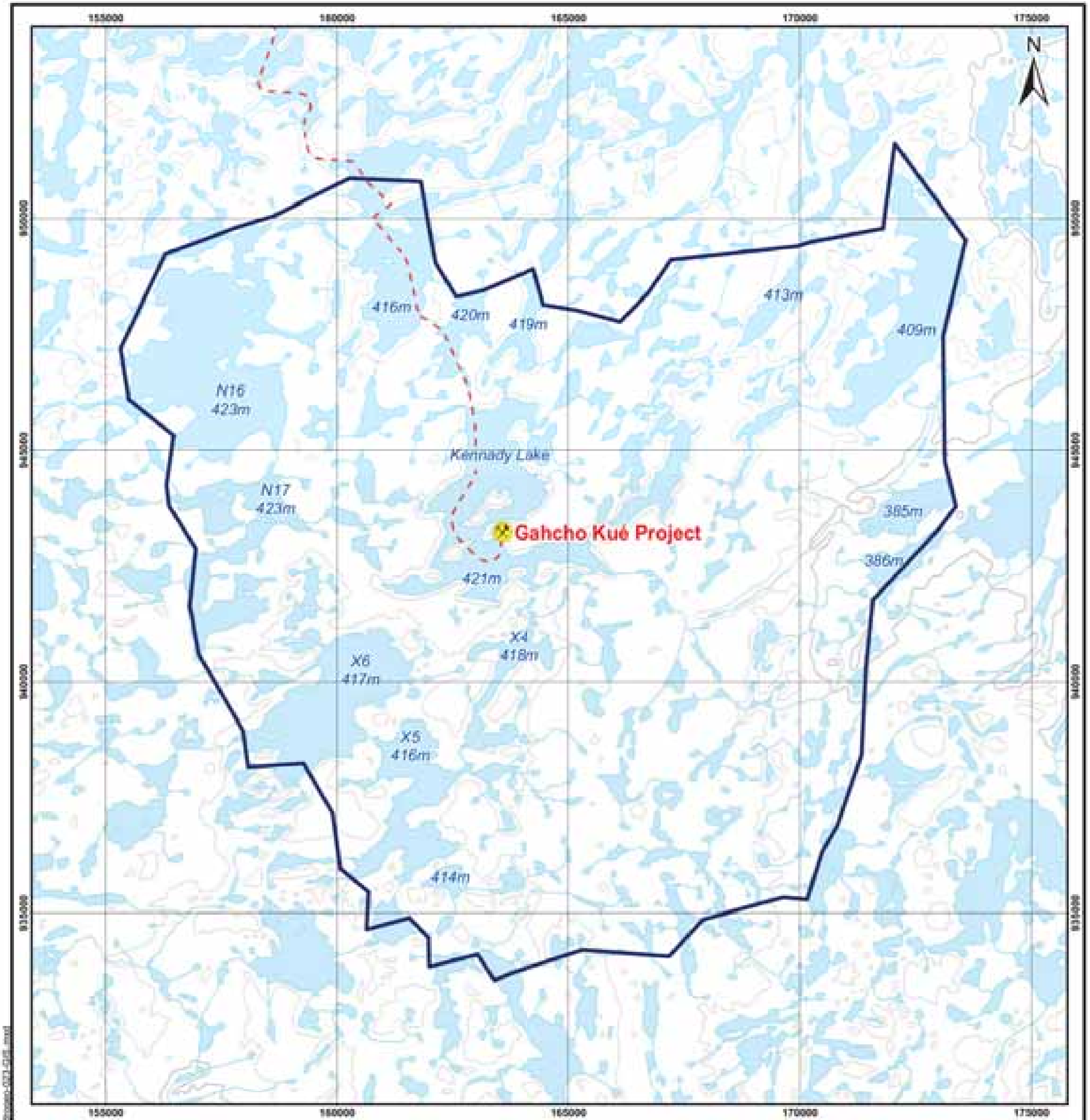
11.6.2.2 Hydrogeology and Groundwater

The following sections establish the geologic and hydrogeologic setting within the Local Study Area (LSA) for the Project (Figure 11.6-2). The baseline setting is defined from published work and field investigations. Figure 11.6-3 presents the Kennady Lake area and the various drillhole locations. For baseline details, the reader is referred to Annex G Hydrogeology Baseline. .

11.6.2.2.1 Bedrock Geology

The Project is located in the southeastern portion of the Slave Geological Province, an Archean craton with a rock record that spans from 4.05 to 2.55 billion years. The dominant rock types within the Kennady Lake area (Figure 11.6-4) are granite and gneissic granite. Metasediments (greywacke and mudstone) are present along the eastern edge of the eastern arm of Kennady Lake (Cairns 2003).

Mafic dykes intruded into the dominantly granitic bedrock form part of the bedrock geology of the Slave Geological Province. Four sets of Proterozoic mafic dykes, including the Mackenzie dyke swarm, are mapped within the Walmsley Lake map area (Cairns 2003). Within the Lac de Gras area, four and possibly five sets of Proterozoic dykes are identified with ages between 2.23 and 1.27 billion years (LeCheminant 1994). Several kimberlite pipes have been identified in the Kennady Lake area, of which four main pipes, named 5034, Hearne, Tuzo, and Tesla are located within Kennady Lake. A dyke correlated with the Mackenzie dykes is located to the northeast of the Tuzo kimberlite.



LEGEND

- Gahcho Kué Project
- Winter Access Road
- Watercourse
- Contour (20m interval)
- Waterbody
- Local Study Area

NOTES

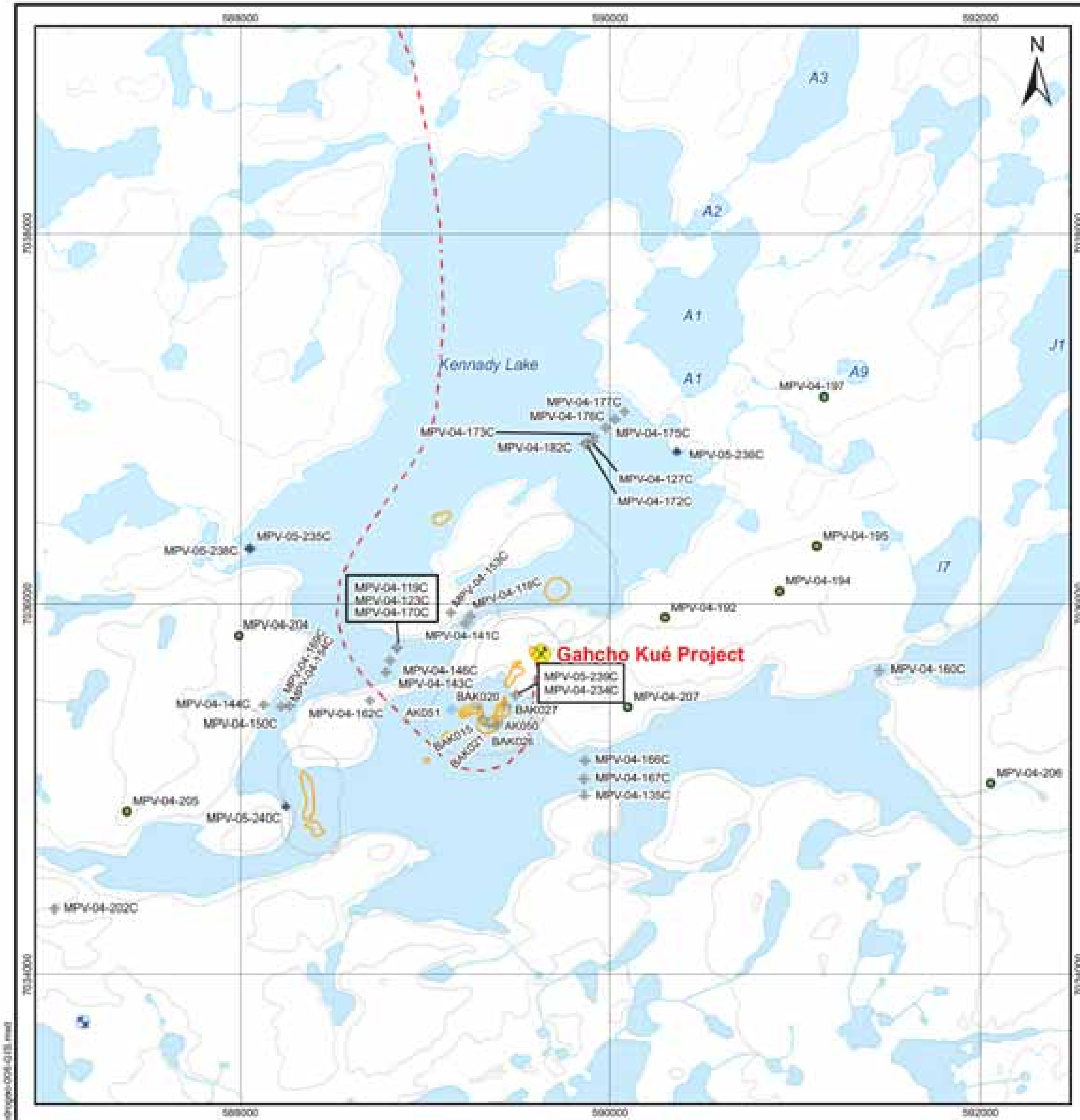
Base data source: The Atlas of Canada
Elevations shown are approximate (+/- 1m).
Lake elevations were derived from National Topographic Base Data (NTDB) 1:50,000 data and LiDAR data provided by the client.

GAHCHO KUÉ PROJECT

Local Study Area

PROJECTION: Canadian Lambert Conf. Conic	DATUM: NAD83		
Scale: 1:120,000 (2 1 0 2 Kilometres)			
FILE No: B-Hydrogeo-023-GIS.mxd		DATE: October 22, 2010	
JOB NO: 09-1365-1004	REVISION NO: 1		
OFFICE: GOLD-CAL	DRAWN: JH	CHECK: DC	Figure 11.6-2

DE BEERS CANADA



LEGEND

- Gahcho Kué Project
- Winter Access Road
- Contour (10m interval)
- Watercourse
- Waterbody
- Shallow Groundwater Sampling Location
- Till Sampling Drillhole Location

Borehole

- 1996
- 2004
- 2005
- Kimberlite Outline
- Pit Outline

NOTES

1) Base Data Source: National Topographic Base Data (NTDB) 1:50,000
2) Borehole Data Sources:
-Hydrological Consultants Inc. December 2005. Draft Predicted Hydrologic Effects of Developing Gahcho Kué Diamond Project. Prepared for SRK Ltd. HCI-1759.
-Bruce Geotechnical Consultants. 1996. AK5034: Diamondiferous Kimberlite Pipe Geotechnical Studies, Permafrost and Ground Ice Conditions. A report prepared for Canamera Geological Ltd.

GAHCHO KUÉ PROJECT

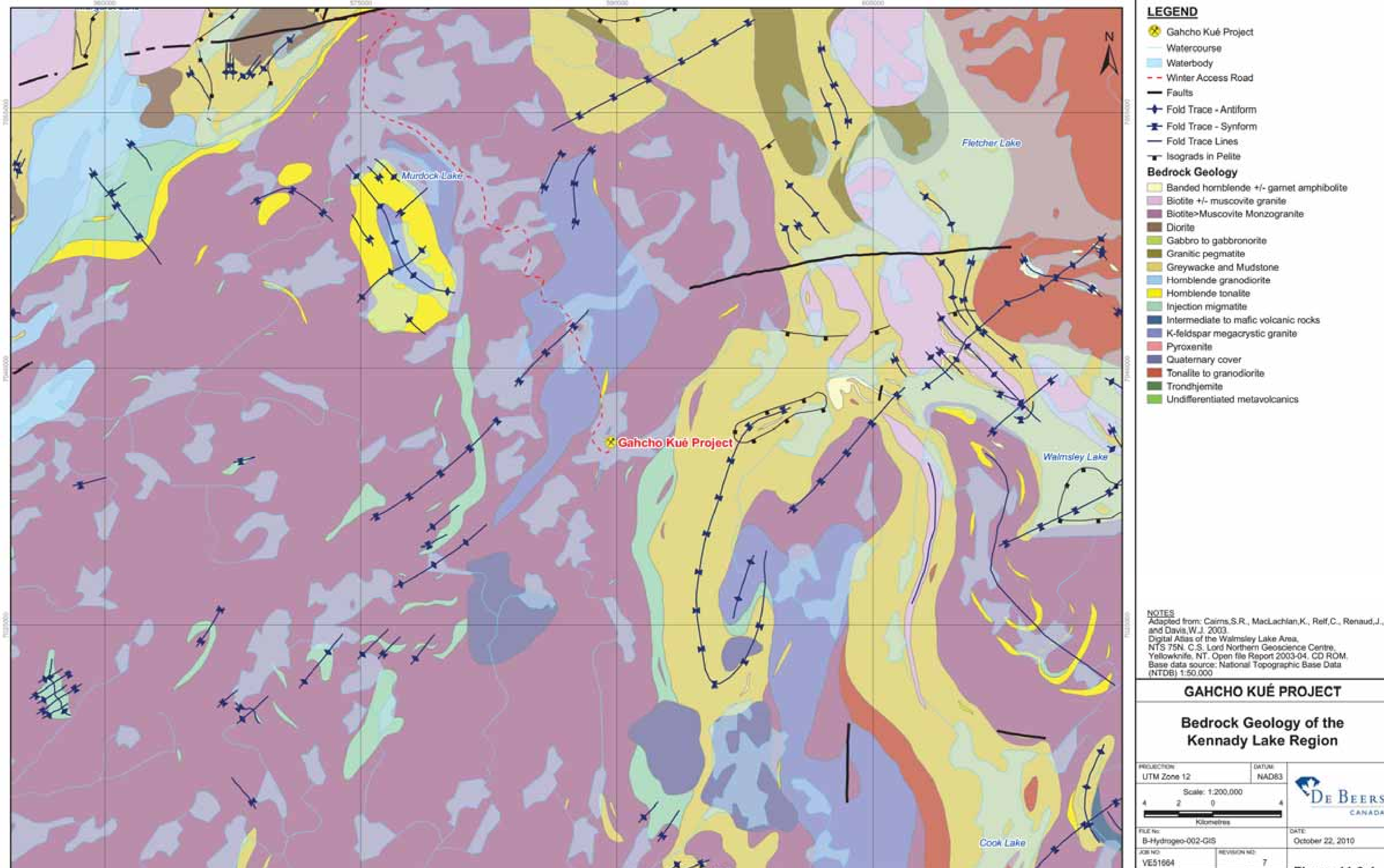
Borehole Locations

PROJECTION:	DATUM:
UTM Zone 12	NAD83

Scale 1:30,000
400 200 0 400
Metres

DE BEERS CANADA

FILE No:			
B-Hydrogeo-006-GIS			October 22, 2010
JOB NO:	REVISION NO:		
09-1365-1004	4		
OFFICE:	DRAWN:	CHECK:	
GOLD-CAL	JH	DC	Figure 11.6-3



NOTES
Adapted from: Cairns,S.R., MacLachlan,K., Relf,C., Renaud,J., and Davis,W.J. 2003.
Digital Atlas of the Walmsley Lake Area,
NTS 75N. C.S. Lord Northern Geoscience Centre,
Yellowknife, NT. Open file Report 2003-04. CD ROM.
Base data source: National Topographic Base Data (NTDB) 1:50,000

GAHCHO KUÉ PROJECT

Bedrock Geology of the Kennady Lake Region

PROJECTION: UTM Zone 12	DATUM: NAD83
Scale: 1:200,000 (4 2 0 4 Kilometres)	DE BEERS CANADA
FILE No: B-Hydrogeo-002-GIS	DATE: October 22, 2010
JOB NO: VE51664	REVISION NO: 7
OFFICE: AMEC-BBY	DRAWN: JH; CHECK: DC

Figure 11.6-4

The Kennady Lake kimberlites are within the southeast Slave kimberlite field, which is Cambrian in age, circa 545 to 525 million years (Hetman et al. 2003). These kimberlites underlie lakes and do not outcrop within the LSA (Baker 1998).

Major Lithologies

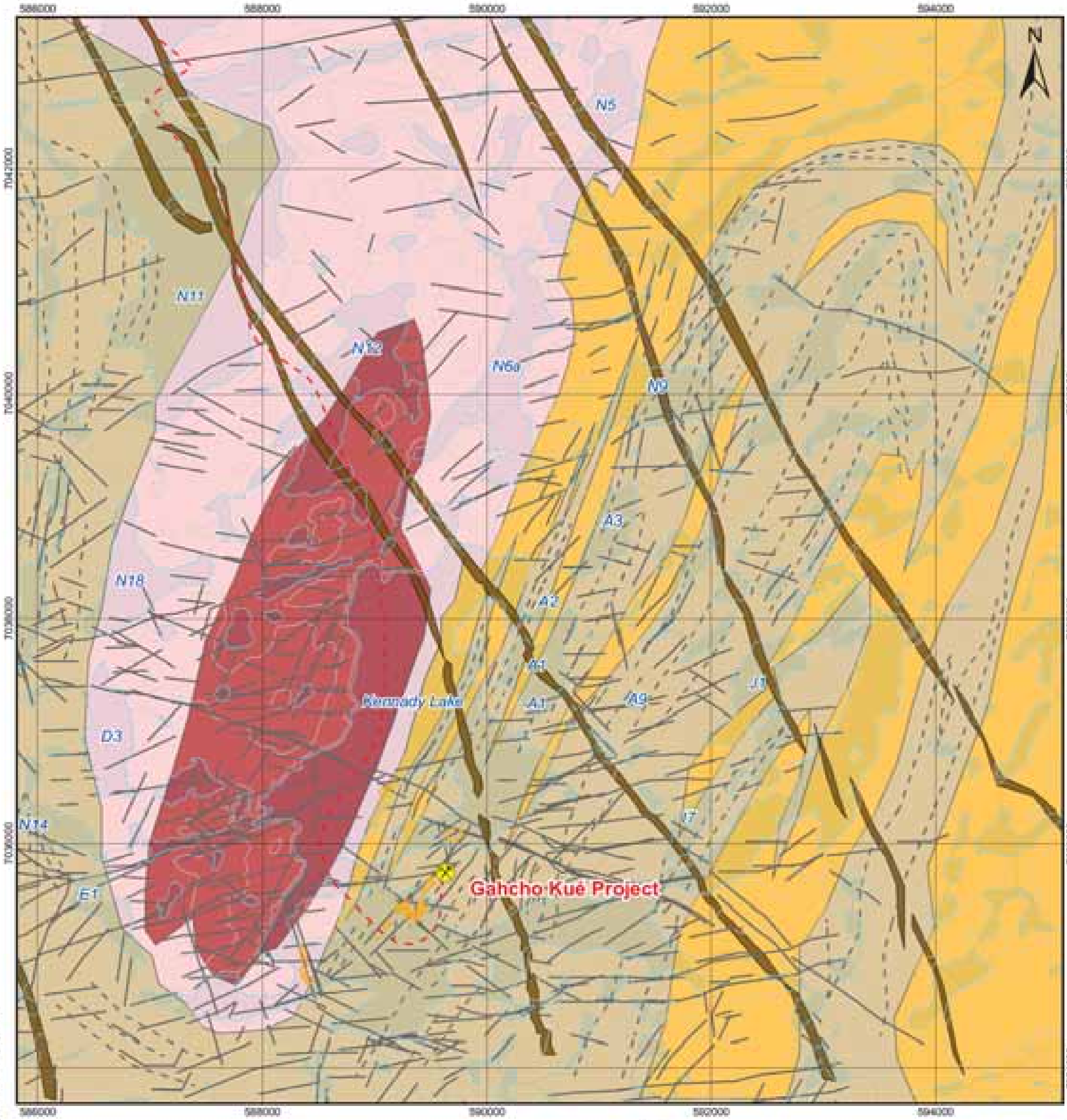
Granite and granitic gneiss comprise the most common bedrock rock lithologies, and range in texture from medium-grained to coarse-grained and pegmatitic. The granite locally exhibits a foliated to schistose fabric resulting from the alignment of mafic mineral grains. Generally, the granite is an incipiently to moderately altered mineral assemblage, which includes chlorite, calcite, epidote, and minor pyrite. In the more schistose portions of the "granite," joints and fracture orientations strongly align with the mineral fabric.

Diabase dykes, often several metres in width, were observed to cut the granite in three of the testholes (MPV-05-236C, MPV-05-238C, and MPV-05-239C), but were most common in MPV-05-236C (Figure 11.6-5). The dykes ranged in texture from medium-grained to very coarse-grained gabbroids. Locally, primary foliations in the dykes define principal orientations of fractures and joints.

Kimberlite was encountered in MPV-05-239C. The kimberlite had a distinct "contact zone" (with granite above it) where the kimberlite was altered to clay. The kimberlite was extremely solid and "tight" with few fractures in the middle of the kimberlite zone. Near the bottom of this borehole intersection, altered granitic inclusions occurred in minor amounts for about 15 m, became more frequent over the next 10 m, and then graded into brecciated granite over the next 21 m. The brecciated granite zone contacted another kimberlite stringer, and then highly fractured and locally altered granite and kimberlite alternated for 35 m until finally grading into unaltered granite for the remainder of the borehole. This hole confirms the existence, at least in some cases, of a distinct contact area between the kimberlite and country rock. This borehole was completed with a Westbay multiport piezometer.

Structural Features in the Kennady Lake Area

An assessment of regional and local structural features is provided by SRK (2004), a copy of which is included in Annex G, Appendix G.V. A structural analysis of geophysical data indicates a tight fold along the northeastern arm of Kennady Lake that wraps around an ultramafic intrusive body located to the west of the kimberlite cluster (Figure 11.6-5). The ultramafic intrusive body was intersected by boreholes MPV-04-144C, MPV-04-169C, MPV-04-204, MPV-04-235C, MPV-04-238C.



LEGEND

- Gahcho Kué Project
- Winter Access Road
- Watercourse
- Contour (10m interval)
- Waterbody
- Brittle Structure
- Magnetic Fabric
- Dyke
- Kimberlite Outline

Geological Interpretation

- Granitoids Diorite
- Granitoids Gabbro
- Paragneiss - Strong
- Paragneiss - Weak

NOTES
Base data source: National Topographic Base Data (NTDB) 1:50,000
Geological data source: Based on Aeromagnetic Data SRK, 2004

GAHCHO KUÉ PROJECT

Geological Interpretation of the Kennady Lake Area

PROJECTION: UTM Zone 12	DATUM: NAD83
Scale: 1:50,000 (1 0.5 0 1 Kilometers)	
FILE No: B-Hydrogeo-003-GIS	DATE: October 22, 2010
JOB NO: 09-1365-1004	REVISION NO: 8
OFFICE: GOLD-CAL	DRAWN: JH / CHECK: DC

DE BEERS CANADA

Figure 11.6-5

Structures encountered in drill core include joints, fractures, minor faults, breccia zones, and rare quartz veins. Joints comprise a variety of styles, including cemented with calcite-chlorite fill dominant, slickensided, planar, curved, rough, stepped, and others (Annex G, Appendix G.V).

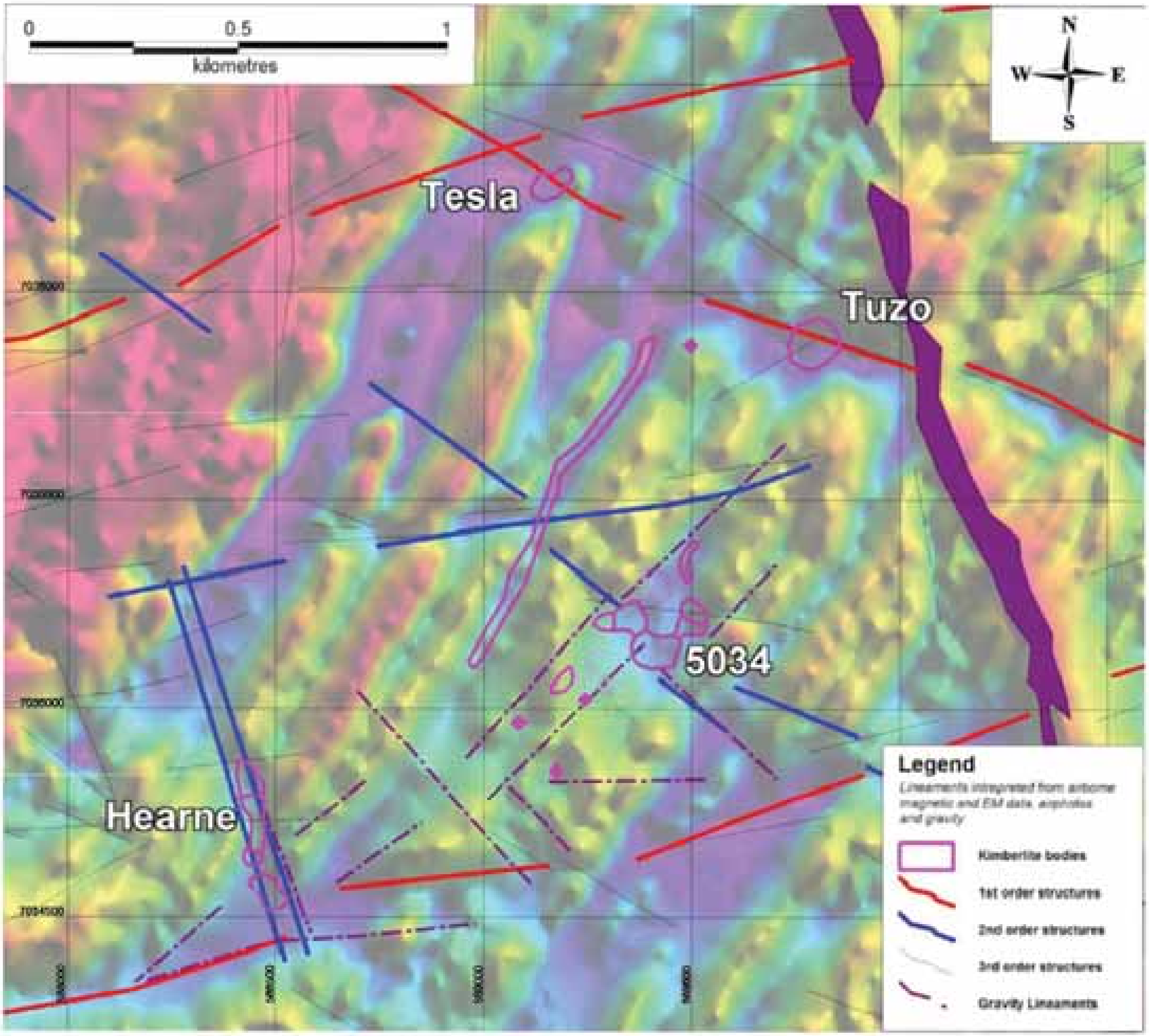
Within the immediate area of the kimberlite cluster, there is a dominant northeast-trending fabric. Discrete primary and secondary brittle structures (i.e., fractures, dykes, faults, joints, shear zones) were mapped using the geophysical information and appear to control the emplacement of the kimberlites. Primary structures are structures interpreted to have continuous strike extensions greater than 10s of kilometres and typically very wide alteration zones while secondary structures are developed locally with limited strike extents and less intense alteration haloes.

As shown in Figure 11.6-6, the Tuzo, and Tesla kimberlites are situated along a primary structure, while the Hearne kimberlite lies along a secondary fault near the fault's intersection with a primary structure to the south. The 5034 kimberlite occurs along a secondary structure away from any primary structures.

Data collected from orientated core drilling in 2004 was used to identify joint sets in the area of the proposed pits. This analysis indicated:

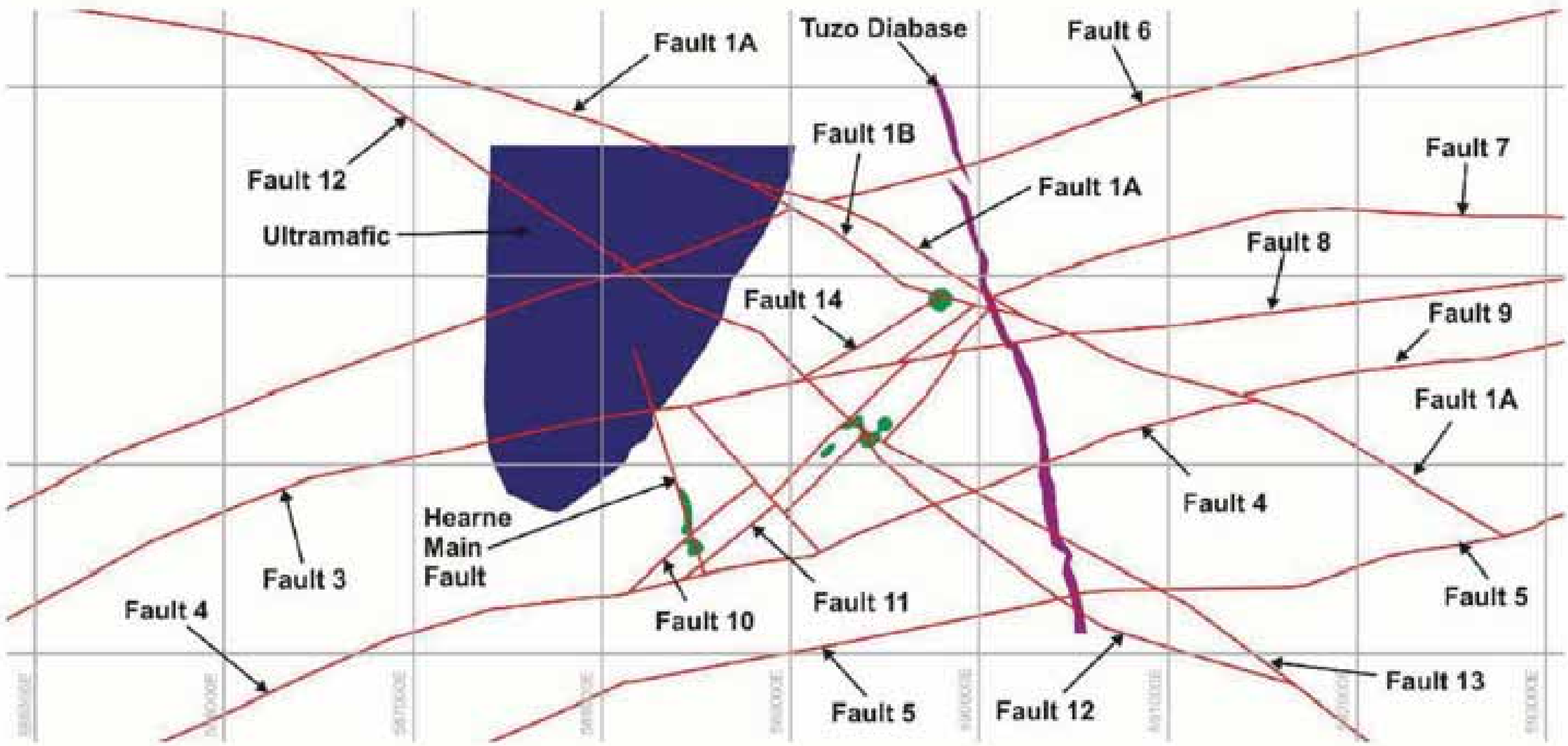
- the prevalence of shallow-dipping to sub-horizontal joints, and related elastic rebound of the rock due to glacial unloading (joint frequency partly biased by drillhole orientations); and
- joint orientations that are largely controlled or influenced by the orientations and proximity to first- and second-order structures.

Several faults outlined in the Project structural interpretation (Figure 11.6-7), derived from the geophysical data set and lithologic variations, were intersected in the 2004 and 2005 drilling campaigns. Where the faults were intersected by boreholes, they were found to be steep to sub-vertical often with well-developed joint sets in the orientation of the fault at approximately 20 m either side of the fault surface. A number of these faults intersect the kimberlite pipes and could possibly be of hydrogeologic significance for governing groundwater flow during operation of the proposed mines. These include Fault 1A and 1B, Fault 10 and 11, Fault 12 and 13, and the Hearne Main Fault.



NOTES
Source of data: Figure 3.3, Gahcho Kué Diamond Project, Mining Geotechnics, SRK Consulting (Canada) Inc., November 2004, prepared for DeBeers Canada Ltd.

GAHCHO KUÉ PROJECT			
Magnetic Image of Geologic Structures			
PROJECTION: N/A	DATUM: N/A		DE BEERS CANADA
SCALE: AS SHOWN			
FILE No: B-Hydrogeo-015-CAD.dwg			DATE: October 25, 2010
JOB No: 10-1365-1004	REVISION No: X		Figure 11.6-6
OFFICE: GOLD - CGY	DRAWN: RFM	CHECK: DC	



GAHCHO KUÉ PROJECT

Gahcho Kué Project
Structural Geology Model

PROJECTION: N/A	DATUM: N/A	
SCALE: NOT TO SCALE		
FILE No: 8-Hydrogeo-001-CAD.dwg		DATE: October 25, 2010
JOB No: 09-1365-1004	REVISION No: 0	
OFFICE: GOLD - CGY	DRAWN: RFM	CHECK: DC

Figure 11.6-7

Source:
Figure 3.5, SRK (SRK Consulting (Canada) Inc.). 2004. Gahcho Kué Diamond Project - Mining Geotechnics. Prepared for De Beers Canada Ltd. November 2004.

11.6.2.2.2 Quaternary Geology

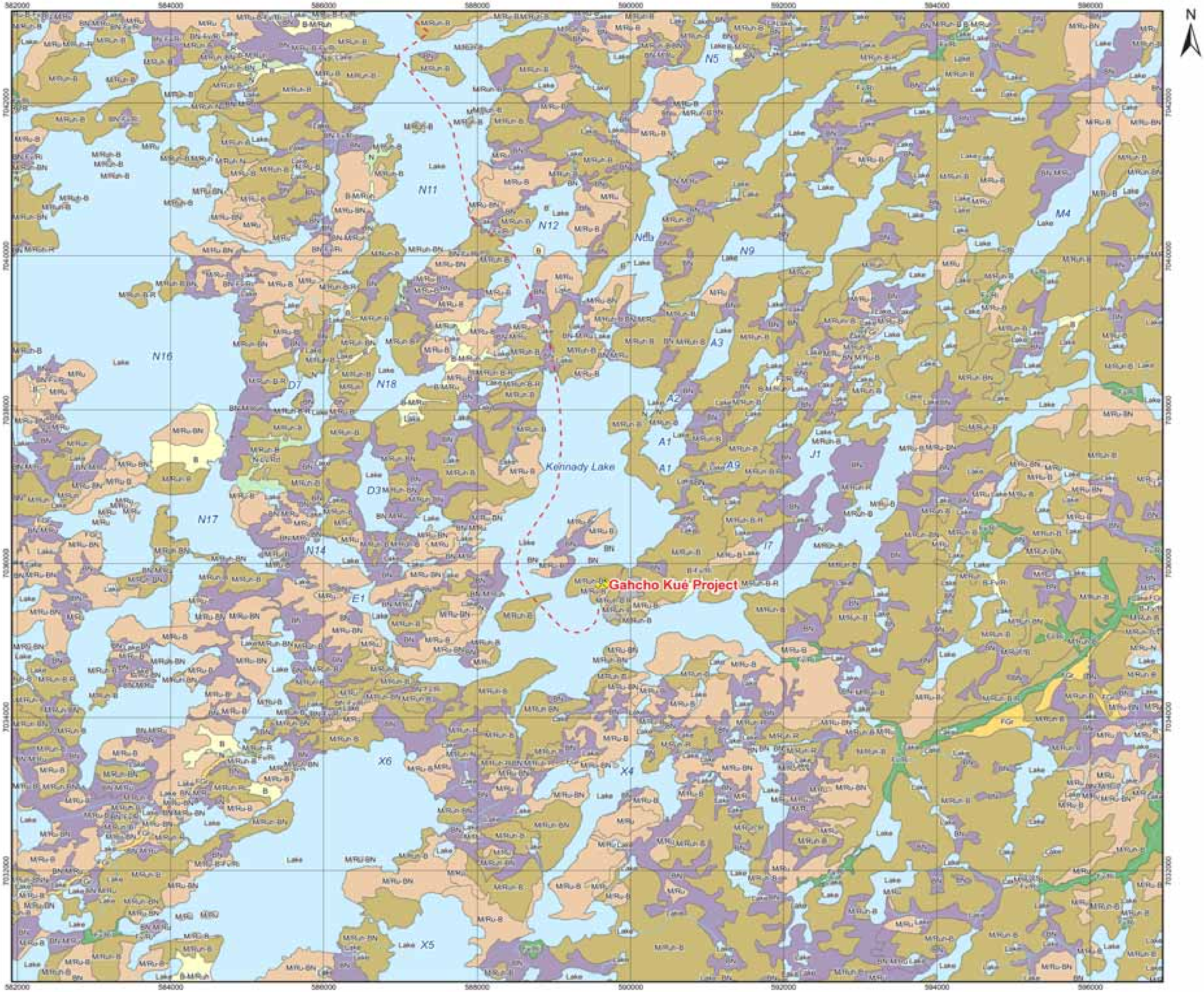
Glacial deposits and features within the Kennady Lake area (as shown in Figure 11.6-8) are related to the Late Wisconsin glaciation (Aylsworth and Shilts 1991; Dredge et al. 1996; Hardy 1997). The area of the NWT that was under the influence of the Keewatin Ice Divide of the Laurentide Ice Sheet has been divided into four zones of different glacial landform assemblages (Aylsworth and Shilts 1991). The regional area is located within Zones 3 and 4. Most of the region is situated within the outer part of Zone 3, which is characterized by till veneer (i.e., less than 2 m thick). Till is not present within Zone 4 in the northwest portion of the region. The region is characterized by ice-moulded bedrock, eskers, and related glaciofluvial features. Eskers are widespread within the region, and in some locations have associated outwash fans and glaciofluvial deltas.

Till veneers and blankets are common in the LSA and tend to become thin to non-existent over the elevated terrains where bedrock is exposed and ice moulded. On land, hand-auger probe holes could only penetrate to a very shallow depth because numerous cobbles and boulders are within the till.

A considerable portion of till in the LSA has been reworked, as former glaciolacustrine lake levels were several metres higher than present lake levels. Water flow, either sub-glacial or at the front of ice, caused reworking of the original till at many locations. As a result, the till lost part of its matrix, which in combination with frost action, has led to the formation of numerous stone polygons and channels.

Where present in its original composition, the till matrix grain size is characterized as silt to medium sand (Hardy 1997). Grain size analyses of till samples are included in Annex G, Appendix G.II. Till in areas elevated more than 10 m above current water level in lakes represents an ablation till that is described as clast-supported with a coarse matrix (medium sand to gravel) and angular clasts.

Esker deposits have been identified within the LSA. These materials are coarse sand, gravel, and cobbles, and an overall thickness of a few metres is common.



LEGEND

- Gahcho Kué Project
- Winter Access Road
- Watercourse
- Waterbody

Units

- B: Bog; peat plateau
- B-M/Ru: Bog with Morainal veneer over Bedrock; peat plateau with undulating
- B-M/Ruh: Bog with Morainal veneer over Bedrock; peat plateau with undulating to hummocky
- B-Fv/Ri: Bog with fluvial veneer over bedrock; peat plateau with gently inclined
- BN: Bog and Fen; planar
- BN-Fv/Ri: Bog and Fen with Fluvial veneer over bedrock; planar with gently inclined
- BN-M/Ru: Bog and Fen with Morainal veneer over Bedrock; planar with undulating
- BN-M/Ruh: Bog and Fen with Morainal veneer over Bedrock; planar with undulating to hummocky
- FGr: Glaciofluvial; esker ridges
- Fv/Ri: Fluvial veneer over Bedrock; gently inclined
- M/Ru: Morainal veneer and blankets over Bedrock; undulating
- M/Ru-B: Morainal veneer over Bedrock with Bog; undulating with peat plateaus
- M/Ru-B-Fv/Ri: Morainal veneer over Bedrock with Bog and localized Fluvial veneers over Bedrock; undulating to gently inclined with peat plateaus
- M/Ru-BN: Morainal veneer over Bedrock with Bog and Fen; undulating with peat plateaus
- M/Ru-N: Morainal veneer over Bedrock with Fen; undulating with planar
- M/Ruh: Morainal veneer and blanket over Bedrock; undulating to hummocky
- M/Ruh-B: Morainal veneer over Bedrock with Bog; undulating to hummocky with peat plateaus
- M/Ruh-B-R: Morainal veneer over Bedrock with Bog and localized exposed Bedrock; undulating to hummocky with peat plateaus
- M/Ruh-BN: Morainal veneer over Bedrock with Bog and Fen; undulating to hummocky with peat plateaus
- M/Ruh-N: Morainal veneer over Bedrock with Fen; undulating to hummocky with planar
- M/Ruh-R: Morainal veneer over Bedrock with exposed Bedrock; undulating to hummocky
- M/Ruhr-B: Morainal veneer over Bedrock with Bog and localized eskers; undulating to hummocky with peat plateaus
- N: Fen; planar
- N-Lv/Rd: Fen with Lacustrine veneer over Bedrock; planar to depressional
- R: Bedrock; variable topography

NOTES

Base data source: National Topographic Base Data (NTDB) 1:50,000

GAHCHO KUÉ PROJECT

Surficial Geology of the Kennady Lake Area

PROJECTION: UTM Zone 12	DATUM: NAD83
Scale: 1:50,000 (1 0.5 0 1 Kilometres)	
FILE No: B-Hydrogeo-005-GIS	DATE: October 22, 2010
JOB NO: 09-1365-1004	REVISION NO: 4
OFFICE: GOLD-CAL	DRAWN: JH
CHECK: DC	

DE BEERS CANADA

Figure 11.6-8

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Peat bogs overlie a majority of the glaciolacustrine and glaciofluvial deposits. Peat is usually well decomposed and of dark brown colour. Limited drillhole data suggest that many bog peat deposits are shallow (less than 1 m), but thicker deposits may also occur, particularly where they are associated with polygonal peat plateau and high-centre lowland polygons surface forms. Other bog forms include plateau bog and veneer bog. Microtopography is typically hummocky. Materials are weakly to moderately decomposed and underlain by glaciolacustrine or glaciofluvial deposits. While these deposits may be very thin sediments over till and/or bedrock, they can be up to 7 m thick in the immediate vicinity of Kennady Lake. The maximum lake bottom sediment thickness encountered was from 8 to 12 m.

11.6.2.2.3 Hydrogeology

Groundwater Flow Regimes

The hydrogeology of the Project area is controlled by the area’s permafrost characteristics, distribution, and spatial and temporal dynamics. It is divided into two primary groundwater regimes:

- shallow groundwater regime; and
- deep groundwater regime.

The shallow groundwater regime consists of the active layer above the permanent permafrost. This is an ephemeral system in that in winter time it is primarily frozen and is only active in the summer months. The deep groundwater regime is laterally continuous and found in bedrock below the permafrost at approximately 300 m below ground surface (m-bgs) depth. Because of the thick, low permeability permafrost; there is generally little to no hydraulic connection between the two flow regimes.

Groundwater in the shallow groundwater system is underlain by permanently frozen unconsolidated sediments (till, sand, and organic soils) or by frozen bedrock with low hydraulic conductivity. Groundwater in the active layer is controlled by surface topography and flows towards local lows, represented by lakes and the surface water drainage network. This conceptual framework applies to the on-land areas underlain by massive and continuous permafrost.

Taliks are found in unfrozen ground encountered within the discontinuous permafrost zone. Closed taliks exist beneath smaller lakes that possess sufficient depth such that they do not freeze to the bottom in winter, but not sufficient size for the talik below to extend through to the deep groundwater flow regime. Closed taliks can be also be encountered within isolated areas of glaciolacustrine plains, fluvial-glaciofluvial valleys, and intermittent creek channels treed with spruce, tall willow and high polar birch.

Open taliks penetrate the permafrost completely, connecting shallow and deep groundwater (van Everdingen 1998). Open taliks may be found below large rivers and lakes and may be noncryotic (hydrothermal talik) or cryotic (hydrochemical talik). An open talik exists under Kennady Lake and other large lakes in the region measuring several hundred metres in size.

Recharge to the deep groundwater flow regime is predominantly limited to areas of open taliks beneath large, surface waterbodies. Generally, deep groundwater will flow from higher elevation lakes to lower elevation lakes. To a lesser degree, groundwater beneath the permafrost is influenced by density differences due to the upward diffusion of deep-seated brines (density-driven flow).

Groundwater Usage

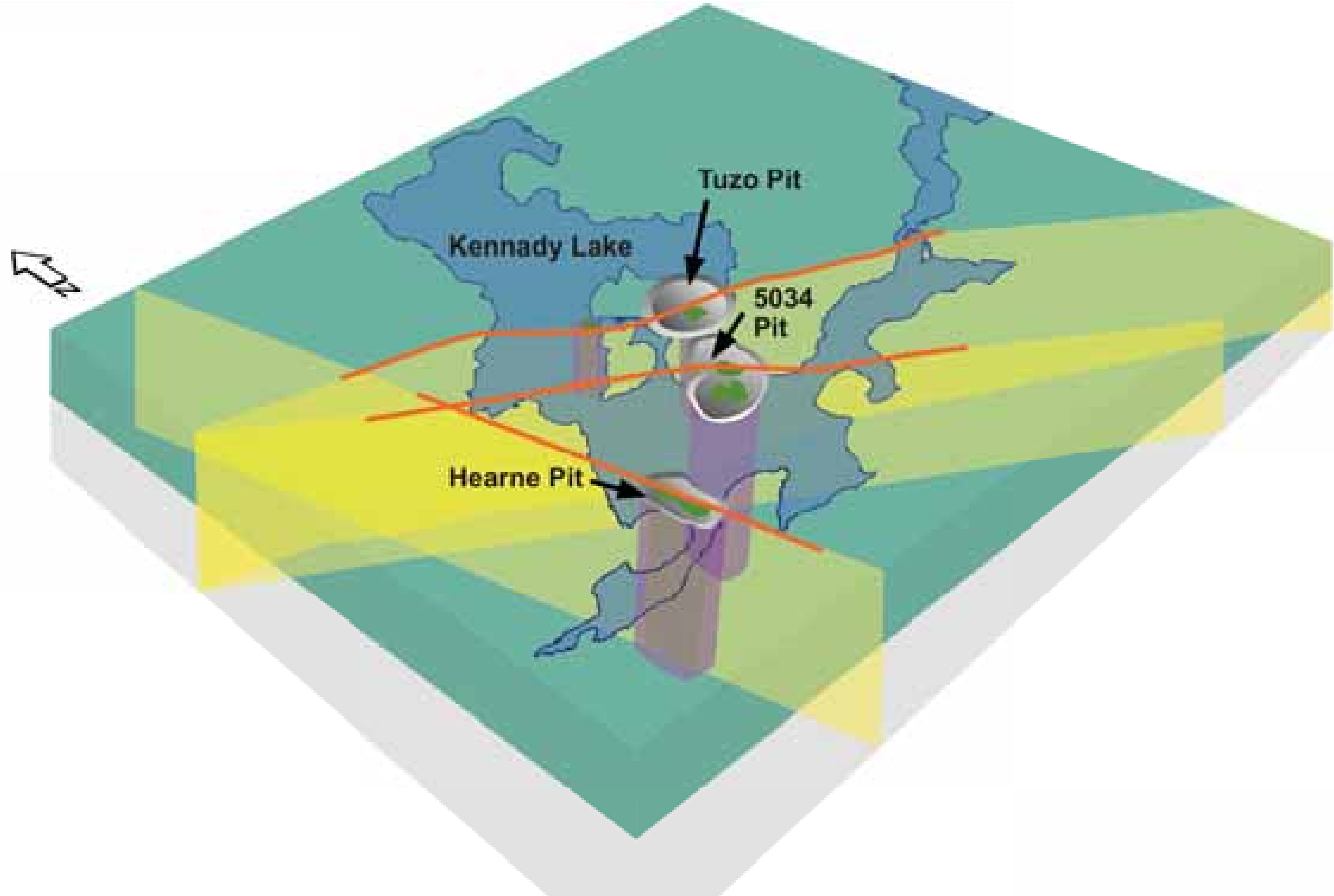
Groundwater sources from both the active layer and from the deep groundwater below the permafrost are not used for drinking water in continuous permafrost regions. Due to the presence of deep permafrost, the seasonal nature of the active layer, and the availability of good quality drinking water from surface water sources near the project site, it is unlikely that groundwater will be used as a drinking water source in the future.

Hydrostratigraphy

The conceptual hydrogeological model comprises six hydrostratigraphic units consisting of till, shallow exfoliated rock, deep competent rock, kimberlite, kimberlite contact zone, and enhanced permeability zones associated with sub vertical faults (Figure 11.6-9 and 11.6-10). Relatively competent bedrock is assumed to comprise the majority of the rock domain, and the hydraulic conductivity of competent rock is assumed to decrease with depth. Areas of greater fracturing associated with post-glacial rebound, faulting or along the kimberlite contact are assumed to have greater hydraulic conductivity than the less disturbed rock mass.

In developing of the conceptual hydrogeological model for the project, a reasonably conservative approach was undertaken, so that it is expected that the actual groundwater inflows to the open pits and associated impacts to the environment will be less than those predicted by the numerical hydrogeological model. Where uncertainty in parameter values exists, reasonable upper bound values of hydraulic conductivities have been selected.

L:\2009\1365\09-1365-1004\21000\Report B\CorelDraw figures Gahcho Kue Profile 09-1365-1004 C Bieber J Farah\B-Hydrogeo-004-CAD HydroStratigraphy.cdr



LEGEND

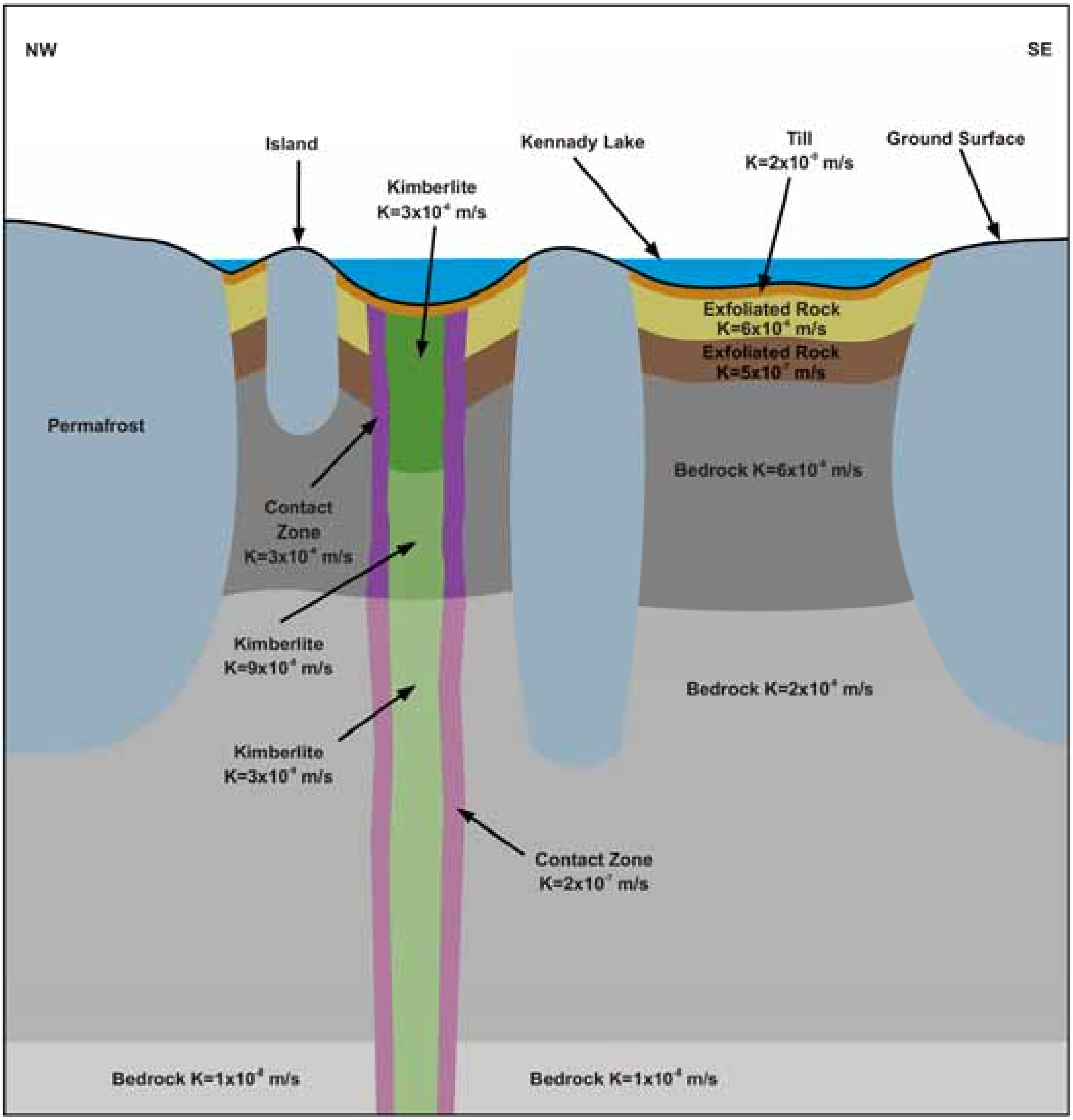
- Surface Expression of Potential Enhanced Permeability Zone
- Contact Zone
- Deep Bedrock
- Kimberlite Pipe
- Lake
- Permafrost
- Potential Enhanced Permeability Zone

Schematic Only

GACHO KUÉ PROJECT

Hydrostratigraphy

PROJECTION: N/A		DATUM: N/A	DE BEERS CANADA
SCALE: NOT TO SCALE			
FILE No: B-Hydrogeo-004-CAD			DATE: October 21, 2010
JOB No: 09-1365-1004	REVISION No: 0		Figure 11.6-9
OFFICE: GOLD - CAL	DRAWN: DLM	CHECK: DC	



LEGEND

- Ground Surface
- Till
- Bedrock
- Contact Zone
- Exfoliated Rock
- Kimberlite Pipe
- Lake
- Permafrost

Schematic Only

NOTE

Potential enhanced permeability zones not shown in section - see Figure 5.4-1 for locations

GACHO KUÉ PROJECT

Hydrostratigraphy – Cross-Section View

PROJECTION: N/A		DATUM: N/A	DE BEERS CANADA
SCALE: NOT TO SCALE			
FILE No: SON-11.6-010-CAD			DATE: September 28, 2010
JOB No: 09-1365-1004	REVISION No: 0		Figure 11.6-10
OFFICE: GOLD - CAL	DRAWN: DLM	CHECK: DC	

Till - The till unit is located directly beneath Kennady Lake. Several lake bottom sediment samples collected below Kennady Lake contained unconsolidated sand, pebbles, cobbles, and boulders with few fines (Annex G). The mean thickness of the lake bottom sediments intersected by drillholes within Kennady Lake was 7 m. No in-situ hydraulic conductivity testing has been carried out in this unit beneath the lake; however, based on the material description, the hydraulic conductivity of this material is expected to be greater than the bedrock below, and therefore will not restrict groundwater flow from Kennady Lake.

Exfoliated Bedrock – The uppermost zone of bedrock typically has numerous horizontal fractures as a result of exfoliation due to rebound following deglaciation. This zone is estimated to be about 60 m thick, and can be further divided into two sub-zones. The exfoliated bedrock forms a relatively permeable unit within the taliks, but, below the land surface, it is entirely within the permafrost zone. Exfoliation planes are near horizontal; therefore, the vertical hydraulic conductivity of this unit is expected to be less than the horizontal hydraulic conductivity, and flow in this unit is expected to be primarily horizontal. The arithmetic mean of single-well response testing in this unit is considered to be most representative of the hydraulic conductivity on the scale of the open pits. Over 100 single-well response tests have been conducted in this unit. The arithmetic mean of these tests above 30 m-bgs is about 6×10^{-6} m/s, while between 30 m-bgs and 60 m-bgs, the arithmetic mean is about 5×10^{-7} m/s (Table 11.6-2).

Massive Bedrock – The massive bedrock unit is dominated by granitoids and granitic gneiss, but is not uniform; ultramafic rocks are also present. The bedrock below 60 m-bgs, is generally less permeable than the overlying sediments, and the hydraulic conductivity is expected to decrease further with greater depths (Stober and Bucher 2007). Nearly 100 single-well response tests have been conducted in the bedrock below 60 m-bgs with the deepest tests extending to nearly 500 m-bgl. The geometric mean of single well response tests carried out from 60 m-bgs to 200 m-bgs is about 2×10^{-8} m/s, while the geometric mean of testing below 200 m-bgl is about 5×10^{-9} m/s. All of these tests were of short duration and conducted within single wells.

Research has shown that these types of tests generally underestimate the hydraulic conductivity at the scale of excavations with similar dimensions to that of the open pits at the Project (Illman and Tartakovsky 2006, Niemann and Rovey 2008). The reason for this is that single-well tests investigate hydraulic conductivity over a small scale volume of rock near to the well screen. The resulting values of hydraulic conductivity from these tests are more often representative of the lower-permeability rock composed of poorly connected and small aperture discontinuities (fractures, etc.). Testing of a larger volume of rock generally will include better connected and larger aperture discontinuities; hence, a higher permeability. It has been found that hydraulic conductivity values determined from single-well response tests generally underestimate the large-scale hydraulic conductivity by a factor of 2 to 5 times, depending on the relative scale of the disturbance to the hydrogeologic regime. Single-well response tests result in a relatively small disturbance to the hydrogeologic regime compared to the disturbance caused by the excavation of the open pit,

Table 11.6-2 Summary of Hydrostratigraphy in EIS Model

Hydrostratigraphic Unit	Depth (m-bgs)	Average Hydraulic Conductivity[(a)] (m/s)
Exfoliated bedrock	0 to 30	6×10^{-6}
	30 to 60	5×10^{-7}
Bedrock	60 to 200	6×10^{-8}
	200 to 500	2×10^{-8}
Kimberlite pipe	0 to 100	3×10^{-6}
	100 to 200	9×10^{-8}
Contact between kimberlite pipes and bedrock	60 to 200	3×10^{-6}
	200 to 400	2×10^{-7}
Potential Enhanced Permeability Zones	60 to 400	1×10^{-6} to 3×10^{-6}

(a) For exfoliated rock and enhanced permeability zones, average hydraulic conductivity was calculated using the arithmetic mean of hydraulic conductivity values calculated from testing. For all other units, averages were calculated using the geometric mean. Values calculated based on the geometric mean were multiplied by a scaling factor of 3.

mbgl = metres below ground level; m/s = metres per second.

In the conceptual model, the hydraulic conductivity of the massive bedrock was increased by a factor of 3 to account for scaling affects related to the relative difference between the volume of rock tested in a single-well response test and the volume of the excavation at the open pits within the Project site. Accordingly, the geometric mean values of hydraulic conductivity determined from the single-well response tests were increased by a factor of 3 times in the conceptual hydrogeologic model (Table 11.6-2). Although hydraulic conductivity testing is limited to less than 500 m depth, the hydraulic conductivity of the bedrock is expected to decrease further with depth, as observed at other sites (Stober and Bucher 2007). Based on published reductions in hydraulic conductivity with depth (Stober and Bucher 2007); the hydraulic conductivity of the bedrock below 500 m is expected to decrease to less than 1×10^{-8} m/s

Kimberlitic Pipe Zone – Nearly 50 single well response tests have been carried out in eight boreholes drilled into the 5034 pipe to a maximum depth of nearly 300 m-bgl. The geometric mean of hydraulic conductivity tests in the kimberlite to 100 m depth is about 9×10^{-7} m/s, while the geometric mean of testing from 100 m-bgl to 200 m-bgl was about 3×10^{-8} m/s. The results of three single well response tests carried out in the 5034 pipe in borehole MPV-05-239C below 200 m-bgs suggest that the hydraulic conductivity of the kimberlite decreases further at greater depths with the highest hydraulic conductivity measured below 200 m-bgl being 1×10^{-9} m/s. Similar to the massive bedrock, the geometric mean of the hydraulic conductivity of the kimberlite was increased by a factor of 3 to account for scaling effects.

Contact Zone(s) – A distinct contact zone with enhanced permeability was encountered between the 5034 kimberlite pipe and the bedrock in five boreholes: BAK020, BAK015, MPV-04-234, MPV-05-239C, and MPV-05-240C. This zone is estimated to be between 50 m and 100 m wide. The geometric mean of hydraulic conductivity tests within this zone to 200 m-bgs is about 1×10^{6} m/s. The geometric mean of comparable tests completed below 200 m bgs is about 7×10^{8} m/s. Although the enhanced permeability indicated from testing in boreholes MPV-04-234 and MPV-05-239C could also be due to increased fracturing or larger fracture aperture associated with a linear structural feature, these results are also included in calculations of average hydraulic conductivity of the contact zone, as these structures would likely overlap.

The contact zones between other geologic formations were also tested. The contact zones between the granite and a dolerite dyke in MPV-04-127C and between the granite and ultramafic rocks in MPV-04-144C did not identify any increased hydraulic conductivity.

Enhanced Permeability Zones – Enhanced permeability zones or zones of greater fracturing or larger apertures related to structures such as faults have been found to be present at operating diamond mines in crystalline rock of the Canadian Shield. These zones have been found at Diavik, Ekati and at Snap Lake; none of which were identified during extensive field investigations at these sites prior to mining. At Diavik, in addition to the 100 m wide enhanced permeability zone referred to as Dewey's Fault, similar but thinner zones have been found: one zone parallel to Dewey's Fault and the other two perpendicular.

Higher permeability zones due to greater fracturing or larger fracture aperture associated with structural features may be present at the Project site. As discussed above, analysis of airphotos, gravity and aeromagnetic data was used by SRK (2004) to identify possible enhanced permeability zones associated with faults. Three of these zones (Figure 11.6-9), one passing through each of the three pipes, are considered to be of potential importance for governing groundwater inflow quality and quantity to the three planned open pits. These zones correspond to Fault 1A/1B, Fault 12 and the Hearne Main Fault identified in Figure 11.6-7. The results of single-well response testing across these potential enhanced permeability zones have been somewhat inconclusive. Attempts to test some of these features were unsuccessful. Where the features may have been intersected it could not be determined if the high permeabilities calculated from the tests were related to these structures or to a highly permeable contact zone around the kimberlite. Nevertheless, because the zones associated with faults have been identified at three mines with similar host rocks, it was considered prudent to include these potential enhanced permeability zones in the conceptual hydrogeologic model developed for the Project. Therefore, the three zones identified in Figure 11.6-9 were assumed to have enhanced permeability.

Tests in three boreholes MPV-04-234, MPV-05-238C, MPV-05-239C may have measured the hydraulic conductivity of the potential enhanced permeability zone passing through the 5034 pipe. Because of the assumed enhanced permeability of these zones compared to the surrounding rock, the dominant groundwater flow pattern induced during mining will be near parallel to the features; therefore, the arithmetic mean of single-well response testing within these features provides the best approximation of the bulk hydraulic conductivity. The arithmetic mean of the hydraulic conductivity values calculated below 60 m-bgs in these wells is 3×10^{-6} m/s. The continuous and relatively high flows of water observed during purging of the three boreholes prior to groundwater sampling corroborates the high hydraulic conductivity values measured in these boreholes.

Enhanced permeability zones associated with structural features have been observed at other diamond mines in the north, and it is possible that additional enhanced permeability zones may be identified within the Project area once mining begins.

11.6.2.2.4 Water Quality

Shallow Groundwater Flow System

The shallow groundwater system is only active in the summer season, and receives water mainly from summer precipitation, with possibly a minor contribution from snowmelt. Groundwater samples in the active layer had total dissolved solids (TDS) concentrations ranging from 44 to 544 milligrams per litre (mg/L), which is classified as fresh water (less than 1,000 mg/L TDS).

The chemistry of shallow groundwater is expected to be similar over most of the LSA. The shallow groundwater system is disconnected from the deep groundwater regime below the permafrost. Shallow groundwater can discharge to the surface drainage system. No evidence of saline seeps was reported from surface water quality, soil or vegetation studies completed for the Project.

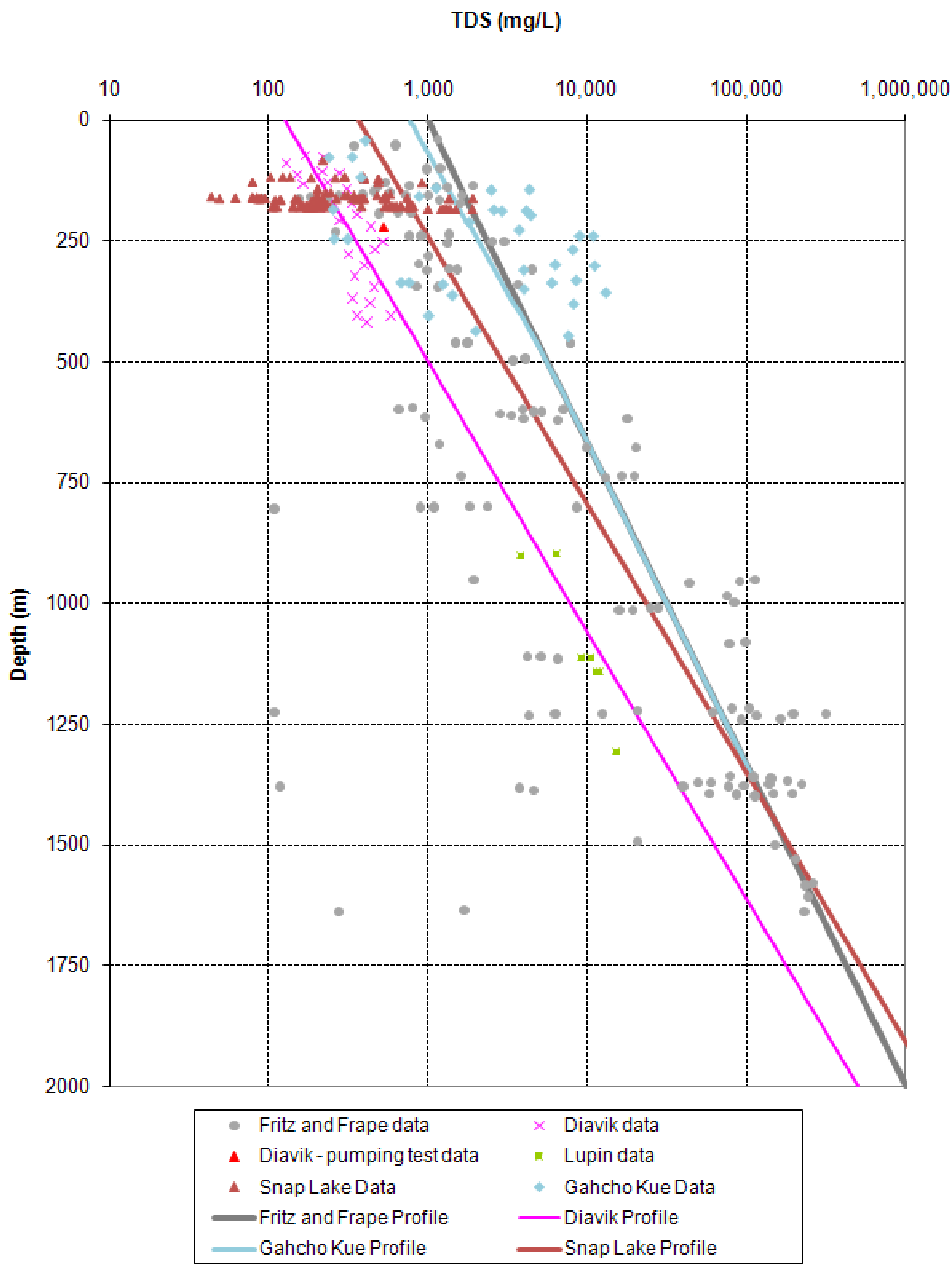
Deep Groundwater Flow System

Permafrost in the LSA extends to a depth of about 300 m below surface in areas outside the influence of lakes or taliks, which can be considered as a typical permafrost thickness corresponding to permafrost formation in the Project area's climate condition (Brown 1970). In the region beneath continuous permafrost, groundwater mineralization with depth in the Canadian Shield is expected to approximate the regional relationship developed by Fritz and Frape (1987) and shown in Figure 11.6-11. Up to 50% by weight of the dissolved solids in saline samples could be attributed to chloride.

Figure 11.6-11 presents TDS values for groundwater samples collected at the Project site (within the talik zones and below the permafrost), together with three other profiles developed from samples collected from deep groundwater at other sites in the Canadian Shield.

The chemistry of some of the groundwater samples collected at the site were affected by sampling difficulties resulting in dilution of the samples by drilling fluids. Five groundwater samples collected in 2004 in boreholes MPV-04-118C, MPV-04-127C, and MPV-04-135C were considered to be notably contaminated and removed from Figure 11.6-11.

Figure 11.6-11 Total Dissolved Solids in Groundwater versus Depth



TDS = total dissolved solids; mg/L = milligrams per Litre; m = metre

Groundwater quality within the Project area is variable, even at a given depth. This variability may be due to local variations in the vertical and horizontal components of the convective flux due to variations in the hydraulic and density gradients, and hydraulic conductivity. In addition, local variations in the diffusive flux from the deep-seated saline groundwater may be present due to variations in the relative interconnection of pore space in the rock mass. Difficulties encountered during groundwater sampling that resulted in mixing of groundwater samples with drilling fluids, which, depending on the groundwater quality and chemical composition of these fluids, could over- or under-estimate the actual TDS concentrations, may also have contributed to this variability. Despite this variability, TDS levels in groundwater samples collected from the Project site are generally consistent with those observed in groundwater at other sites in the Canadian Shield (Figure 11.6-11), and the dataset is considered sufficient for characterization of the average increase in TDS levels with depth in the Project area.

The Fritz and Frape profile (1987) shown in Figure 11.6-11 was developed using chemical analyses of deep saline water collected by various investigators from several sites in the Canadian Shield. The Diavik profile was derived from site-specific data from Diavik, supplemented by information from the Lupin mine site located about 200 km north of Diavik (Kuchling et al. 2000). The Diavik Site is located about 300 km northeast of Yellowknife, and about 150 km northwest of the Project site. Data for the Snap Lake Project, which is located about 85 km northwest of the Project, consist of site information augmented with deep groundwater data from the other data sources discussed previously.

The Project TDS versus depth profile was developed based on a best fit to the TDS of groundwater samples at the site to the maximum depth of site-specific data (450 m-bgs). Below this depth, the profile was assumed to follow the Fritz and Frape profile (Fritz and Frape 1987), which is the most conservative profile of TDS with depth for data collected in the Canadian Shield.

In general, groundwater below the permafrost is dominated by chloride and calcium, with sodium, magnesium and sulphate levels increasing in step with increasing TDS levels. This trend is similar to the typical pattern observed in the deep waters from the Canadian Shield.

11.6.2.2.5 Groundwater Flow

Shallow Groundwater Flow

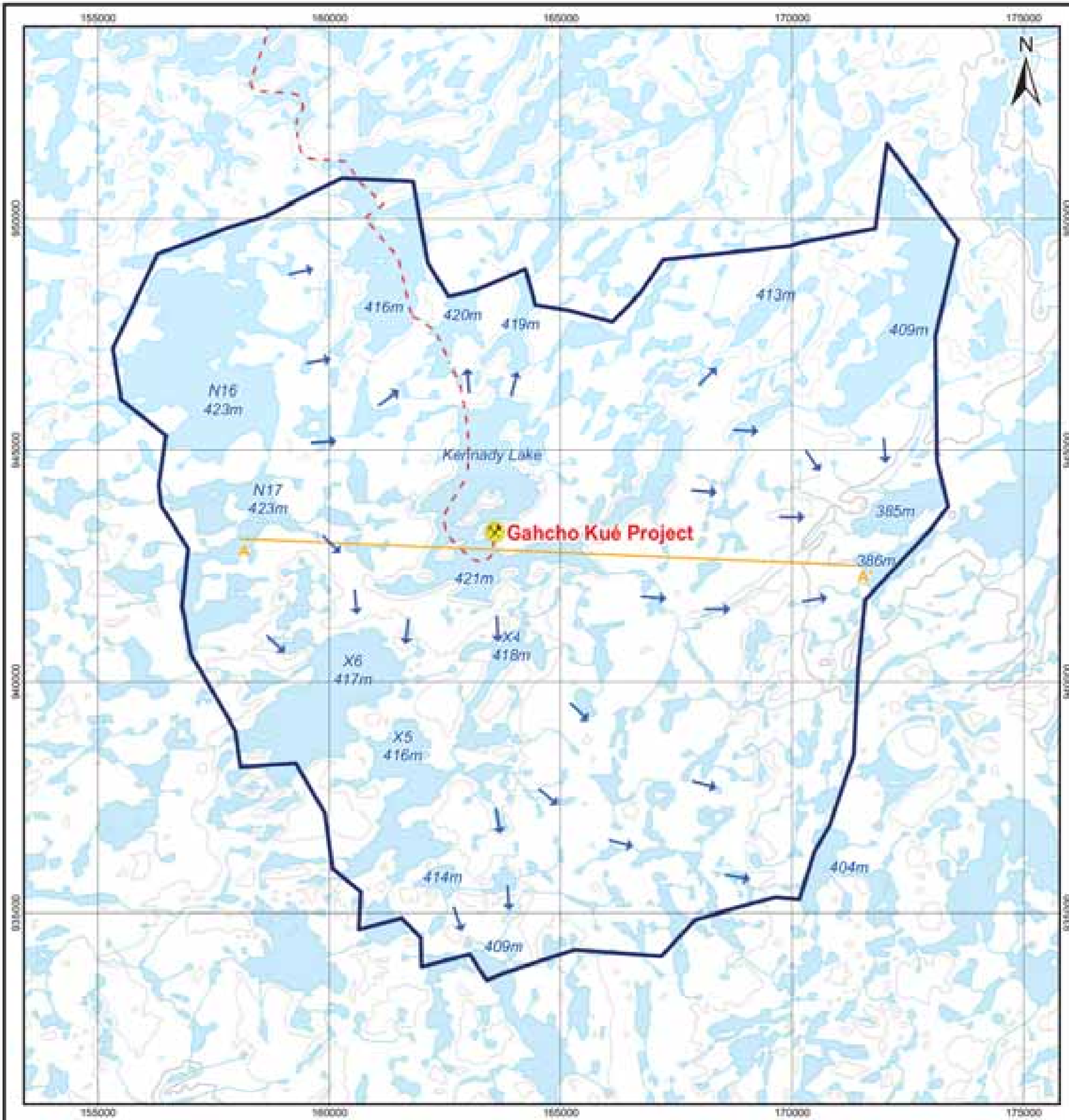
In the shallow seasonally active groundwater regime, hydraulic gradients closely follow land topography. On this basis, the slope of the local terrain suggests hydraulic gradients in the active zone may range from 0.001 to 0.1 metre per metre (m/m). Based on surficial geology and vegetation mapping results, most of the elevated terrains appear to be well drained, and the groundwater table was not encountered within auger holes drilled in elevated areas during the 2004 field inspection. The auger holes never penetrated deeper than 0.4 to 0.6 m below grade due to auger refusal. In the fluvial channels, groundwater can be expected at shallower depths (less than 1 m), and in the peat bogs the groundwater table usually coincided with the ground surface. In terms of travel distance, groundwater in the till is likely to move in the range of centimetres per day, but locally faster groundwater movement may also occur. Groundwater flow in the shallow system is controlled by local topography, and, as a result, the total travel distance would usually extend only to the nearest pond, lake, or stream.

Deep Groundwater Flow

Open taliks play a pivotal role in controlling the deep groundwater flow, as the overlying lakes provide the driving head for the flow system beneath the zone of continuous permafrost. Generally, groundwater will flow from higher elevation lakes to lower elevation lakes.

Lakes expected to have open taliks extending to the deep groundwater flow system and their respective elevations are identified in Figure 11.6-12. Flow directions in the deep groundwater flow regime were inferred from the elevations of these lakes and are also presented in Figure 11.6-12 and Figure 11.6-13. The elevations of these lakes indicate that the groundwater flow direction in the deep groundwater flow regime in the area of the LSA is generally to the south and east.

These groundwater flow directions were inferred assuming that open taliks exist beneath lakes identified in Figure 11.6-12. On a regional scale, it was also assumed that the hydraulic conductivity of the bedrock beneath the permafrost is relatively homogeneous and isotropic.



LEGEND

- Gahcho Kué Project
- Contour (20m interval)
- Watercourse
- Winter Access Road
- Waterbody
- Conceptual Cross Section
- Inferred Groundwater Flow Direction Beneath Permafrost
- Local Study Area

NOTES
Base data source: The Atlas of Canada
Elevations shown are approximate (+/- 1m).
Lakes labelled with elevations are assumed to have open taliks. Lake elevations were derived from National Topographic Base Data (NTDB) 1:50,000 data and LiDAR data provided by the client.

GAHCHO KUÉ PROJECT

Conceptual Model of Groundwater Flow in the Kennady Lake Area - Pre-Mining

PROJECTION:	DATUM:
Canadian Lambert Conf. Conic	NAD83

Scale: 1:120,000

2 1 0 2

Kilometres

DE BEERS CANADA

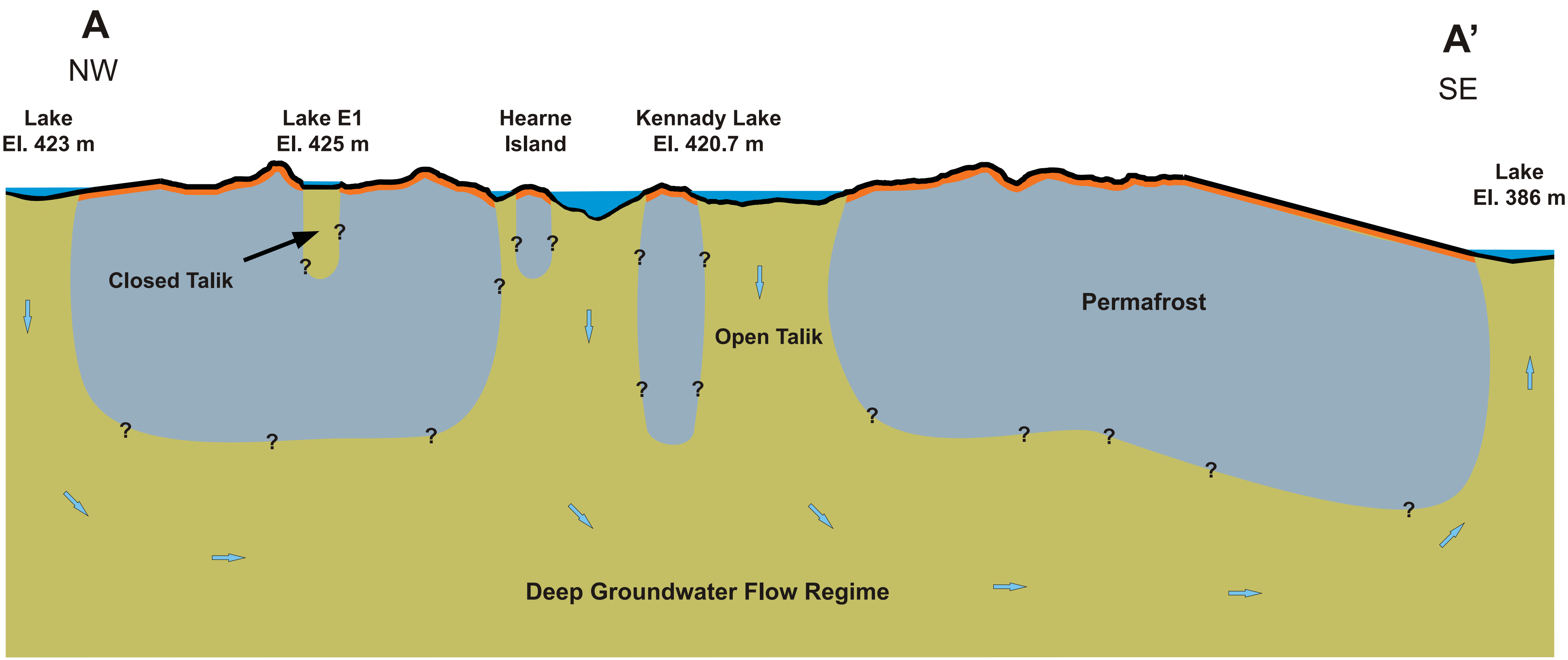
FILE No:	DATE:
SON-11.6-002-GIS	December 9, 2010

JOB NO:	REVISION NO:	
09-1365-1004	1	

OFFICE:	DRAWN:	CHECK:
GOLD-CAL	CW	DC

Figure 11.6-12

L:\2009\1365\09-1365-1004\21000\Report C SON 11.6-I\CorelDraw Figures Section SON-11_6_I\SON-11.6-011-CAD Conceptual Profile.cdr



LEGEND

Active Layer (Shallow Groundwater Flow Regime)

Ground Surface

Inferred Groundwater Flow Direction

Deep Groundwater Flow Regime

Permafrost

Schematic Only
Approximate vertical exaggeration of 1:8

GACHO KUÉ PROJECT

Conceptual Model of Groundwater Flow – Cross-Section View Pre-Mining

PROJECTION: N/A	DATUM: N/A	
SCALE: NOT TO SCALE		
FILE No: SON-11.6-011-CAD		DATE: September 29, 2010
JOB No: 09-1365-1004	REVISION No: 0	Figure 11.6-13
OFFICE: GOLD - CAL	DRAWN: DLM	CHECK: DC

DE BEERS CANADA

11.6.3 Permafrost

11.6.3.1 Pathway Analysis

11.6.3.1.1 Methods

Pathway analysis is used to identify and assesses the issues and linkages between the Project components or activities, and the correspondent potential residual effects on permafrost. It involves a three-step process for initially identifying and then validating linkages between Project activities and environmental effects. Potential pathways through which the Project could influence permafrost were identified from a number of sources including:

- the Terms of Reference for the Gahcho Kué Environmental Impact Statement (Gahcho Kué Panel 2007) and the Report of Environmental Assessment (MVEIRB 2006);
- a review of the Project Description and scoping of potential effects by the environmental assessment and Project engineering teams for the Project; and
- consideration of potential effects identified for the other diamond mines in the NWT and Nunavut.

The first part of the analysis involves producing a list of all potential effects pathways for the Project. Each pathway is initially considered to have a linkage to potential effects on permafrost. This step is followed by the development and/or identification of environmental design features / mitigation measures incorporated into the Project to remove the pathway or limit (mitigate) the effects to permafrost. These design features are often developed through an iterative process involving the Project's engineering and environmental teams, and they include Project designs and environmental best practices, and management policies and procedures.

Knowledge of the ecological system, the environmental design features and other mitigation measures is then applied to each of the pathways to determine the expected amount of Project-related change that may occur and the associated residual effects (i.e., after mitigation) on permafrost. For an effect to occur there has to be a source (Project component or activity) and a correspondent effect.

Pathway analysis is a screening step that is used to determine the existence and magnitude of linkages from the initial list of potential effects pathways for the Project. This screening step is largely a qualitative assessment, and is intended to focus the effects analysis on pathways that require a more comprehensive assessment of effects on permafrost. Pathways are determined to be primary, secondary (minor), or as having no linkage using scientific and traditional knowledge, logic, and experience with similar developments and environmental design features. Each potential pathway is assessed and described as follows:

- no linkage – pathway is removed by environmental design features and/or other mitigation measures, so that the Project results in no detectable environmental change and, therefore, no residual effects to the environmental component in question relative to baseline or guideline values;
- secondary - pathway could result in a measurable and minor environmental change, but would have a negligible residual effect on the environmental component in question relative to baseline or guideline values; or
- primary - pathway is likely to result in a measurable environmental change that could contribute to notable residual effects to the environmental component in question relative to baseline or guideline values.

Primary pathways require further effects analysis to allow for a classification of the potential impacts on the end use or ecological system affected by the change to the component in question (e.g., permafrost). Pathways with no linkage or that are considered minor (secondary) are not analyzed further, because environmental design features and other mitigation measures will remove the pathway (no linkage) or residual effects can be determined to be negligible through a simple qualitative evaluation of the pathway. Primary pathways are assessed in more detail, using quantitative approaches.

11.6.3.1.2 Results

Pathways by which changes to permafrost could occur include direct surface disturbances during construction and operation of the Project. These changes could lead to changes to mean annual soil temperature, thickness of the active layer and seasonal frost penetration. Specific Project activities that could alter permafrost conditions include the following:

- dewatering of Kennady Lake;
- establishment of the mine rock piles, the Coarse PK Pile, and the Fine PKC Facility and other above ground earthen structures;
- construction of roads and the airstrip;
- construction and operation of heated buildings;

- stripping of ground vegetation and subsoil layer; and
- temporary flooding of selected areas around adjacent lakes.

Table 11.6-3 provides a summary of these potential effects pathways, along with the results of the pathway analysis.

Table 11.6-3 Potential Pathways Relevant to Permafrost

Project Component/ Activity	Effects Pathway	Environmental Design Features	Pathway Assessment
Dewatering of Kennady Lake	removal of lake water will allow for greater frost penetration, freezing of surface soils and establishment of permafrost within the exposed lake bed	- establishment of water management pond within Kennady Lake will limit the areal extent of exposed lake bed - refilling of Kennady Lake at the end of operations will allow for a return to pre-development permafrost conditions	secondary
Establishment of mine rock piles, Coarse PK Pile, Fine PKC Facility and other permanent above ground earthen structures	placement of warm material on ground surface will result in the formation of closed taliks, which will freeze back over time as heat dissipates	- aerial footprints of the mine rock piles, Coarse PK Pile, Fine PKC Facility and other earthen structures will be optimized to limit surface disturbance to the extend practical and possible	secondary
	permanent placement of earthen materials in portions of Kennady Lake will allow for a lateral expansion of permafrost into these areas		secondary
Construction of roads and the airstrip	slower melting of compacted snow in spring/summer and associated ponding of the melt water could result in a change in soil temperature and change in the thickness of the active layer	- the roads and airstrip constructed as part of the Project will include drainage systems to prevent the accumulation of ponded water on or adjacent to these structures	secondary
Construction and operation of heated buildings	heat from buildings will result in the formation of closed taliks	- buildings will be insulated to minimize heat loss - buildings will be dismantled as part of reclamation, which will allow for a return to pre-development conditions	secondary
Stripping of ground vegetation	removal of insulating layer could lead to cooler soil temperatures	- ground clearing will be kept to a minimum; it will occur primarily in areas where project facilities are to be built	no linkage
temporary flooding of selected areas around adjacent lakes	expansion of open water areas in raised lakes adjacent to Kennady Lake could result in the expansion of the taliks present under those lakes		secondary

PK = processed kimberlite; PKC = processed kimberlite containment.

Pathways with No Linkage

A pathway may have no linkage if the activity does not occur, or if the pathway is removed by environmental design features and, as a result, the Project results in no detectable (measurable) environmental change and residual effects. The following pathway is anticipated to have no linkage to effects to permafrost.

Removal of Vegetative Ground Cover Could Lead to Cooler Soil Temperature

Stripping of the existing vegetative cover will occur in areas where buildings and some other Project facilities are to be constructed. The loss of the vegetative cover could lead to colder ground temperatures, because of the loss of the insulation that the vegetation provides. However, this effect, were it to occur, would be masked by those associated with the structures that will be build on the clearer areas. As such, this pathway was considered to have no linkage to a measureable effect and was not analyzed further.

Secondary Pathways

In some cases, both a source and a pathway exist, but the change caused by the Project is anticipated to result in a minor environmental change that would have a negligible residual effect on permafrost relative to baseline values. Secondary pathways also include those where a change in permafrost conditions may be expected, but the change is of limited relevance to potential effects to valued components, such as water quality in Kennady Lake. In other words, although a change in permafrost conditions may be anticipated, it is limited in its geographic extent and it has limited influence on the evaluation of potential effects to valued components. Such pathways were determined to be secondary pathways, and were not analyzed further. Secondary pathways identified from the permafrost pathway analysis are outlined below.

Dewatering of Kennady Lake Will Allow for Greater Frost Penetration, Freezing of Surface Soils and Establishment of Permafrost within the Exposed Lake Bed

A talik exists under most of Kennady Lake. During construction and operations, Kennady Lake will be dewatered. Although the water management pond will be placed within a sub-basin of Kennady Lake, areas of the lake will be completely dewatered and exposed to cold air temperatures. The exposure will result in the formation of permafrost in the dewatered lake bed. It is anticipated that the permafrost could reach depths in the order of 14 m during the operational life of the project until Kennady Lake has been refilled. It may reach deeper depths in areas where the underlying bedrock is closer to the lake bed surface.

Permafrost-related processes, such as frost cracking, may occur within the exposed lake bed, with the consequential formation of a polygon landscape and thin ice wedges in the cracks. It is unlikely that major slope instability within the dewatered lake bed will result, because dewatering will occur over several years. This approach should allow for the dissipation of porewater pressure over both the steeper and shallower sections of the exposed lake bed. That said, the potential exists for some local slope failure/deformation in steeper sloped areas around the perimeter of the exposed lake bed.

After lake refilling, the permafrost that will have formed during the operational life of the Project will slowly degrade over time, because of the insulation and heat provided by the refilled lake. A return to pre-development conditions in the reflooded areas is expected within 30 years of refilling. Disturbance of the lake bed and any resulting earth processes would be promptly levelled under the wave action after refilling in the shallow portions of Kennady Lake. In areas with deep water, the levelling of the bottom topography will occur more slowly, mainly by gravitational processes. It would, however, be expected to eventually return to pre-development conditions.

The development of permafrost within the exposed areas of Kennady Lake represents a change to pre-development permafrost conditions. However, it has limited relevance to the assessment of effects to valued components, because the ingress of permafrost to the lake bed is not expected to directly affect surface water quality or fish in Kennady Lake. As such, this pathway was determined to be a secondary pathway, and was not analyzed further.

Construction of Mine Rock Piles, Coarse PK Pile, Fine PKC Facility and Other Permanent Above Ground Earthen Structures Will Result in Changes to Local Permafrost Conditions

Project activities will result in the establishment of two mine rock piles, a Coarse PK Pile and a Fine PKC Facility, along with a number of permanent dykes. All of these structures are expected to affect local permafrost conditions in a similar manner. Initially, taliks of varying depths will form beneath each structure, as the warm mine rock, coarse PK, fine PK or gravel is placed on the ground surface. As the placed materials cool, the underlying taliks will freeze back. The time required for the underlying taliks to disappear will be dependant on the initial temperature of the placed materials, the size of the taliks that initially develop beneath each structure and the degree to which each structure encroaches on the exposed Kennady Lake bed (which itself will initially be underlain by an existing talik).

The largest talik to be created via this pathway is likely to occur beneath the on-land portions of the Fine PKC Facility. It could be in the order of tens of meters deep, and require a long period of time to refreeze. Taliks formed under the other earthen structures are expected to be smaller and refreeze more quickly, because the materials contained within these structures will be cooler when initially placed. In addition, they will tend to be more porous than fine PK, and subsequently cool more quickly.

Permafrost will form within the mine rock piles, Coarse PK Pile and the on-land dykes as they cool. Cooling will occur through heat loss to the atmosphere and the underlying ground. The development of permafrost in the on-land smaller dykes is expected to occur relatively rapidly, with frozen conditions likely being established during or shortly after placement. The formation of permafrost in the larger mine rock piles is also likely to happen, with frozen conditions expected to be present in both mine rock piles and the Coarse PK Pile by the end of operations and lake refilling. This expectation is supported by information collected at the Ekati Diamond Mine, where permafrost conditions have been detected in the existing mine rock piles.

Permafrost will also form within the Fine PKC Facility, as the material placed within the facility cools. However, this cooling process is expected to take some time.

The development of permafrost within the mine rock piles, Coarse PK Pile and the Fine PKC Facility will limit seepage rates from these structures to Kennady Lake. However, the assessment of potential effects to water quality and fish in Kennady Lake was completed without taking this beneficial effect into account. In other words, the assessment was completed assuming no permafrost was present within the aforementioned structures. As such, further analysis of this pathway was not required to support the assessment of potential effects to valued components, and it was classified as a secondary pathway.

Permanent Placement of Earthen Materials in Portions of Kennady Lake Will Allow for a Lateral Expansion of Permafrost into the Affected Areas

As noted above, portions of the mine rock and Coarse PK Pile, along with a portion of the Fine PKC Facility, will sit within the dewatered Kennady Lake basin. The presence of these permanent structures within the lake may allow for a lateral expansion of the surrounding permafrost into these areas. Although this lateral expansion of the existing permafrost represents a change to pre-development permafrost conditions, it has limited relevance to the assessment of effects to valued components, because this change is not expected to directly affect surface water quality or fish. As such, this pathway was determined to be a secondary pathway, and was not analyzed further.

Altered Snow Conditions Around Roads and the Airstrip Could Result in a Change in Soil Temperature and the Thickness of the Active Layer

The roads and the airstrip constructed as part of the Project will be designed to include appropriate drainage system to prevent the buildup of ponded water around these structures. However, the routine activities of snow removal from the airstrip and roads at the mine site, snow compaction along their boundaries and snow compaction along the winter ice road could result in decreased ground temperatures. Snow clearing will allow for greater heat loss from the ground surface during the winter period, whereas the compacted snow will melt more slowly and reduce the amount of time that the ground surface is exposed to the sun's heat in summer time. The net effect of both mechanisms is a reduction in the transfer and retention of heat in the ground, which can lead to reduced ground temperatures and a reduction in the thickness of the active layer under in the immediate vicinity of the roads and airstrip. The reduction is expected to be limited in its magnitude, with the change in the thickness of the active layer likely ranging from 30 to 120 cm. The effect is also expected to be limited in its geographic extent to the boundaries of the roads, airstrip and the areas where snow cleared from the roads and airstrip are placed.

Following the completion of active mining and site reclamation, the roads located outside of the Kennady Lake basin and the airstrip will be contoured to a more natural configuration, and snow will be allowed to naturally accumulate on the re-contoured surfaces. This accumulation will allow for greater heat retention in the ground and an eventual return to pre-development conditions.

Similarly, a winter road will no longer be required after mine operations and reclamation are complete. Snow compaction along this roadway will cease, and pre-development conditions will become re-established over time.

Although the development and maintenance of roads and the airstrip has the potential to alter permafrost conditions, the potential changes are expected to be limited in magnitude and geographic extent. They are also anticipated to be reversible and of little relevant to assess effects to valued components. As a result, this pathway was determined to be a secondary pathway, and it was not analyzed further.

Heat From Buildings Will Result in the Formation of Closed Taliks

Heat radiating outward from heated buildings and other Project facilities could alter the underlying and adjacent ground temperature regime, mainly through a vertical geothermal flow path from the base of each structure. These changes could result in the formation of closed taliks if notable heat losses occur. However, heated buildings will be insulated to minimize heat loss, and the zone of influence associated with the heat generated from buildings and other mine structures is expected to be minimal, mainly limited to within a few meters of the footprint areas of the structures. No long-term or notable effects are expected. As a result, this pathway was determined to be a secondary pathway, and was not analyzed further.

Expansion of Open Water Areas in Raised Lakes Adjacent to Kennady Lake Could Result in the Expansion of the Taliks Present Under Those Lakes

Project activities will result in increased water surface elevations in four lakes located adjacent to Kennady Lake (i.e., Lakes E1, D2, D3 and A3 - see Section 3 for more information). The increased water surface elevations will result in an expansion of existing lake areas and the flooding of lands currently sitting adjacent to the four affected lakes. Depending on water depth, permafrost will thaw beneath the inundated terrain, resulting in expansions of the existing taliks that are located beneath the aforementioned lakes. These expansions represent a change to pre-development permafrost conditions. However, they have little relevance to the assessment of effects to valued components, because this change is not expected to directly affect surface water quality or fish. As such, this pathway was determined to be a secondary pathway, and was not analyzed further.

11.6.3.2 Residual Effects Summary

All of the pathways for permafrost were determined to possess no linkage or be secondary pathways. Therefore, residual effects from these pathways do not require assessment.

11.6.3.3 Uncertainty

The results of the pathway analysis outlined in Section 11.6.3.1 included estimates of potential depths and time frames over which Project activities may affect permafrost conditions in the vicinity of mine site. These estimates are subject to both geologic and operational uncertainties.

Geological uncertainty relates to the physical and thermal properties of the native materials located at the Project site, including the following:

- moisture content;
- dry density;
- thermal conductivity; and
- volumetric heat capacity.

Operational uncertainty relates to the properties of the materials produced as a result of mining. Key attributes include the initial temperatures of the mine rock, coarse PK and fine PK when they are first deposited, the moisture content of each coarse PK and mine rock plie or the Fine PKC Facility and the salinity of the PK. Higher initial temperatures will result in longer cooling times and the development of larger taliks under each facility, relative to those that would occur with cooler initial temperatures. Similarly, higher moisture content within the deposited materials could result in warmer temperatures and prolonged cooling times. Moisture content within the mine rock and PK deposits will largely be a function of the deposition rate, drainage control and earthwork management, all of which will be optimized to the extent possible and practical to encourage the development of permafrost and limit talik formation.

Salinity has a similar direct influence on permafrost formation. Higher salinity concentrations result in greater freezing point depression and greater potential for unfrozen zones within the Fine PKC Facility. Higher levels of initial salinity may also result in the development of high hydrostatic pressure zones within the deposit that will remain unfrozen over time.

11.6.3.4 Monitoring and Follow-up

In light of the uncertainties outlined above, De Beers is committed to monitoring permafrost conditions at the Project site. Monitoring activities will include the following:

- the installation and maintenance of thermistor strings and data loggers within the mine rock piles, the Coarse PK Pile and the Fine PKC Facility to assess temperature conditions and to track the progress of permafrost development within each deposit;
- routine inspection of the exposed lake bed to assess freezing rates and the development of frost cracking and other earth processes;
- routine inspection of permafrost conditions in areas adjacent to the open mine pits during operations; and
- routine inspection of the gravel/sand borrow source areas to identify any large ice deposits and to initiate appropriate handling of this material.

Results of these monitoring programs will be used to evaluate how permafrost conditions may be changing during Project construction, operation and reclamation. Results will also be compared to those obtained from other diamond mines in the NWT. Adaptive management plans will be developed and implemented as required, should effects to permafrost differ from those expected and outlined herein.

11.6.4 Groundwater and Hydrogeology

11.6.4.1 Pathway Analysis

11.6.4.1.1 Methods

Detailed methods for the pathway analysis completed for groundwater and hydrogeology were the same as those used for permafrost, and are found in Section 11.6.3.1.1.

Groundwater within the LSA does not constitute a valued component. Groundwater is not used as a resource by local populations and is not anticipated to become one at any time. As a result, potential effects to groundwater were examined, but residual impacts were not classified. This examination included an assessment of both changes to groundwater and hydrogeology that are specific to that system (e.g., the removal of bedrock and kimberlite material may affect groundwater quantity in Kennady Lake area, or spills can cause changes to groundwater quality) and changes to groundwater and hydrogeology that may present potential effect pathways to valued components, such as surface water quality (e.g., inflow of saline groundwater to the mine out pits may lead to potential effects to the water quality of Kennady Lake after refilling).

Issues identified by communities, regulator, and other interested parties are the basis of this EIS. Issues were derived from MVEIRB (2006) technical and community issues scoping workshops and hearings, De Beers' community and regulatory engagement process (Section 4) and other sources. The pathways analysis in Section 8 lists the issues that are relevant to all aquatic resources disciplines, including groundwater. From this broad list of potential pathways, a shorter, more focused list of pathways that are relevant to groundwater and hydrogeology was derived and is discussed below.

11.6.4.1.2 Results

Project activities will result in changes to the shallow and deep groundwater regimes. These changes will occur as a result of the dewatering of Kennady Lake, the development of the open mine pits and the construction of the mine rock piles, Coarse PK Pile, and the Fine PKC Facility. As the pits are developed, groundwater will be induced to flow into the open pits. As described above in Section 11.6.2.2.4, groundwater quality is expected to change with depth. The higher TDS content water found at depth will influence pit water quality during the life of the mine and during closure activities when the pits are backfilled and flooded. If not properly handled, the higher TDS content pit water may be released to surface waterbodies and negatively affect the receiving environment.

Table 11.6-4 provides a description of all pathways that are relevant to groundwater and hydrology, both from the perspective of direct effects focused on these systems and effects that create potential pathways for effects to other components.

Pathways with No Linkage

A pathway may have no linkage if the activity does not occur (e.g., effluent is not released), or if the pathway is removed by environmental design features so that the Project results in no detectable (measurable) environmental change and no residual effects to groundwater and hydrogeology. The following pathways are anticipated to have no linkage to groundwater and hydrogeology, and will not be carried through the effects assessment.

Permafrost Development on the Newly Exposed Lake Bed Could Potentially Mobilize Poor Quality Water from Depth and Negatively Affect Surface Water Quality

This pathway is not considered to be valid. Permafrost aggradation on the exposed lake bed is expected to have limited penetration after approximately 20 years of exposure, which would be insufficient to mobilize poor quality water. As such, the residual effect from mobilization of poor quality water from depth is expected to have no measurable influence on surficial groundwater quality or surface water quality.

Seepage from Mine Rock Piles Could Result in Changes to Groundwater Quality

Most of the mine rock from the excavation of the open pits will be sourced from the bedrock surrounding the kimberlite deposits. The mine rock will be stored in one of the following locations:

- mine rock piles in and adjacent to Area 5 (West Mine Rock Pile) and Area 6 (South Mine Rock Pile); and
- the mined-out 5034.

Approximately 63% of the mine rock will be deposited in the mine rock piles, with the remainder being deposited in the mined-out 5034 pit. A small proportion of the mine rock will be used for construction of roads, dykes, dams and reclamation of the Coarse PK Pile and Fine PKC Facility.

Table 11.6-4 Potential Pathways Relevant to Groundwater and Hydrogeology

Project Component/ Activity	Effects Pathway	Environmental Design Features	Pathway Assessment
Dewatering areas of Kennady Lake.	flow of groundwater to dewatered areas of Kennady Lake, which could affect surface water quality in the receiving environment	- groundwater reporting to the dewatered areas of Kennady Lake will not be directly released to the environment; it will be placed into the Water Management Pond and only released during operations if it can be done without notable effects to the receiving environment - as part of reclamation, saline waters will be placed in the backfilled pits to limit release to the environment - at closure, water levels in Kennady Lake will be restored to pre-mining water levels, limiting groundwater inflow rates	secondary
	permafrost development on the newly exposed lake bed could potentially mobilize poor quality water from depth, which could negatively affect surface water quality	- area of exposed lake bed will be minimized by the placement of the Water Management Pond in Areas 3 and 5 - exposure time will be in the order of 19 years, based on a 11 year mine life and an eight year refilling period	no linkage
	alteration of groundwater flows from dewatering Kennady Lake may result in changes to groundwater discharge rates to other lakes	- at closure, water levels in Kennady Lake will be restored to pre-mining water levels, eliminating the groundwater flow gradient towards Kennady Lake	secondary
Pit Development	alteration of the groundwater regime that results from pit development may result in decreased groundwater discharge rates to other lakes	- at closure, water levels in Kennady Lake will be restored to pre-mining water levels, eliminating the groundwater flow gradient towards Kennady Lake	secondary
	removal of saline groundwater inflow from the mine pits may cause changes to groundwater quantity and quality	- during operations, perimeter dykes will be constructed around the circumference of the open pits to reduce the inflow of surface runoff into the open mine pits, thereby limiting the potential exchange of saline groundwater and fresh lake water - at closure, water levels in Kennady Lake will be restored to pre-mining water levels, eliminating the need for groundwater removal	secondary
	removal of bedrock and kimberlite material may affect groundwater quantity in Kennady Lake area	- groundwater removed during mining will be replaced when pits are backfilled and Kennady Lake is refilled	secondary

Table 11.6-4 Description of Pathways Relevant to Groundwater and Hydrogeology and a Summary of the Pathway Validation Results (continued)

Project Component/ Activity	Effects Pathway	Environmental Design Features	Pathway Assessment
Refilling of Kennady Lake	effect of refilling Kennady Lake on the deep groundwater regime and deep groundwater flows to the refilled Tuzo Pit	- during reclamation, water flow into the mined-out pits will include surface water and groundwater; refilling will not rely solely on refilling by groundwater - at closure, water levels in Kennady Lake will be restored to pre-mining water levels, eliminating the groundwater flow gradient towards Kennady Lake	secondary
Storage of Processed Kimberlite and Mine Rock	seepage from mine rock and could result in changes to groundwater quality	- at closure, the mine rock piles will be re-shaped and completed with a one m thick layer of non-acid generating mine rock to prevent erosion and water ponding on the surface of the rock piles - potentiallly acid generating (PAG) rock will comprise only a small proportion of the overall mine rock tonnage and will be sequestered within the mine rock piles - thermistors will be installed within the mine rock piles to monitor the progression of permafrost development - runoff from the mine rock piles will be managed to prevent ponding.	no linkage
	seepage from backfilled PK and mine rock material placed in the mined out pits may change groundwater quality	- the water contained in the backfill pits will have a lower TDS level than the surrounding groundwater.	no linkage
	seepage from the Fine PKC Facility and the Coarse PK Pile foundation may cause changes to groundwater flows and quality	- permafrost development in the Fine PKC Facility is expected to occur over time; thermistors will be installed in the Fine PKC Facility to monitor the formation of permafrost in the solids - the Coarse PK Pile, adjacent to Area 4, will be shaped and completed with a one m thick layer of non-acid generating mine rock to prevent erosion and water ponding on the surface of the rock piles; permafrost conditions are anticipated to be established in the pile by the end of mine life. - placement of these facilities adjacent to and encroaching within Kennady Lake will create a seepage gradient from the facilities to Kennady Lake, thereby limiting / preventing seepage into the underlying groundwater systems	no linkage

Table 11.6-4 Description of Pathways Relevant to Groundwater and Hydrogeology and a Summary of the Pathway Validation Results (continued)

Project Component/ Activity	Effects Pathway	Environmental Design Features	Pathway Assessment
Spills and Accidents	spills can cause changes to groundwater quality.	- petroleum products will only be handled by site personnel who have received appropriate training - an emergency and spill contingency plan will be developed for the Project - spill containment supplies will be stored in well-labelled, designated areas - any spills will be isolated and immediately cleaned up by a trained spill response team consisting of on-site personnel - mine vehicles and heavy equipment will be maintained to operational standards - all fuel storage tanks will be designed and constructed according to the American Petroleum Institute 650 (API) standard - fuel tanks will be placed within a lined and dyked containment area; the design of the containment area will be based on the requirements of the CCME Environmental Code of Practice for Above-Ground Storage Tanks Systems Containing Petroleum Products (2003), the National Fire Code of Canada, and any other standards that are required. - the containment area will be sized to hold 110% of the volume of the largest storage tank and will include a gravel base with a continuous high-density polyethylene liner sheet installed under the tanks and the internal sides of the berm - a fuel unloading pumping module will be installed within a spill containment area adjacent to the fuel storage tank farm - aviation fuel will be stored in self-contained, Underwriters Laboratories Canada (ULC)-rated envirotanks mounted on an elevated pad at the air terminal shelter; aviation fuel for helicopters will be stored in sealed drums inside a lined berm area near the airstrip	no linkage

Table 11.6-4 Description of Pathways Relevant to Groundwater and Hydrogeology and a Summary of the Pathway Validation Results (continued)

Project Component/ Activity	Effects Pathway	Environmental Design Features	Pathway Assessment
Spills and Accidents (continued)		- to prevent accumulation and/or runoff of de-icing fluids at the airstrip from aircraft de-icing operations, aircraft will be sprayed in a specific area that will be equipped with swales to collect excess fluids, if necessary; any affected soil and gravel resulting from spills will be collected and transferred to the landfarm; - puddles of de-icing fluids in the swales will be removed by vacuum truck and deposited into waste de-icing fluid drums for shipment to recycling facilities, if necessary - waste oil will be collected and stored in the waste oil storage tank and incinerated for heat generation or used with explosives, if not shipped off-site for recycling - the grease used in the diamond recovery process will be recycled to the extend possible and disposed of as appropriate - spent chemicals, such as de-icing fluid, acids, solvents, battery acids and laboratory agents, will be collected in lined trays and drums and stored in suitable sealed containers in the waste transfer area. - chemicals that cannot be incinerated will be shipped off-site for disposal or recycling - hazardous, non-combustible waste and contaminated materials will be temporarily stored in the waste storage transfer area in sealed steel or plastic, wildlife-resistant drums, and shipped off-site for disposal or recycling - the waste transfer storage area will include a lined and enclosed pad for the collection and subsequent return of hazardous waste to suppliers or to a hazardous waste disposal facility - emulsion materials will be stored at the emulsion plant where spills will be 100% contained within the building - processing of the kimberlite ore will be mechanical, with minimal use of chemicals	

The South Mine Rock Pile (Area 6) will store mine rock from the 5034 excavation until Year 3, after which it will serve as an overburden storage area for the Hearne and Tuzo pits. The 5034 mine rock generated in Years 3, 4 and 5 will be hauled to the West Mine Rock Pile (Area 5). At this point, the 5034 pit will be available for mine rock storage, and the mine plan designates 5034 pit as the primary disposal for Tuzo mine rock. Tuzo mine rock generated after the 5034 pit is full will be placed in the West Mine Rock Pile. Hearne mine rock will be placed in the West Mine Rock Pile as well. Some mine rock from the pits will be diverted to cover the Coarse PK Pile and the Fine PKC Facility once they are full.

Less than 6% of the mine rock that will be excavated through open-pit mining will have to be managed as being potentially acid generating (PAG). This rock will be managed appropriately to avoid the generation of acidic leachate and limit the release of the metals and other elements. The management strategy will involve sequestering any PAG mine rock, as well as any barren kimberlite, within the interior of the mine rock piles. Till from on-going pit stripping will be used to cover PAG rock placed within the interior of the structure to keep water from penetrating into that portion of the repository. Further, the PAG rock will be enclosed within enough non-acid generating (non-AG) rock, such that the active zone will not extend into the enclosed material, and water runoff will occur on the non-AG rock cover areas. While some water may continue to penetrate into the deeper section of the rock piles, this water is expected to be trapped in void spaces and likely freeze. Minimal water is expected to penetrate to the PAG rock areas.

Experience at the Ekati Diamond Mine indicates that permafrost develops rapidly within mine rock piles, with an active freeze/thaw layer of about 8 m. Material more than 8 m below the surface of the mine rock tends to be permanently frozen. As such, the isolation of potentially reactive rock within the centre of the mine rock piles is expected to effectively mitigate the long-term potential for acid rock drainage to develop in these areas. Temperature monitoring systems will be placed in the mine rock piles as they are being constructed to assess the degree of freezing that develops within the piles.

Finally, the final surface of the mine rock piles will be graded to promote runoff of precipitation, limiting the potential for seepage generation over the long-term. Based on the above, this pathway is invalid.

Seepage from Backfilled PK and Mine Rock Material in Pits May Change Groundwater Quality

At the end of mining, all three pits, either those that are backfilled or empty, will be flooded with fresh water. After filling, the water within the backfilled pits is expected to have a maximum average TDS level of about 600 mg/L. This TDS level is lower than the average TDS level that has been measured in the baseline groundwater; therefore, seepage from the backfill material will not increase the TDS levels in the surrounding groundwater, and this pathway is not considered to be valid.

Seepage from the Fine PKC Facility and the Coarse PK Pile Foundation can Cause Changes to Groundwater Flows and Quality

As with the mine rock piles, permafrost is expected to develop within the Fine PKC Facility and the Coarse PK Pile. Both facilities will also be shaped and contoured to encourage surface runoff, thereby limiting infiltration and potential foundation seepage. In addition, these facilities will be placed adjacent to and encroaching within Kennady Lake, which will create a seepage gradient from the facilities to Kennady Lake. As a result, foundation seepage rates into the underlying groundwater system are expected to be small, with no measureable effect beyond the boundaries of the facilities themselves .

Spills can Cause Changes to Groundwater Quality

Spills are usually localized, and will be quickly reported and managed. Mitigation identified in the Emergency Response and Spill Contingency Plan (Section 3, Appendix 3.I, Attachment 3.I.1), and other environmental design features (e.g., containment dykes, liners, proper storage conditions) will be in place to minimize the frequency and extent of spills that result from Project activities, as outlined in Table 11.6-4. Chemical spill containment will be incorporated into the plant design, and spill response materials will be available in well marked, designated areas.

Employees will be trained in the transportation of dangerous goods, and domestic and recyclable wastes will be stored in appropriate containers until they can be disposed off at approved facilities or through approved means. Storage facilities for hazardous substances and waste dangerous goods will meet regulatory requirements and will be designed to protect the environment and workers from exposure.

The implementation of emergency response and contingency, environmental design features and monitoring programs is expected to result in no detectable change to groundwater quality relative to baseline conditions. Consequently, this pathway was determined to have no linkage to effects.

Secondary Pathways

In some cases, both a source and a pathway exist, but the change caused by the Project is anticipated to result in a minor environmental change, and would have a negligible residual effect. The following pathways are anticipated to be secondary, or minor, and will not be carried through the effects assessment.

Flow of Groundwater to Dewatered Areas of Kennady Lake, Which Could Affect Surface Water Quality in The Receiving Environment

Dewatering of Kennady Lake will increase the hydraulic gradient in the active surface groundwater flow regime and exposes the lake bed to freezing conditions. The altered hydraulic gradient will increase groundwater discharge rates to the Kennady Lake basin. However, the change in the hydraulic head is expected to be limited, particularly in comparison to that which is expected to occur as a result of the construction of the open mine pits. As such, this pathway is expected to result in negligible effects on groundwater flows, and limited relevance to potential effects to surface water quality.

Alteration of Groundwater Flows from Dewatering Kennady Lake May Result in Changes to Groundwater Discharge Rates to Other Lakes

Dewatering of Kennady Lake will increase the hydraulic gradient in the active surface groundwater regime, which may extend 1 to 5 m below the ground surface of the Kennady Lake watershed, depending on the topography. However, the change in the hydraulic head is expected to be limited, and the volume of groundwater ingress into the affected area is expected to be minimal. As such, this pathway is expected to result in negligible effects groundwater discharge rates to other lakes.

Alteration of the Groundwater Regime that Results from Pit Development May Result in Decreased Groundwater Discharge Rates to Other Lakes

Creation of the open mine pits will induce groundwater to flow toward these areas from all directions. The reduced groundwater pressures in the deep groundwater flow system will cause a small volume of water to flow from Lakes X4 and X6 toward the pit. Changes in groundwater discharges to other lakes within the LSA are predicted to be less than those to these two lakes.

The maximum reduction in groundwater discharge due to dewatering and pit development is predicted to be on the order of 100 m^3/d. The net precipitation to the lake surfaces only, not including the rest of the catchment, is on the order of 2,400 m^3/d. Climatic inputs to the area vastly overwhelm the magnitude of the change potential induced by mine pit development.

Although changes to groundwater flow directions and intercepts are likely, no measureable effects are anticipated in the receiving environment (such as reduced water levels in the surrounding lakes). As such, this pathway was determined to have negligible residual effect on valued components and was classified as a secondary pathway that required no further analysis.

Removal of Saline Groundwater Inflow from the Mine Pits May Cause Changes to Groundwater Quantity and Quality

During mining, the open mine pits will act as sinks for groundwater flow. Groundwater seeping into the open pits will originate from surface waters and from deep bedrock. Groundwater flow originating from deep bedrock will draw high TDS content groundwater to the pits. The TDS content of groundwater flowing into the pits will increase as each pit gets deeper, because of the higher salinity of the groundwater in the deep bedrock encountered as the pits extend to greater depths, and the upwelling of saline water from beneath the pits due to the vertical hydraulic gradient that gets created as a result of Project activities.

Water entering the open pits during mining will be routed by ditches to a series of sumps. Temporary sumps will be developed in working areas that will allow initial settlement of coarse suspended solids from the water. From the temporary sumps, water will be directed through a combination of ditches and pipelines to main sumps equipped with multiple storage areas and pumps. A limited amount of storage capacity will be provided in the open pits to prevent flooding of sumps and working areas.

As required, perimeter dykes will be constructed around the circumference of the open pits to reduce the inflow of surface runoff from the exposed lakebeds. A small amount of seepage may reach the open pits during runoff events, because the perimeter dykes will not be constructed with water-retaining cut-off walls.

Groundwater inflows collected in the pit dewatering systems will be discharged to the water management pond or the process plant. Once the 5034 Pit is mined out in Year 5, discharge of groundwater into the water management pond will stop, and the groundwater entering the 5034 Pit will be retained in the pit. Pit water from the Hearne Pit will be sent to the mined-out 5034 Pit..

The concentration of TDS in the pit water from groundwater infiltration is expected to increase with depth, and the concentration will determine its destination. At first, pit water can be pumped to the water management pond. As the concentration of TDS increases, the pit water will be used as process water. Groundwater pumped to the process plant will eventually be incorporated in the PKC slurry and discharged to the Fine PKC Facility. From Year 5 onwards, mined-out pits will be available and deep groundwater will be retained in or discharged to the mined-out pits, as necessary.

As previously outlined, the creation of the open mine pits will induce groundwater to flow toward the open pits from all directions. The reduced groundwater pressures in the deep groundwater flow system will cause a small volume of water to flow from neighbouring lakes toward the pit. The maximum reduction in groundwater discharge due to dewatering and pit development is predicted to be on the order of 100 m^3/d, which is small in comparison to surface inflows (which can be in the order of 2,400 m^3/d). As such, climatic inputs to the area vastly overwhelm the magnitude of the change potential induced by mine pit development.

Although changes to groundwater flow directions and intercepts are likely, no measureable effects are anticipated in the receiving environment (such as reduced water levels in the surrounding lakes). Therefore, this pathway was determined to have negligible residual effect on valued components and was classified as a secondary pathway that required no further analysis. However, a quantitative analysis of groundwater inflow rates and associated TDS mass loading rates to the mine pits was completed, because this pathway may still be valid to surface water quality in Kennady Lake.

The results of the quantitative analysis, which is described in more detail in Appendix 11.6.I, indicate that groundwater inflow to the 5034 pit is predicted to be fairly constant, varying from 2,100 m^3/day in Year 2 to 2,500 m^3/day in Year 7 (Table 11.6-5). In the initial stages of mining when the pit depth is relatively shallow, much of the groundwater inflow is attributed to water released from storage in the shallow tills beneath Kennady Lake. In the later stages of mining, this unit has been dewatered, and groundwater inflow to the pit is through the enhanced permeability zone and the surrounding bedrock. The TDS of groundwater inflow to the 5034 pit is predicted to increase from 300 mg/L in Year 2 to 4,000 mg/L in Year 7.

Table 11.6-5 Predicted Groundwater Inflow Quantity and Quality During Mining

Calendar Year	Mine Year	Inflow (m^3/d)			TDS (mg/L)			Lakewater Contribution (%)			Pit Elevation (masl)		
		5034	Hearne	Tuzo	5034	Hearne	Tuzo	5034	Hearne	Tuzo	5034	Hearne	Tuzo
2013	-2	-	-	-	-	-	-	-	-	-	421	-	-
2014	-1	2100	-	-	300	-	-	67	-	-	373	-	-
2015	1	2300	-	-	1100	-	-	29	-	-	349	-	-
2016	2	2100	-	-	2000	-	-	24	-	-	301	-	-
2017	3	2400	-	-	2500	-	-	32	-	-	253	-	-
2018	4	2600	400	-	3300	100	-	39	83	-	181	409	-
2019	5	2500	800	600	4000	600	200	46	44	74	121	361	397
2020	6	2200	1200	800	4000	1400	700	53	34	38	205[(a)]	301	361
2021	7	1200	1400	1100	2500	1800	1100	71	42	32	300[(a)]	217	325
2022	8	1400	700	1800	2600	1100	2000	70	70	29	300[(a)]	337[(a)]	253
2023	9	1400	300	2100	2600	400	3100	72	89	35	300[(a)]	376[(a)]	193
2024	10	1400	100	2200	2500	50	4000	74	90	40	300[(a)]	410[(a)]	157
2025	11	1400	50	2400	2400	50	5200	75	90	43	300[(a)]	421[(a)]	121

(a) Elevation of the water level in the backfilled or flooded pit.

m^3/d = cubic metres per day; mg/L = milligrams per litre; % = percent; masl = metres above sea level.

Groundwater inflow to the Hearne pit is predicted to be much lower initially than at its ultimate depth, as the shallow till in the vicinity of the Hearne pit has already been depressurized as a result of mining in the 5034 pit. Therefore, much less water is released from storage during initial mining of the Hearne pit than during initial mining in the 5034 pit. At the start of mining in the Hearne pit in Year 6, predicted groundwater inflow is about 400 m^3/day, while predicted groundwater inflow when the pit reaches its ultimate depth in Year 9 is 1,400 m^3/day. Groundwater inflow to the pit is predicted to gradually decrease as the pit is backfilled with fine PK, and is predicted to be about 50 m^3/day in 2025. Predicted groundwater inflows to this pit are approximately 40% lower than those predicted to the other pits, because the Hearne pit is smaller and shallower than the 5034 or Tuzo pits. The TDS of groundwater inflow to the Hearne pit is predicted to vary from 100 mg/L in Year 6 to 1,800 mg/L in Year 9.

Groundwater inflow to the Tuzo pit is predicted to increase from 600 m^3/day in Year 7, when mining of this pit is planned to begin, to 2,400 m^3/day at the end of mining (Year 13). The TDS of groundwater inflow is predicted to increase from 200 mg/L in Year 7 to 5,200 mg/L in Year 13 at the end of mine life.

Predicted groundwater inflows to the combined 5034 and Tuzo Pit from Year 12 to Year 17 are summarized in Table 11.6-6. Groundwater inflow to the pits is predicted to vary from 1,700 to 300 m^3/day from Year 12 to Year 17, respectively. The TDS of inflow to the pits during the refilling period is predicted to gradually decline from 2,100 mg/L in Year 12 to 400 mg/L in Year 17. The percentage contribution of groundwater inflow originating from lake water is predicted to vary from about 75% to 80% as the water level in the pits rises. After Year 17, the hydraulic gradient between the flooded pits and surrounding surface water is expected to be negligible. Groundwater inflows after this time were assessed using a post-closure model discussed in Appendix 11.6.II.

Table 11.6-6 Predicted Groundwater Inflow Quantity and Quality During Refilling

Calendar Year	Mine Year	5034 and Tuzo Combined			
		Inflow (m^3/d)	TDS (mg/l)	Lake Water Contibution (%)	Pit Elevation (masl)[(a)]
2026	12	1700	2100	75	318
2027	13	1700	2100	75	335
2028	14	1500	2000	76	351
2029	15	1100	1600	77	368
2030	16	800	1100	78	384
2031	17	300	400	79	401

(a) Elevation of the water level in the backfilled or flooded pit.

m^3/d = cubic metres per day; mg/l = milligram per litre; % = percent; masl = metres above sea level.

After flooding of the Tuzo Pit and dissipation of the large hydraulic head gradients around the flooded pit, the conditions that create the near hydrostatic fluid pressures that characterize the pre mining groundwater regime will be re established.

Removal of Bedrock and Kimberlite Material May Affect Groundwater Quantity

Mining will remove approximately 270 million tonnes (Mt) of rock, primarily from the talik, but also from the deep groundwater system. This mass of rock occupies an approximate volume of 46 million cubic metres (Mm^3). With an average porosity of 0.01, the groundwater within this volume is about 0.5 Mm^3. This volume of groundwater will be permanently removed and incorporated into the mine rock piles, the Coarse PK Pile, and the Fine PKC Facility, or managed through the water management pond. Pore spaces of the mine rock and processed kimberlite material used to backfill Hearne pit and the backfilled portion of 5034 pit will contain pore water that originates primarily as groundwater. This water will be augmented by fresh water during refilling. Therefore, the groundwater volume removed from the pits will be replaced by groundwater in the backfill material and fresh water. As such, the residual effect to groundwater quantity is expected to be negligible.

Effect of Refilling Kennady Lake on The Deep Groundwater Regime and Deep Groundwater Flows to the Refilled Tuzo Pit

Once Kennady Lake has been refilled, groundwater with a higher salinity and density than fresh water may seep into the refilled Tuzo pit due to density gradients. The ingress of groundwater will be slow, and density stratification will develop where the lower-density fresh water will float on top of the higher-density saline water.

Flooding of the Tuzo pit basin (Tuzo pit and unfilled portion of the 5034 pit) with fresh water will alter hydraulic and density gradients until new pressure and chemical equilibriums are established. The water quality within the talik that will reform directly under the refilled Kennady Lake will initially be more dilute due to fresh water from the pit flowing into the talik groundwater system.

Once hydraulic heads return to equilibrium shortly after pit refilling is complete, it is expected any high TDS groundwater that has upwelled beneath the pit during mining will begin to sink due to its higher relative density. Water in the backfilled pit is expected to be drawn downward from the bottom of the flooded pit into the bedrock, while relatively fresh groundwater discharges into the upper part of the pit. At later times, as the pre-mining fluid density profile is restored, the effects of density-driven flow are expected to be reduced, velocities and should, consequently, decrease and diffusion should become the dominant transport process.

Potential effects related to this pathway are anticipated to be negligible in the context of general flow patterns in the deep groundwater system and the quality of the waters moving through this system. As such, this pathway is considered to be secondary, and does not to require further analysis from a groundwater perspective. However, a quantitative analysis of potential groundwater interactions with the refilled Tuzo pit was undertaken, because this pathway may still be valid to surface water quality in Kennady Lake.

The quantitative analysis is outlined in Appendix 11.6.II. Results of the analysis substantiate the expectations outlined above, and indicated that, during the post-closure period, groundwater inflow rates to the pit are predicted to range between approximately 0.5 and 3 m^3/day, whereas predicted outflows from the lake to the surrounding groundwater system are predicted to range from 0.2 and 8 m^3/day. The corresponding TDS mass flux into the flooded pit ranges between approximately 300 to 4,500 g/day, and, although it will take some time for the system to reach equilibrium, fluid density gradients will create very little flux into the flooded pit.

11.6.4.2 Residual Effects Summary

All of the pathways for groundwater and hydrogeology were determined to possess no linkage or be secondary pathways. Therefore, residual effects from these pathways do not require assessment.

11.6.4.3 Uncertainty

As with all other geologic and hydrogeologic studies, there is a level of uncertainty in all effects analysis results. These uncertainties are inherent in these studies due to uncertainties within the groundwater measurement database, and the requirement to extrapolate or interpolate properties to a continuum based on sparse measurements. An evaluation of the primary sources of uncertainty for the groundwater effects analysis is presented below.

The primary uncertainties with regard to groundwater issues are prediction of:

- pit inflow volumes;
- water qualities; and
- direction and magnitude of groundwater flow in the talik.

Other mine developments in the north have experienced significant under estimations of the volumes of water reporting to the pits or underground workings, particularly in the Snap Lake and Diavik projects. This under estimation of groundwater inflow prior to mining has been due to the presence of enhanced permeability zones. Enhanced permeability zones are zones of greater fracturing or larger fracture aperture related to structures such as faults. These zones have been found at Diavik, Ekati and at Snap Lake; none of which were identified during extensive field investigations prior to mining. At Diavik, in addition to the 100 m wide enhanced permeability zone referred to as Dewey's Fault, similar but thinner zones have been found: one zone parallel to Dewey's Fault and the other two perpendicular to this fault.

The hydrogeological model developed for the Project assumes that enhanced permeability zones are present and associated with geologic faults, identified in the geophysical surveys that intersect the proposed open pits. However, their presence has not yet been confirmed, and it is possible that the structures are less permeable, thinner and/or less lateral extensive than the ones represented in the base case hydrogeological model.

Based on past experiences at other mines in the north, increases in the overall mine inflow result in increased mass loading as more groundwater is moving upwards from the region where the deep-seated saline groundwater is present. At the Project site, this phenomenon is expected to be more pronounced, because of the presence of permafrost that nearly surrounds all three of the planned open pits (which will limit the dilution of the deep-seated saline groundwaters by shallow fresher groundwaters). The average model-predicted percentage of groundwater inflow that originates from the freshwater lakes at the Project site is about 40% to 50%. At the Diavik Diamond Mine, there is a continuous source of freshwater from Lac de Gras and the percentage of groundwater inflow that originates from the lake is estimated to be greater than 70%.

Groundwater quality within the Project area is quite variable, even at a given depth. This variability may be due to difficulties encountered during groundwater sampling that resulted in mixing of groundwater samples with drilling fluids, which, depending on the groundwater quality and chemical composition of these fluids, could result in over- or under-estimates of actual TDS levels in the deep groundwater. This observed variability could also be due to local variations in the vertical and horizontal components of the convective flux due to variations in the hydraulic gradients, density gradients, hydraulic conductivity and/or local variations in diffusive flux from the deep-seated saline groundwater due to variations in the relative interconnection of pore space in the rock mass. Despite this variability, the TDS values of groundwater samples are generally consistent with the TDS of groundwater observed at other sites in the Canadian Shield (Figure 11.6-11).

Because the inflow and TDS mass are interdependent, it is likely that if reasonably highly conservative values of bedrock hydraulic conductivity were simulated together with a reasonably highly conservative TDS/depth profile the result would be an overly conservative groundwater inflow and TDS mass. Therefore, in a model sensitivity which employs a more conservative TDS/depth profile, less conservative values of bedrock hydraulic conductivity are considered to be appropriate.

As a consequence of the above, two model sensitivities were undertaken; they were as follows:

- Sensitivity Run #1: In this model simulation, the enhanced permeability zones were removed from the model. All other parameters, including the TDS/depth profile, remained the same as the Base Case model. This simulation resulted in a lower bound estimate of inflow and TDS mass.
- Sensitivity Run #2: In this model simulation, the enhanced permeability zones were removed, but a conservative TDS/depth profile was used. The TDS concentrations in this profile are twice that used in the Base Case model. All other hydrogeologic parameters remain the same as those in the Base Case model.

Results of Model Sensitivity #1 indicate that groundwater inflows to the mines, if the enhanced permeability zones were not present, would be on average approximately 40% lower than predicted in the Base Case. Generally, predicted groundwater inflows in this sensitivity simulation are very close to those predicted in the Base Case when the pits are shallow and groundwater inflow occurs primarily through the till and exfoliated rock units; however, for the ultimate pit configurations predicted groundwater inflows are between 50% and 70% lower than in the base case predictions. Predicted groundwater quality in this simulation is generally somewhat less than that predicted for the base case.

Predicted TDS concentrations for Sensitivity Run #2 are, on average, 1.5 to 2 times greater than those predicted for the Base Case. However, because predicted groundwater inflow rates in this scenario are lower than those under the Base Case, the overall mass loading to the pits is similar between the two scenarios (i.e., Sensitivity Run #2 and the Base Case).

While considerable effort has been expended assessing the dynamics of pit dewatering, backfilling, and flooding, the assessments have simplified a highly complex and dynamic system and represent bounding conservative calculations that result in a high degree of confidence that effects on groundwater and the potential for changes in groundwater to affect surface waters have not been underestimated.

11.6.4.4 Monitoring and Follow-up

This section describes, in broad terms, the type of groundwater monitoring that will be implemented for the Project. Monitoring will occur at the onset of development to determine the response of the environment to the disturbance by mining. The hydrogeological conditions will be monitored for changes throughout each phase of the Project. Groundwater quality monitoring will mostly occur quarterly during the development of the first open pit, and is expected to be scaled down to an annual to semi-annual basis during development of the Hearne and Tuzo pits. Water level monitoring will mostly occur on a daily basis (tranducers and dataloggers will be installed for this purpose) during the development of the first open pit, and it is expected that the frequency of these measurements will be scaled down during development of the Hearme and Tuzo pits. Modifications to the monitoring interval will be based on a comparison of the monitored information to the predicted values. If the observed values or changes are less than predicted, then the intervals between monitoring events would likely be increased (i.e., less frequently sampled). If the observed values or changes are greater than predicted, then the interval between sampling events would likely be decreased (i.e., more frequently sampled).

Groundwater will be monitored using the two Westbay wells, which will remain following pit development. The other two Westbay wells (MPV-05-240C and MPV-05-239C) located within open pit development areas will also be monitored until their destruction during development of respective pits.

The monitoring program will focus on providing data required to update groundwater modelling results, specifically:

- to assess ongoing effects of pit development on groundwater movement and water quality;
- to predict long-term groundwater movement and water quality; and
- to provide details to the design team for adaptive management of groundwater flows and pit water quality.

During each phase of the Project, groundwater monitoring will include the following on a quarterly to annual basis:

- implementation of established quality assurance/quality control measures for data acquisition, groundwater sampling, and analysis;
- pressure measurements from ports at designated depths and respective water levels in the Westbay wells;
- collection of groundwater samples from ports in the Westbay wells;
- water sample analysis for main ions and other parameters of interest;
- review and compilation of relevant permafrost, soils quality, surface water quality and hydrology reports and information; and
- data and information assessment and completion of a groundwater monitoring report including recommendations for mine management team.

Potential for effects on groundwater quality from the mine rock piles, Coarse PK Pile, and the Fine PKC Facility will be evaluated using water quality monitoring results for perimeter collection systems. If unexpected results are observed, revisions to the groundwater monitoring program will be made.

The groundwater monitoring program described above is summarized below in Table 11.6-7.

Table 11.6-7 Summary of Monitoring Program for Groundwater

Monitored Feature	Type of Monitoring Program	Timing of Monitoring	Monitoring Results
Groundwater quantity and level	monitoring Westbay wells MPV-05-236C and MPV-05-238C	daily	groundwater pressure profiles with depth
Groundwater quantity and level	monitoring Westbay wells MPV-05-239C and MPV-05-240C	daily until destroyed by mining	groundwater pressure profiles with depth
Groundwater flow	pit flow meters	daily	water inflow measurements to the mine
Groundwater quality	monitoring Westbay wells and sampling of pit inflows	quarterly for wells and monthly for pit inflows	seasonal variations in groundwater quality in wells and characterization of pit inflows

11.6.5 References

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11.6.6 Acronyms and Glossary

11.6.6.1 Acronyms

AMEC	AMEC Earth & Environmental
De Beers	De Beers Canada Inc.
e.g.	for example
EIS	environmental impact statement
i.e.	that is
ICP/MS	Inductively Coupled Argon Plasma Atomic Emission Spectrometric Analysis/Mass Spectrometry
LSA	local study area
MDL	Method detection limit
MVEIRB	Mackenzie Valley Environmental Impact Review Board
MVRMA	*Mackenzie Valley Resource Management Act*
NTU	Neplelometric turbidity units
NWT	Northwest Territories
PK	processed kimberlite
PKC	processed kimberlite containment
Project	Gahcho Kué Project
SIMPTEMP	computer software for finite element temperature analysis
TDS	total dissolved solids
VC	valued component

11.6.6.2 Units of Measure

%	percent
°C	degrees Celsius
μg/L	micrograms per litre
kg/m^3	kilogram per cubic metre
km	kilometre
km/h	kilometre per hour
km^2	square kilometre
m	metre
m/m	metres/metre
m/s	metres per second
masl	metres above sea level
mg/L	milligrams per litre
mg/L/m	milligrams per litre per metre
$MJ/m^3/°C$	mega joules per cubic metre per degree Celsius
mm	millimetre

Mm^3	million cubic metres
mS/cm	millisiemens per centimetre
Mt	million tonnes
MW	mega watt
ppb	parts per billion
ppm	parts per million
W/m/°C	watts per metre per degree Celsius
W/m^2	watt per square metre
wt%	Weight percent
m-bgs	metres below ground surface

11.6.6.3 Glossary

Ablation till	Loose, permeable till deposited during the final down-wasting of glacial ice. Lenses of crudely sorted sand and gravel are common.
Active layer	The top layer of ground in permafrost region where temperature fluctuates above and below 0°C during the year.
Active layer	The layer of ground above the permafrost that thaws seasonally during the summer and refreezes in the fall.
Baseline	Background or reference; conditions prior to project development.
Batholith	A large generally discordant plutonic mass that has more than 40 100 km^2 of surface exposure and no known floor. Its formation is believed by most investigators to involve magmatic processes.
Bedrock	The solid rock (harder than 3 on Moh's scale of hardness) underlying soils and the regolith in depths ranging from zero (where exposed to erosion) to several hundred metres.
Berm	A wall of earth.
Blanket	A mantle of unconsolidated materials thick enough to mask minor irregularities in the underlying unit but which still conforms to the general underlying topography. As used in this report, a blanket is generally greater than 100 cm thick and has a surface form similar to a particular material's genesis.
Brecciated	Consisting of angular fragments cemented together; resembling breccia in appearance.
Brittle structure	Planar features, which have experienced displacement, such as faults and fractures zones.
Compacted snow	Snow that was compacted by special equipment to increase its density for traffic use at winter roads.
Contact zone	Zone where plutonic igneous rock intrude into country rock. Contact refers to the effect on country rocks of conductive or convective heat transfer.
Continuous permafrost	Permafrost occurring everywhere beneath the exposed land surface throughout a geographic region with the exception of widely scattered sites, such as newly deposited unconsolidated sediments, where the climate has just begun to impose its influence on the thermal regime of the ground, causing the development of continuous permafrost.

Continuous permafrost zone	The major subdivision of a permafrost region in which permafrost occurs everywhere beneath the exposed land surface with the exception of widely scattered sites.
Country rock	The surrounding rock.
Craton	Part of the earth's crust that has been stable and little deformed for a prolonged period of time.
Diabase	A dark coloured, fine to medium-grained igneous intrusive rock.
Diatreme	A diatreme is a breccia filled volcanic pipe that was formed by a gaseous explosion. Kimberlite volcanic pipes associated with diamond occurrences are usually considered to be volatile charged piercement structures or diatreme volcanic features from the lower crust or upper mantle.
Diatreme facies	Middle unit of 3 distinct units into which geologists have divided kimberlites, based on their morphology and petrology.
Diffusion	The movement of particles from an area of high concentration to an area of low concentration in a given volume of fluid (either liquid or gas) down the concentration gradient.
Diffusion Coefficient	The mathematical coefficient that controls the rate of diffusion for a particular ion. In dilute aqueous solutions the diffusion coefficients of most ions are similar and have values at room temperature in the range of 0.6×10^{-9} to 2×10^{9} m^2/s.
Discharge	The volumetric rate of flow of water in a watercourse at a specified point, expressed in units of m^3/s or equivalent.
Discontinuous permafrost	Permafrost occurring in some areas beneath the exposed land surface throughout a geographic region where other areas are free of permafrost. Discontinuous permafrost occurs between the continuous permafrost zone and the southern latitudinal limit of permafrost in lowlands. Depending on the scale of mapping, several subzones can often be distinguished, based on the percentage of the land surface underlain by permafrost. Terms used are: extensive - 65 to 90%; intermediate - 35 to 65%; sporadic - 10 to 35%; and, isolated patches - 0 to 10%.
Dyke	An embankment built to hold semi-solids or fluids.
Earth processes	Processes that build and shape the ground surface.
Electrical conductivity	The ability of water to conduct an electric current per unit area divided by the voltage drop per unit length. Commonly used as an index of salinity, and usually measured as decisiemens per metre.
Eskers	Long, narrow bodies of sand and gravel deposited by a subglacial stream running between ice walls or in an ice tunnel, left behind after melting of the ice of a retreating glacier.
Eskers	An Esker is a long, winding ridge of stratified sand and gravel believed to form in ice-walled tunnels by streams which flowed within and under glaciers.
Flow rate	The time required for a volume of groundwater to move between points. Typically groundwater moves very slowly - sometimes as little as centimetres per year.
Freezing rate	Speed of advancing below 0 oC temperature into ground.
Frost cracking	This occurs when the frozen ground reaches very low temperatures. At low temperatures, frozen ground contracts, splitting up to form a pattern of polygonal cracks.
Gabbroid	Adjective used for gabbro containing rocks. Gabbro is an intrusive igneous rock that develops from mafic magma and whose mineral crystals are coarse.
Geotechnical	Pertaining to earth or rock structures and their properties.

Geothermal flow path	This is a synonym for heat flux defined as a flow of energy per unit of area per unit of time.
Glacial Veneer	Glacial sediments, under 1 m thick, overlying bedrock.
Glaciofluvial (or Glacio-Fluvial)	Sediments or landforms produced by melt waters originating from glaciers or ice sheets. Glaciofluvial deposits commonly contain rounded cobbles arranged in bedded layers.
Glaciolacustrine (or Glacio-Lacustrine)	Sediments that were deposited in lakes that formed at the edge of glaciers when the glaciers receded. Glaciolacustrine sediments are commonly laminar deposits of fine sand, silt and clay.
Gneiss	A coarse crystalline metamorphic rock in which there are bands of light and dark minerals of widely varying origin and mineralogy.
Granite	A coarsely crystalline igneous intrusive rock composed of quartz, potassium feldspar, mica, and/or hornblende.
Granitic gneiss	A coarsely crystalline metamorphic rock composed of bands of grey or pink feldspar and white to grey quartz, alternating with bands of black minerals, chiefly biotite mica and hornblende. The overall composition is similar to granite.
Granitoid	Rocks with a composition the same as, or similar to granite.
Groundwater	Water within interconnected pore spaces of the subsurface within the saturated zone below the water table.
Groundwater flow	The movement of water through interconnected voids in the phreatic zone.
Heat Flux	Amount of heat to be transferred at a unit of time through a unit area.
Hydraulic conductivity	A parameter that describes the rate at which water can move through a permeable medium and is dependent on the characteristics of the medium.
Hydraulic gradient	The difference in piezometric level or hydraulic head between two points over a change in distance in the direction, which yields the greatest change in hydraulic head.
Hydraulic head	The level to which water will rise if a standpipe is installed.
Hydrogeology	The scientific study of occurrence and flow of groundwater and its effects on earth materials.
Hydrology	Science that deals with the waters above the land surfaces of the Earth, their occurrence, circulation and distribution, both in time and space, their biological, chemical and physical properties, their reaction with their environment, including their relation to living beings.
Ice Lenses	Small ice bodies, usually several centimetres thick, in frozen soils
Ice wedge	A massive, generally wedge-shaped body with its apex pointing downward, composed of foliated or vertically banded, commonly white, ice.
Kimberlite	Igneous rocks that originate deep in the mantle, and intrude the earth's crust. These rocks typically form narrow pipelike deposits that sometimes contain diamonds.
Kimberlite diatreme	Kimberlite diatremes are 1 to 2 kilometres deep, generally carrot-shaped bodies which are circular to elliptical at surface and taper with depth. The dip contact with the host rocks is usually 80-85 degrees. The zone is characterized by fragmented volcaniclastic kimberlitic material and xenoliths plucked from various levels in the Earths crust during the kimberlites journey to surface.
Mafic	A term to describe minerals that contain in iron and magnesium.
Mean	Arithmetic average value in a distribution.
Mean annual soil temperature	The mean annual soil temperature is a temperature at some depth from the ground surface, where no considerable seasonal fluctuations of the temperature are observed.

Metasediments	Sedimentary rocks that have been modified by metamorphic processes.
Mud boil	A process related to frost cracking, followed by freezing of the active layer downward from the ground surface, perpendicular to the frost cracks, and upward from the active layer base.
Overburden	The soil, sand, silt or clay that overlies a mineral deposit and must be removed before mining (material below the soil profile and above the bituminous sand).
Parameter	A particular physical, chemical, or biological property that is being measured in a groundwater system; whatever it is you measure in a groundwater system.
Peat bogs	Peat layer, over 1 m thick, overlying mineral soil***
Peat Veneers	Peat layer, under 1 m thick, overlying mineral soil
Pegmatite	An exceptionally coarse-grained igneous rock, with interlocking crystals, usually found as irregular dykes, lenses, or veins, especially at the margins of batholiths.
Pegmatitic	Adjective used to describe pegmatite containing rock.
Permafrost	Soil or rock having temperatures below 0°C during at least two consecutive winters and intervening summer.
Permafrost	A freezing condition in bedrock or soil that persists over two or more winters.
Permafrost conditions	A general term, summarizing permafrost parameters within given area.
Permafrost regime	A general term, summarizing thermal parameters of permafrost, including its aggradation/degradation, temperature gradient, and mean annual temperature.
Permafrost stability	Capacity frozen soils for a structure support or the strength to withstand development of earth processes.
Permafrost thickness	Thickness of frozen soils from elevation of the ground surface down to elevation of zero soil temperature.
Phreatic zone	The soil or rock zone below the level of the water-table, where all voids are saturated.
Piezometer	A standpipe placed in the ground to measure water levels.
Piezometric level	The level to which water will rise if a standpipe is installed.
Polygon landscape	Ground surface pattern as a result of frost cracking.
Porewater	Water between the grains of a soil or rock.
Seasonal frost penetration	Depth of the winter freezing within areas of the unfrozen ground spread.
Slope instability	The problem occurs where either soil or rock move downslope in response to gravity.
Software	A set of instructions to program a computer or other ‘smart’ device.
Spatial	Aerial extent.
Stone channel	Snow meltwater and runoff washed out the soil matrix, leaving a stony material (cobbles, boulders, and rock fragments) in form of channel.
Subject of Note	Issues that require serious attention and substantive analysis (as defined by the Terms of Reference (Gahcho Kué Panel 2007)
Subsoil	In geotechnical science. The most upper soil layer with organic debris and plant roots, usually less than 0.5 m thick.
Talik	A layer or body of unfrozen ground occurring in a permafrost area due to a local anomaly in thermal, hydrological, hydrogeological, or hydrochemical conditions.
Talik	Layer or body of unfrozen ground within permafrost.

Temporal	Through time.
Thermal conditions	A synonym term for temperature conditions.
Thermal properties	Soil properties responsible for heat transfer (heat capacity and thermal conductivity).
Thermistor	A device whose electrical resistance, or ability to conduct electricity, is controlled by temperature.
Thermistor string	A cable with thermistors used for temperature measurements.
Thermo-erosion	The combined thermal and mechanical activity of running water in permafrost areas, resulting in formation of gullies and ravines.
Thermokarst	A variety of surface features resulting from the differential melting of ground ice in permafrost.
Till	Till is an unsorted glacial sediment. Glacial drift is a general term for the coarsely graded and extremely heterogeneous sediments of glacial origin. Glacial till is that part of glacial drift which was deposited directly by the glacier. It may vary from clays to mixtures of clay, sand, gravel and boulders.
Ultramafic	Igneous rocks that consist mainly of mafic minerals and low amounts of silica.
Valued Component	Represent physical, biological, cultural, and economic properties of the social-ecological system that are considered to be important by society and that represent assessment endpoints.
Mine Rock	Excavated bed rock surrounding the kimberlite deposits. Mine rock consists primarily of granitic rock material. It is also sometimes referred to as country rock or waste rock.
Winter ice road	Roads which are built over frozen lakes and tundra. Compacted snow and/or ice is used for embankment construction.
Xenolith	A rock fragment which becomes enveloped in a larger rock during the latter's development and hardening. In geology, the term xenolith is almost exclusively used to describe inclusions in igneous rock during magma emplacement and eruption. Xenoliths may be engulfed along the margins of a magma chamber, torn loose from the walls of an erupting lava conduit or explosive diatreme or picked up along the base of a flowing lava on earth's surface.
Year (e.g., Year 10)**	Refers to the year of the Project from the beginning of operation (i.e., Year 1 is the first year of operation). There is one year of pre-mining construction activity that is referred to as Year 0.

APPENDIX 11.6.I

HYDROGEOLOGICAL MODELS
PRE-MINING, DURING MINING AND CLOSURE

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11.6.I.1 INTRODUCTION

This appendix presents the development and results of a model study that was completed to assess the groundwater regime before and during mining in the vicinity of the planned mines at the Gahcho Kué Project (the Project). The objective of the model simulations was to predict groundwater inflow quantity and quality to the three planned open pit mines at the Project. This model was developed in 2010 and incorporates the mine plan described in the project description Section 3).

During mining, the open pits will act as sinks for groundwater flow and water originating from both from Kennady Lake and from deep bedrock will be induced to flow through the bedrock and enhanced permeability zones to the open pits. The average quality of mine inflow will be a result of mixing of fresh groundwater flowing from Kennady Lake and brackish water flowing up from deep bedrock.

The intent of the modelling study outlined herein was to estimate the groundwater inflow quantity and quality to the mines over the mine life and during refilling of the three planned open pit mines. The results of this study are relevant to the following subject of note and key lines of inquiry:

- Permafrost, Groundwater and Hydrogeology (Section 11.6);
- Water Quality and Fish in Kennady Lake (Section 8)

11.6.I.2 CONCEPTUAL HYDROGEOLOGICAL MODELS

Conceptual hydrogeological models were developed to aid in the construction of the numerical hydrogeological model. A conceptual hydrogeological model is a pictorial and descriptive representation of the groundwater regime that organizes and simplifies the site conditions so it can be modelled. It must retain sufficient complexity, so that the numerical model developed from it adequately reproduces or simulates the actual components of the groundwater flow system to the degree necessary to satisfy the objectives of the modelling study. Figures 11.6-9, 11.6-10, 11.6-11 included in Subject of Note: Permafrost, Groundwater and Hydrogeology (SON 11.6), and 11.6.I-1 to 11.6.I-3 included in this appendix present the conceptual models developed to describe key features of the hydrogeological regime near the Project site, before and during mining. The key features include the hydrostratigraphy, groundwater quality and dominant groundwater flow direction, all of which are described in more detail below.

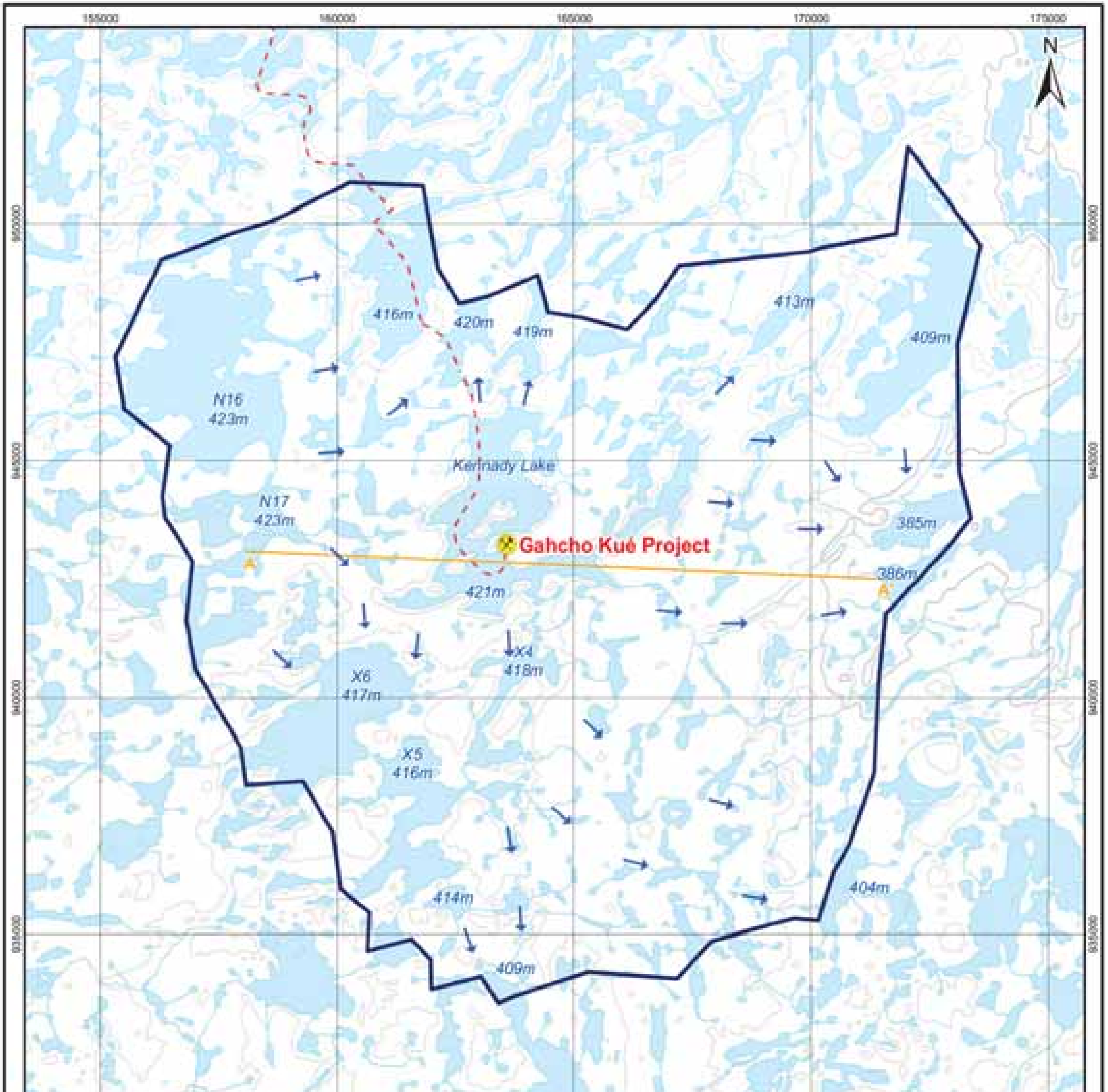
11.6.I.2.1 HYDROSTRATIGRAPHY

The conceptual hydrostratigraphy model for the site consists of six hydrostratigraphic units composed of till, shallow exfoliated rock, deep competent rock, kimberlite, kimberlite contact zone, and enhanced permeability zones associated with sub-vertical faults (Figures 11.6-9 and 11.6-10 included in SON 11.6). This conceptual model is described in detail in section 11.6.2.2.3 of SON 11.6.

In developing the conceptual model of hydrostratigraphy for the site a reasonably conservative approach was undertaken so that the actual groundwater inflows (both quantity and quality) to the open pits will be less than or equal to those values predicted by the numerical hydrogeological model. Where uncertainty in parameter values exists, reasonable upper bound values of hydraulic conductivities have been selected.

11.6.I.2.2 VARIATION IN TOTAL DISSOLVED SOLIDS LEVELS WITH DEPTH

Permafrost in the Local Study Area (LSA) extends to a depth of about 300 m below ground level (mbgl) in areas outside the influence of lakes or taliks, which can be considered as a typical permafrost thickness corresponding to permafrost formation in the Project area's climate condition (Brown 1970). In the region beneath continuous permafrost, groundwater mineralization with depth in the Canadian Shield is expected to approximate the regional relationship developed by Fritz and Frape (1987) and shown in Figure 11.6-11 included in SON 11.6.



LEGEND

- Gahcho Kué Project
- Contour (20m interval)
- Watercourse
- Winter Access Road
- Waterbody
- Conceptual Cross Section
- Inferred Groundwater Flow Direction Beneath Permafrost
- Local Study Area

NOTES

Base data source: The Atlas of Canada
Elevations shown are approximate (+/- 1m).
Lakes labelled with elevations are assumed to have open taliks. Lake elevations were derived from National Topographic Base Data (NTDB) 1:50,000 data and LiDAR data provided by the client.

GAHCHO KUÉ PROJECT

Conceptual Model of Groundwater Flow in the Kennady Lake Area - Pre-Mining

PROJECTION:	DATUM:
Canadian Lambert Conf. Conic	NAD83

Scale: 1:120,000

2 1 0 2

Kilometres

DE BEERS CANADA

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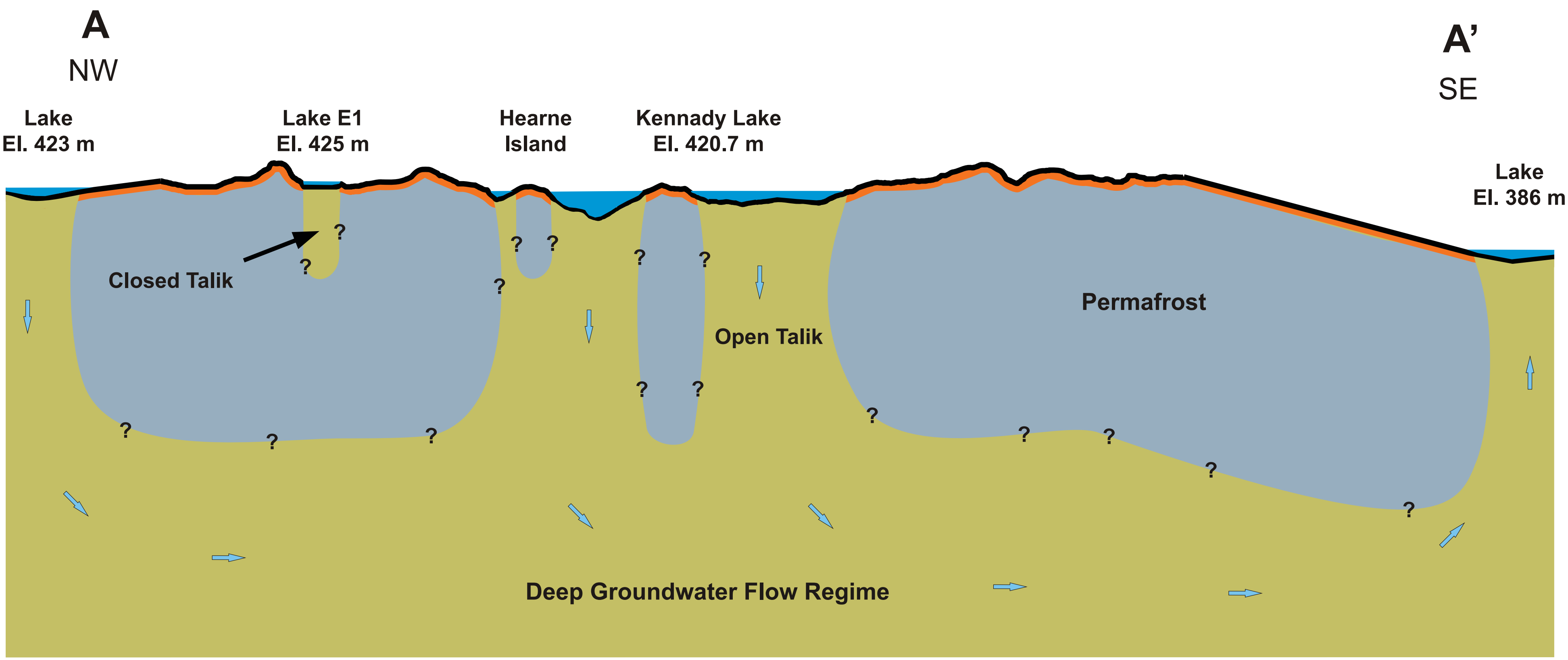

LEGEND

- Active Layer (Shallow Groundwater Flow Regime)
- Ground Surface
- Inferred Groundwater Flow Direction
- Deep Groundwater Flow Regime
- Permafrost

Schematic Only
Approximate vertical exaggeration of 1:8

GACHO KUÉ PROJECT

Conceptual Model of Groundwater Flow – Cross-Section View Pre-Mining

PROJECTION: N/A	DATUM: N/A	DE BEERS CANADA
SCALE: NOT TO SCALE		
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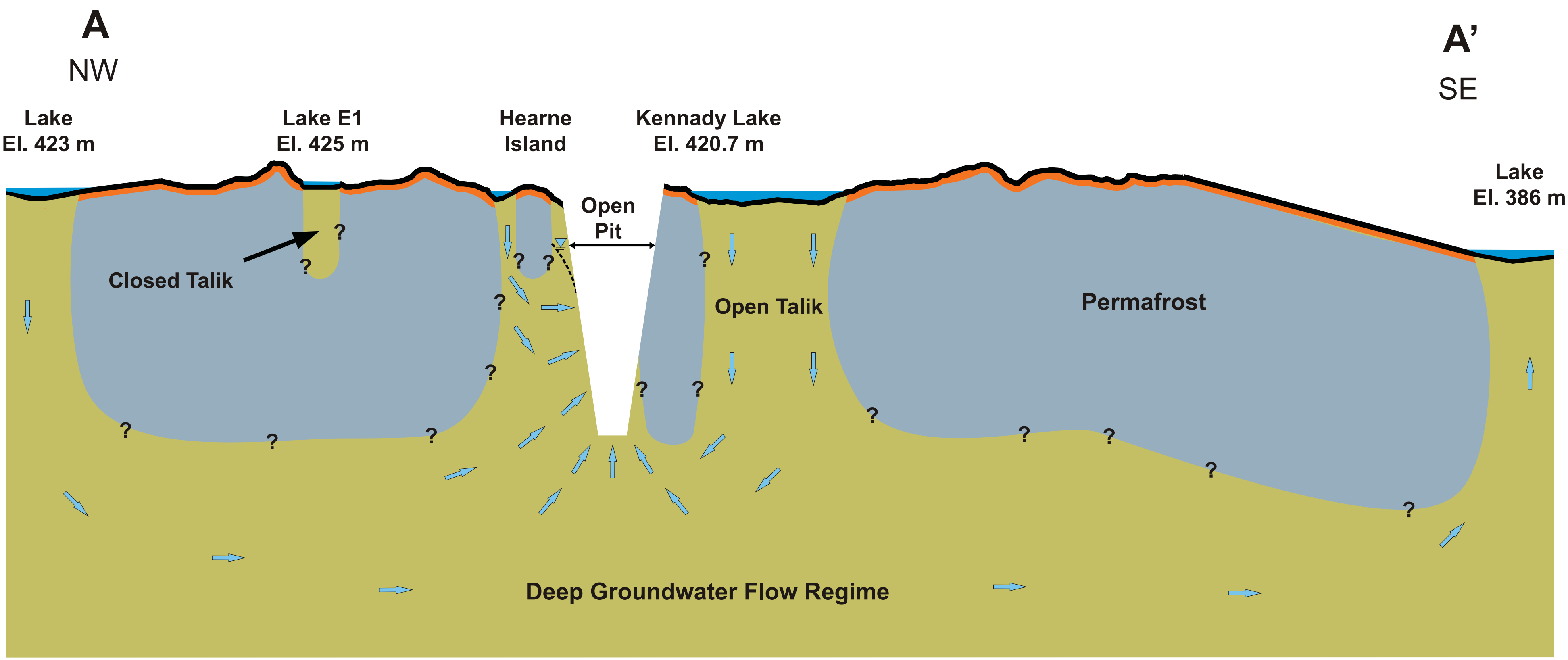

LEGEND

Active Layer (Shallow Groundwater Flow Regime)

Ground Surface

Inferred Groundwater Flow Direction

Water Table

Deep Groundwater Flow Regime

Permafrost

Schematic Only
Approximate vertical exaggeration of 1:8

GACHO KUÉ PROJECT

Conceptual Model of Groundwater Flow – Cross-Section View Mining

PROJECTION: N/A
DATUM: N/A
SCALE: NOT TO SCALE

DE BEERS CANADA

FILE No: SON-11.6-012-CAD
DATE: September 29, 2010
JOB No: 09-1365-1004
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Figure 11.6.I-3

Despite some variability, the total dissolved solids (TDS) values of groundwater samples collected at the Project Site are generally consistent with the TDS of groundwater observed at other sites in the Canadian Shield (Figure 11.6-11). The Project TDS versus depth profile was developed based on a best fit to the TDS of groundwater samples at the site to the maximum depth of site-specific data (450 mbgl). Below this depth, the profile was assumed to follow the Fritz and Frape profile (Fritz and Frape 1987), which is the most conservative profile of TDS with depth for data collected in the Canadian Shield.

11.6.I.2.3 GROUNDWATER FLOW PRE-MINING

In areas of continuous permafrost, there are generally two groundwater flow regimes; a deep groundwater flow regime beneath permafrost and a shallow groundwater flow regime located in the active (seasonally thawed) layer near the ground surface. Because of the thick, low permeability permafrost, there is generally little to no hydraulic connection between the two flow regimes.

Taliks (unfrozen ground surrounded by permafrost) exist beneath lakes that have sufficient depth such that they do not freeze to the bottom over the winter. Taliks beneath larger lakes can extend down to the deep groundwater regime. Consequently, recharge to the deep groundwater flow regime is predominantly limited to areas of taliks beneath large, surface waterbodies. Generally, deep groundwater will flow from higher elevation lakes to lower elevation lakes. To a lesser degree, groundwater beneath the permafrost is influenced by density differences due to the upward diffusion of deep-seated brines (density-driven flow).

Lakes expected to have open taliks extending to the deep groundwater flow system and their respective elevations are identified in Figure 11.6.I-1. Flow directions in the deep groundwater flow regime were inferred from the elevations of these lakes and are also presented in Figures 11.6.I-1, and 11.6.I-2. The elevations of these lakes indicate that the groundwater flow direction in the deep groundwater flow regime in the area of Kennady Lake is generally to the south and east.

These groundwater flow directions were inferred assuming that open taliks exist beneath the larger lakes identified in Figure 11.6.I-1. It was also assumed that on the regional scale, the hydraulic conductivity of the bedrock beneath the permafrost is relatively homogeneous and isotropic.

11.6.I.2.4 GROUNDWATER FLOW DURING MINING

During mining, the open pits will act as sinks for groundwater flow (Figure 11.6.I-3). Seepage faces are anticipated on the pit walls. Water will be induced to flow through the bedrock and enhanced permeability zones to the open pits. Water reporting to mines will originate both from Kennady Lake and from deep bedrock. The average quality of mine inflow will be a result of mixing of fresh groundwater flowing from Kennady Lake and brackish water flowing from deep bedrock.

11.6.I.3 NUMERICAL HYDROGEOLOGICAL MODEL

A numerical hydrogeologic model was constructed based on the conceptual hydrogeologic models outlined above. The purpose of the numerical model was to evaluate baseline hydrogeologic conditions prior to mining and to estimate the quantity and quality of potential inflows to the open pit mines during the operational life of the Project.

11.6.I.3.1 MODEL SELECTION

The numerical model for the Project was constructed using MODFLOW/MT3D model codes. MODFLOW is a finite difference code, developed by the United States Geological Survey (McDonald and Harbaugh 1988), to simulate transient groundwater flow in three-dimensions in a continuous porous medium. MT3DMS is a MODFLOW companion model code developed for the United States Environmental Protection Agency (Zheng and Wang 1998), which is capable of simulating three-dimensional, transient transport of dissolved chemicals in groundwater, using the grid and hydraulic heads calculated by MODFLOW.

Table 11.6.I-1 provides an overall summary of the assumptions and limitations of the numerical modelling outlined herein, including those associated with the underlying modelling codes.

Table 11.6.I-1 Assumptions and Limitations of the Groundwater Model

Groundwater flow in the bedrock was simulated as an “equivalent porous media”. Flow in bedrock is assumed to be laminar, steady and governed by Darcy’s Law.
Horizontal and vertical mesh discretization of approximately 30 m was used to provide sufficient spatial resolution for simulation of groundwater flow and transport near the open pits.[a]
Values assigned to model input parameters were based on the results of permeability testing and, where testing results were not available, on values published in the literature.
Surface waterbodies were simulated using specified head boundaries. It was assumed that the permeability of sediments beneath these waterbodies is similar to the underlying geologic strata. Thus, no restriction of flow between the surface water and individual hydrostratigraphic units was simulated.
Groundwater flow deeper than about 1.5 km below ground level (km bgl) was assumed to be negligible and to have negligible influence on model predictions.

(a) Elements were expanded to a size of about 300 m approximately 1 km away from the open pits.

m = metres; km = kilometres; bgl = below ground level

11.6.I.3.2 MODEL EXTENT AND GRID CONFIGURATION

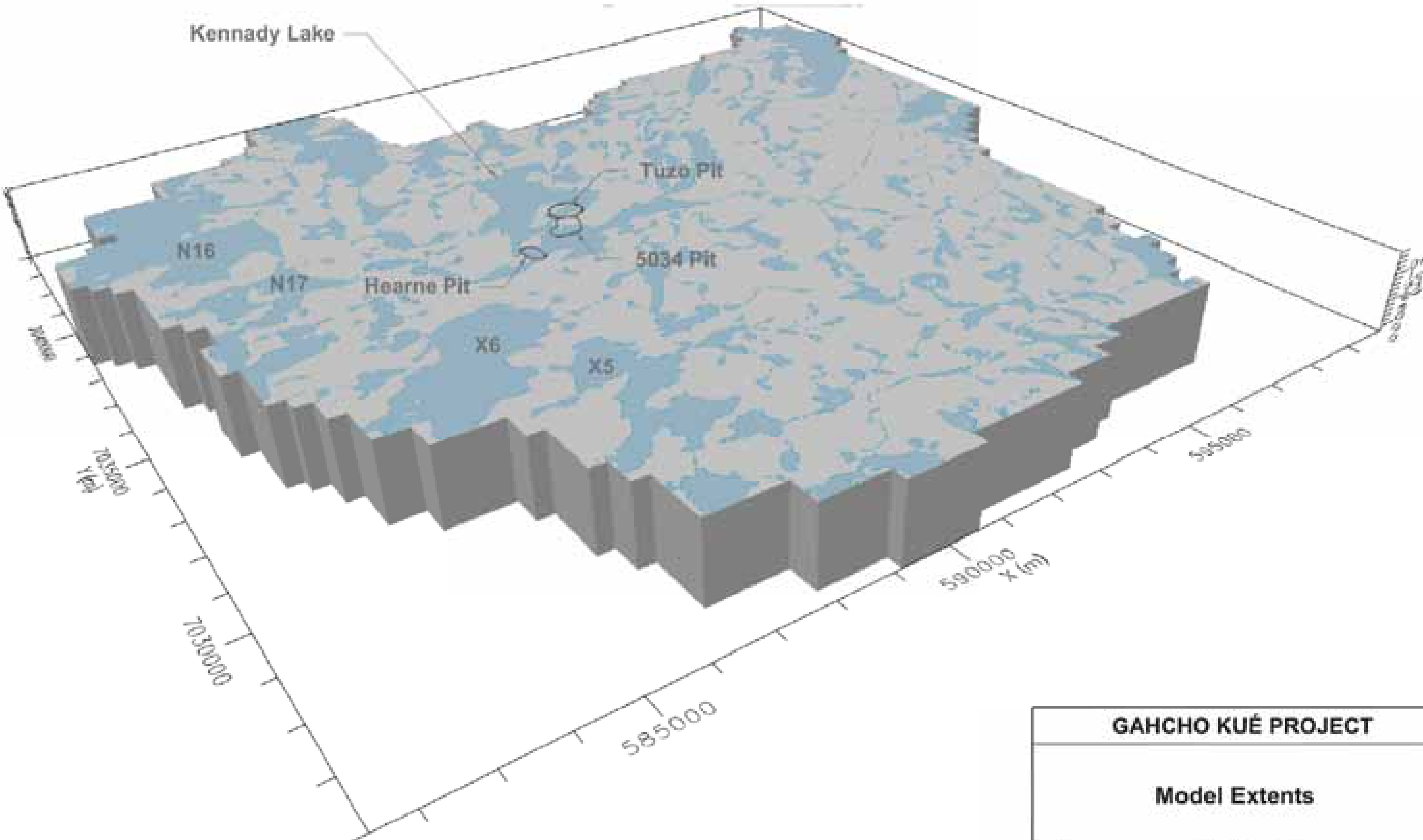
The extent of the numerical model were based on an understanding of groundwater flow conditions near the Project site, with lateral model boundaries set sufficiently far from the Project to allow adequate representation of pre-development conditions and potential seepage pathways during operation. The extent of the model and grid are presented in Figures 11.6.I-4 and 11.6.I-5.

Horizontally, the model extends approximately 18 kilometres (km) in both the east-west and north-south directions and is roughly centred on Kennady Lake. The mesh consists of about 800,000 elements, with a uniform spacing of about 30 m in the area of the open pits where strong hydraulic gradients are expected to develop during operation. Elements were expanded to a size of about 300 m approximately 1 km away from the open pits.

Vertically, the model domain is discretized into 24 layers. The top of Layer 1 was set equal to the elevation of Kennady Lake. The bottom of Layer 24 was set to a constant elevation about 1.5 km bgl, which is more than 1 km below the ultimate depth of the planned open pits.

11.6.I.3.3 HYDROSTRATIGRAPHY AND MODEL PARAMETERS

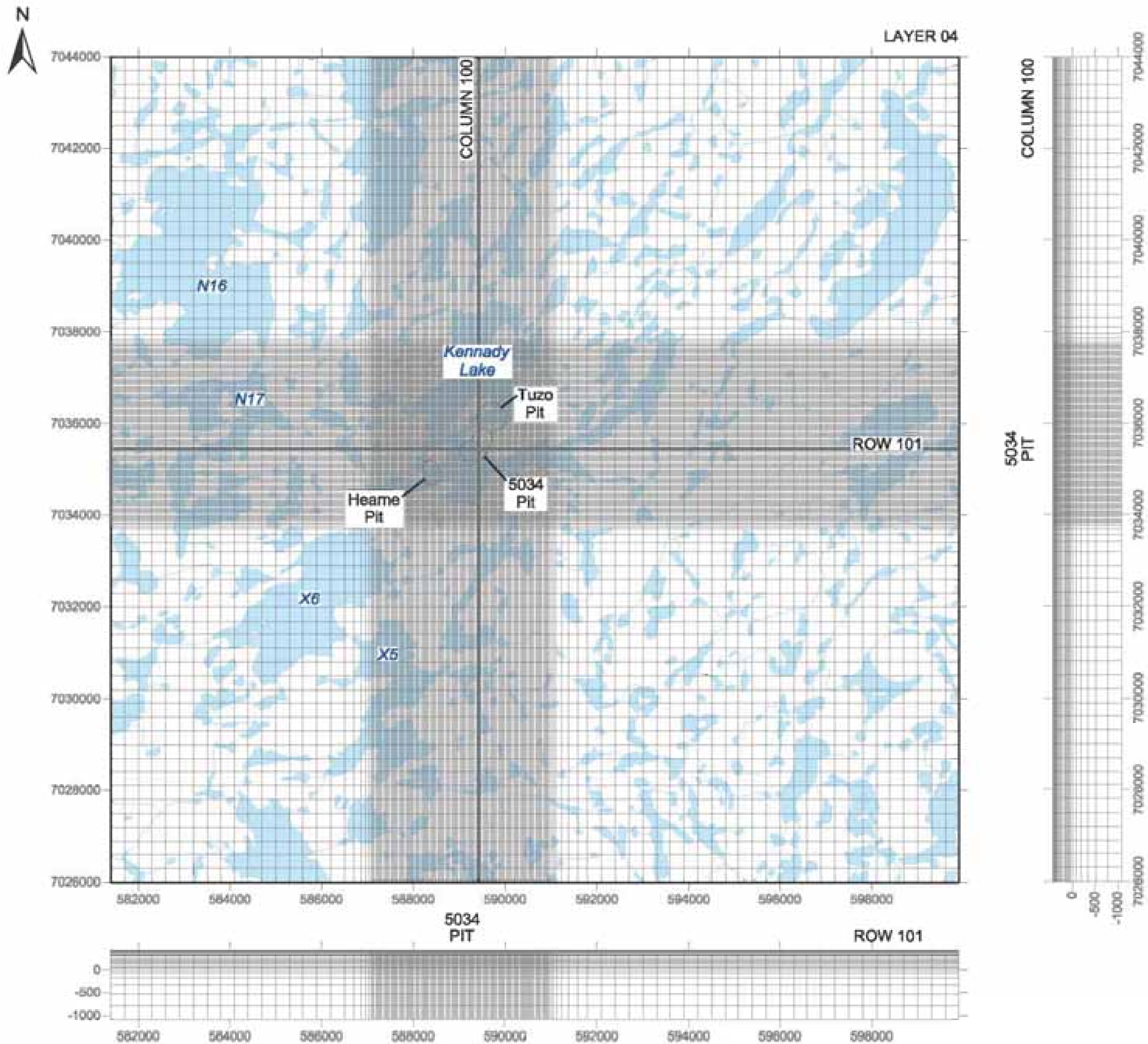
Six hydrostratigraphic units consisting of till, shallow exfoliated bedrock, competent rock, kimberlite, a kimberlite contact zone, and enhanced permeability zones associated with sub-vertical faults were represented in the model (Figure 11.6.I-6). Table 11.6.I-2 provides a summary of the hydrogeologic properties of each unit. This information was obtained from in-situ hydrogeologic testing, where available, and published scientific literature.



GAHCHO KUÉ PROJECT

Model Extents

PROJECTION: N/A		DATUM: N/A	DE BEERS CANADA	
SCALE: NOT TO SCALE				
FILE No: SON-11.6.008-CAD.dwg			DATE: September 28, 2010	
JOB No: 09-1365-1004	REVISION No: 0		**Figure 11.6.I-4**	
OFFICE: GOLD - CGY	DRAWN: JEF	CHECK: DC		



LEGEND

Water Course

Water Body

NOTES

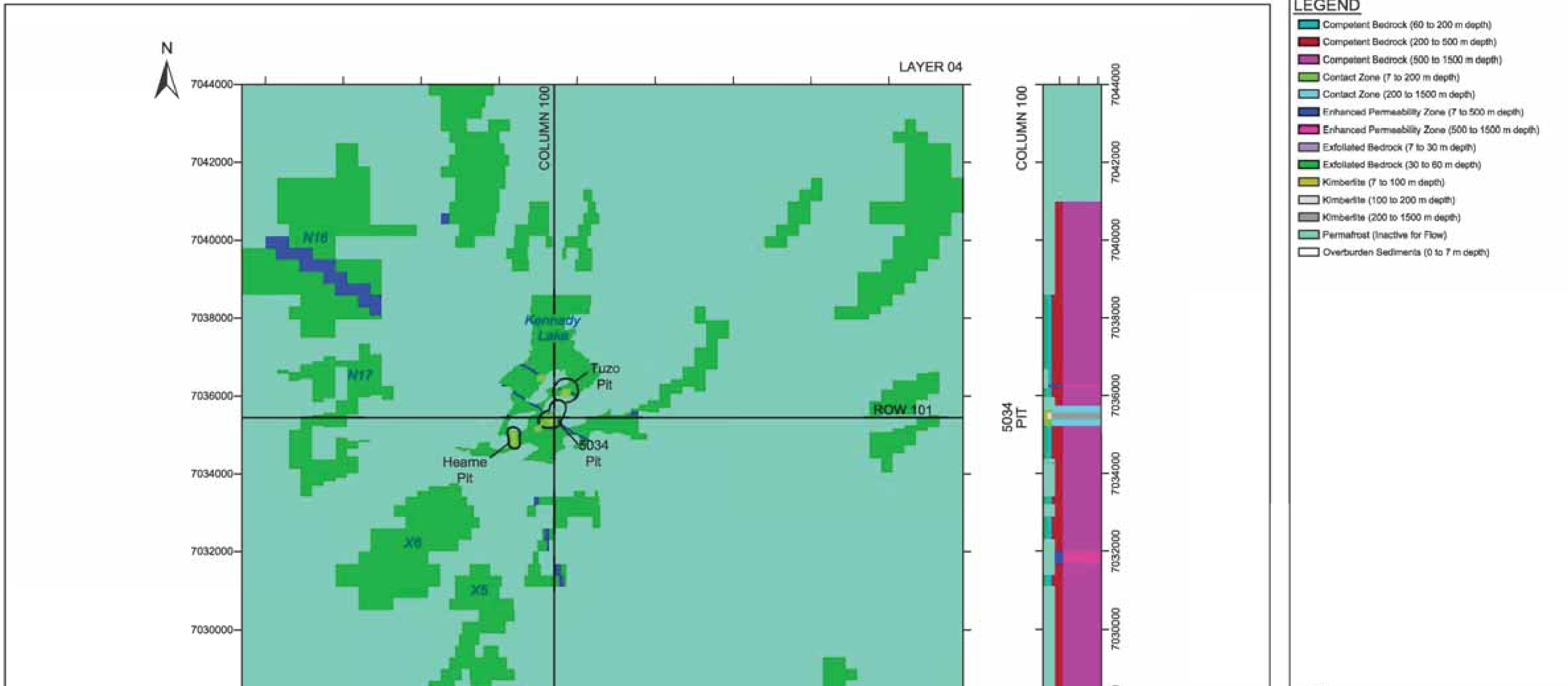
Base Data source: National Topographic Base Data (NTDB) 1:250,000.

All distances in metres.

GAHCHO KUÉ PROJECT

Model Grid

PROJECTION: UTM Zone 12	DATUM: NAD83		
SCALE 2 0 2 KILOMETRES			DE BEERS CANADA
FILE No: BON-11.6-001-CAD			DATE: August 20, 2010
JOB No: 09-1365-1004	REVISION No: 0		Figure 11.6.I-5
OFFICE: GOLD - CAL	DRAWN: RFM	CHECK: DC	



NOTES
Base Data source: National Topographic Base Data (NTDB) 1:250,000.
All distances in metres.

GAHCHO KUÉ PROJECT

Location and Extent of Hydrostratigraphic Units

PROJECTION: UTM Zone 12 | DATUM: NAD83

SCALE 2 0 2 KILOMETRES

DE BEERS CANADA

FILE No: SON-11.6-002-CAD | DATE: August 20, 2010

JOB No: 09-1365-1004 | REVISION No: 0

OFFICE: GOLD - CAL | DRAWN: KJM | CHECK: DC

Figure 11.6.I-6

Table 11.6.I-2 Model Input Parameters

Hydrostratigraphic Unit	Depth Interval (m)	Horizontal Hydraulic Conductivity (m/s)[a]	Ratio of Vertical to Horizontal Hydraulic Conductivity	Specific Storage (1/m)[b]	Specific Yield (-)[b,c]	Effective Porosity (-)[b,c]	Longitudinal Dispersivity (m)[d]	Transverse Dispersivity (m)[d]	Effective Diffusion Coefficient (m^2/s)[e]
Till	0 to 7	$2.E^{-05}$	1:1	$1.E^{-04}$	0.15	0.15	10	1	$2.E^{-10}$
Exfoliated Bedrock	7 to 30	$6.E^{-06}$	1:10	$1.E^{-05}$	0.01	0.01	10	1	$2.E^{-10}$
	30 to 60	$5.E^{-07}$	1:5	$1.E^{-05}$	0.01	0.01	10	1	$2.E^{-10}$
Bedrock	60 to 200	$6.E^{-08}$	1:1	$1.E^{-06}$	0.003	0.003	10	1	$2.E^{-10}$
	200 to 500	$2.E^{-08}$	1:1	$1.E^{-06}$	0.003	0.003	10	1	$2.E^{-10}$
	500 to 1,500	$1.E^{-08}$	1:1	$1.E^{-06}$	0.003	0.003	10	1	$2.E^{-10}$
Kimberlite	7 to 100	$3.E^{-06}$	1:1	$1.E^{-04}$	0.01	0.1	10	1	$2.E^{-10}$
	100 to 200	$9.E^{-08}$	1:1	$1.E^{-04}$	0.01	0.1	10	1	$2.E^{-10}$
	200 to 1,500	$3.E^{-09}$	1:1	$1.E^{-05}$	0.005	0.05	10	1	$2.E^{-10}$
Contact Zone	60 to 200	$3.E^{-06}$	1:1	$1.E^{-05}$	0.01	0.01	10	1	$2.E^{-10}$
	200 to 1,500	$2.E^{-07}$	1:1	$1.E^{-05}$	0.01	0.01	10	1	$2.E^{-10}$
Fault Zone	60 to 500	$3.E^{-06}$	1:1	$1.E^{-05}$	0.01	0.01	10	1	$2.E^{-10}$
	500 to 1,500	$3.E^{-07}$	1:1	$1.E^{-05}$	0.01	0.01	10	1	$2.E^{-10}$

(a) In-situ testing.

(b) Maidment (1992).

(c) Stober and Bucher (2007), except for kimberlite Golder (1999).

(d) Schulze-Makuch (2005).

(e) Davison et al. (1994).

m = metres; m/s = metres per second; 1/m = 1/metres; m^2/s = square metres per second (-) = unitless.

11.6.I.3.4 MODEL BOUNDARIES

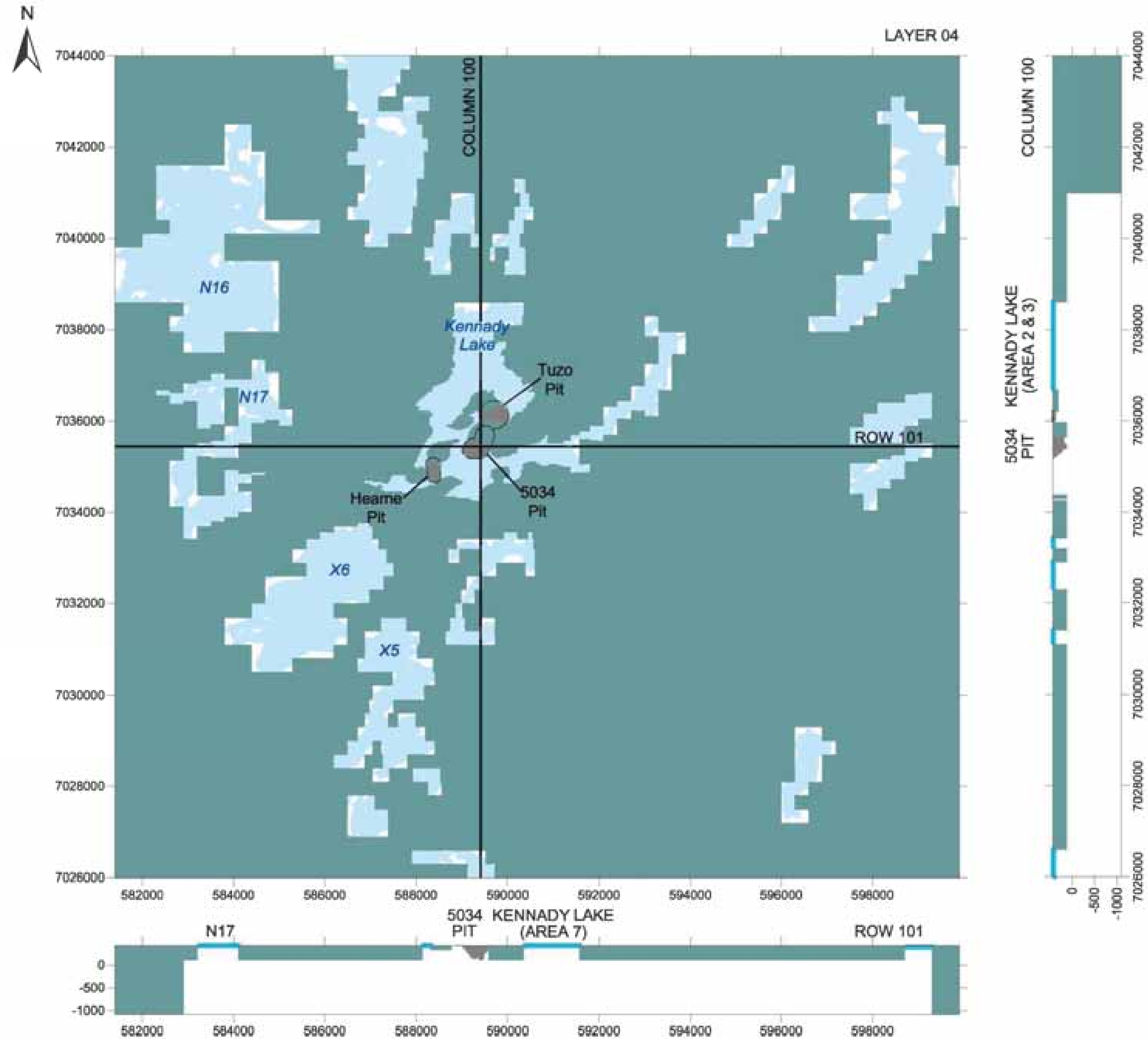
Flow Boundaries

Three types of boundary conditions were used in the model: specified head, no-flow and head-dependent boundaries. These boundary conditions are illustrated in Figure 11.6.I-7 and summarized below.

Specified head boundaries were assigned to Layer 1 of the model to represent all lakes assumed to have open taliks connected to the deep groundwater flow regime. Each of these boundaries was set to the surveyed lake elevation shown in Figure 11.6.I-1.

A no-flow boundary was applied along the bottom of the model at a depth of 1.5 km bgl and along the outermost rows and columns in Layers 15 to 24. The effect of the no-flow boundaries along the outermost rows and columns was investigated in an alternate simulation where these boundaries were replaced with specified head boundaries with elevation based on the pre-mining flow field. These boundaries were found to have negligible impact on predicted groundwater inflows to the open pits. No-flow boundaries were also assigned along the edges of permafrost as the permafrost is expected to be relatively impermeable.

Head-dependent boundaries constrained to inflow only were used to simulate the open pits. At model cells that are assigned head-dependent boundaries, the flow into the boundary is proportional to the hydraulic head calculated at each individual cell and the specified elevation of the boundary assigned to that cell, with the flow rate controlled by the conductance. If the hydraulic head in the cell is less than the specified elevation of the boundary assigned to the cell, the cell becomes a no-flow boundary during the simulation. Head dependent boundaries were assigned to cells corresponding to the outlines of the open pits. During the simulation of the mine schedule, these boundaries were adjusted automatically to reflect changes in the excavation of the pit over time.



LEGEND

- Head Dependent Boundary
- Permafrost (Inactive for Flow)
- Specified Head Boundary
- Water Body

NOTES

Base Data source: National Topographic Base Data (NTDB) 1:250,000.
All distances in metres.

GAHCHO KUÉ PROJECT

Boundary Conditions - Groundwater Flow

PROJECTION: UTM Zone 12	DATUM: NAD83
SCALE: 2 0 2 KILOMETRES	DE BEERS CANADA
FILE No: SON-11.6-003-CAD	DATE: August 20, 2010
JOB No: 09-1365-1004	REVISION No: 0
OFFICE: GOLD - CAL	DRAWN: KJM
CHECK: DC	Figure 11.6.I-7

Transport Boundaries and Initial Conditions

Initial TDS concentrations in each model layer were assigned based on the assumed TDS depth profile shown in Figure 11.6-11 (SON 11.6), with the exception of Layer 1. Layer 1 was used to represent the shallow till to seven metres depth. Groundwater in the till is assumed to be relatively fresh and to have the TDS concentration equivalent to lake water. To minimize errors due to numerical dispersion, transport simulations were run on a subset of the flow model domain where the model grid was uniform and grid cells were all 30 m by 30 m.

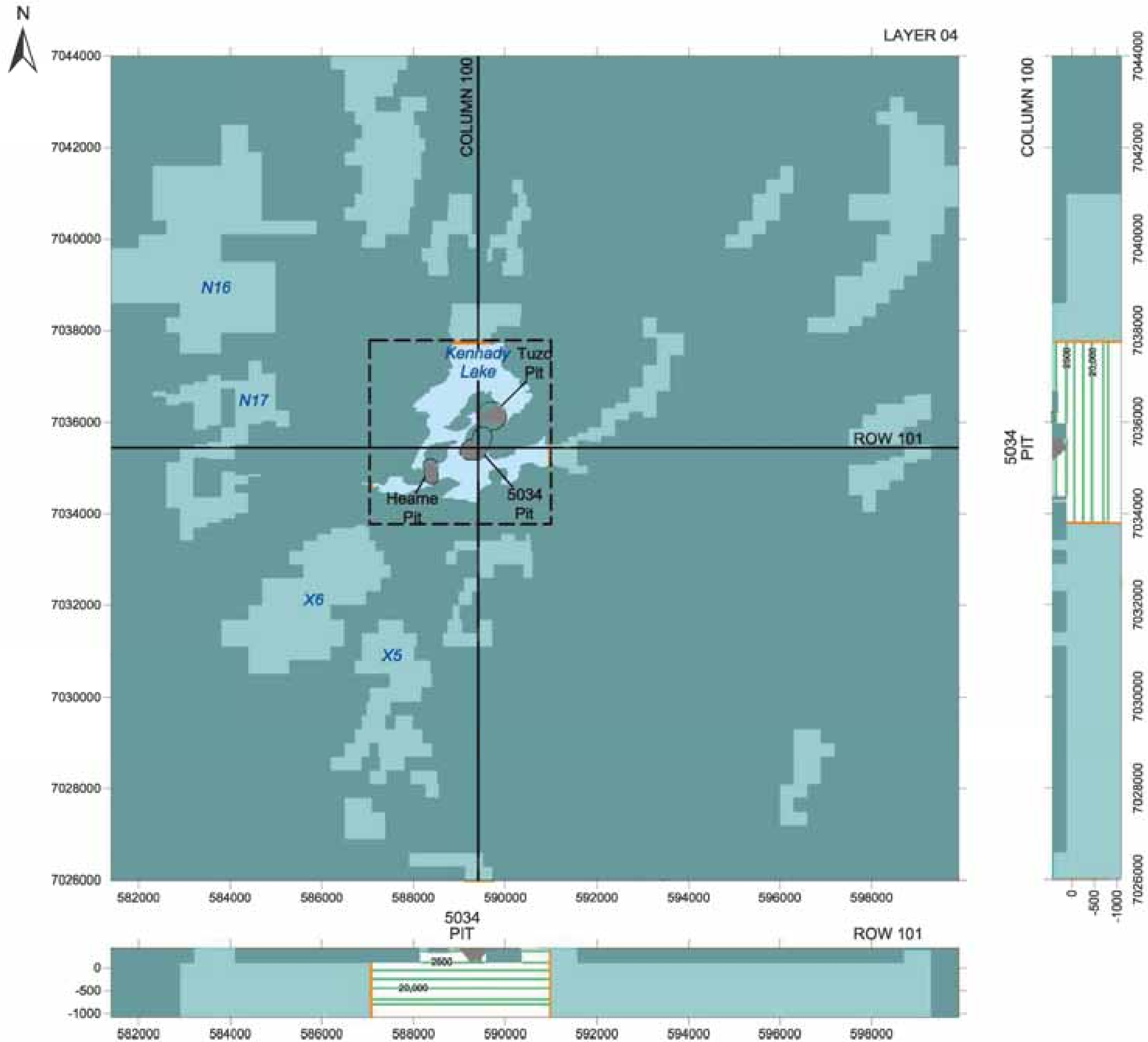
Three types of boundary conditions were used to simulate transport of TDS in groundwater: specified concentration boundaries, zero flux boundaries, and exit (Cauchy type) boundaries. The locations of these boundaries are shown in Figure 11.6.I-8.

Specified concentration boundaries of zero milligrams per litre (mg/L) were assigned along the bottom of all lakes assumed to be associated with open taliks that were connected to the deep groundwater flow regime, including all un-dewatered portions of Kennady Lake. The TDS of the un-dewatered portions of Kennady Lake will vary over the mine life and are related to quantity and quality of the groundwater inflow to the open pits that will be conveyed to these portions of the lake. Although the actual TDS of the lakes in the model area prior to mining are greater than zero at about 11 mg/l, the initial concentration of the un-dewatered portions of Kennady Lake and the change in concentrations of the lake over the mine life will be simulated via a “feedback loop” in the Site Wide Water Quality model described in Appendix 8.I.

Specified concentration boundaries corresponding to the site specific TDS versus depth profile (Figure 11.6-11) were applied at the edges of the transport domain.

Zero flux boundaries were assigned along the bottom of Layer 24, 1.5 km bgl. Mass flux from beneath this depth was considered to have negligible impact on model predictions.

Exit (Cauchy type) boundaries were assigned to the gridblocks representing the pit walls. These boundaries simulate the movement of TDS mass out of the surrounding groundwater system into the open pits.



LEGEND

- 1000 TDS Concentration Contour (mg/L)
- Exit (Cauchy type) Boundary
- Inactive for Transport
- Permafrost (Inactive for Flow)
- Specified Concentration Boundary
- Waterbody
- Extents of the Model Domain for Solute Transport

NOTES

1. TDS is displayed with a non-linear contour interval (1000 mg/L, 2500 mg/L, 5000 mg/L, 10,000 mg/L, 20,000 mg/L, 50,000 mg/L, 75,000 mg/L).
2. Base Data source: National Topographic Base Data (NTDB) 1:250,000. All distances in metres.

GAHCHO KUÉ PROJECT

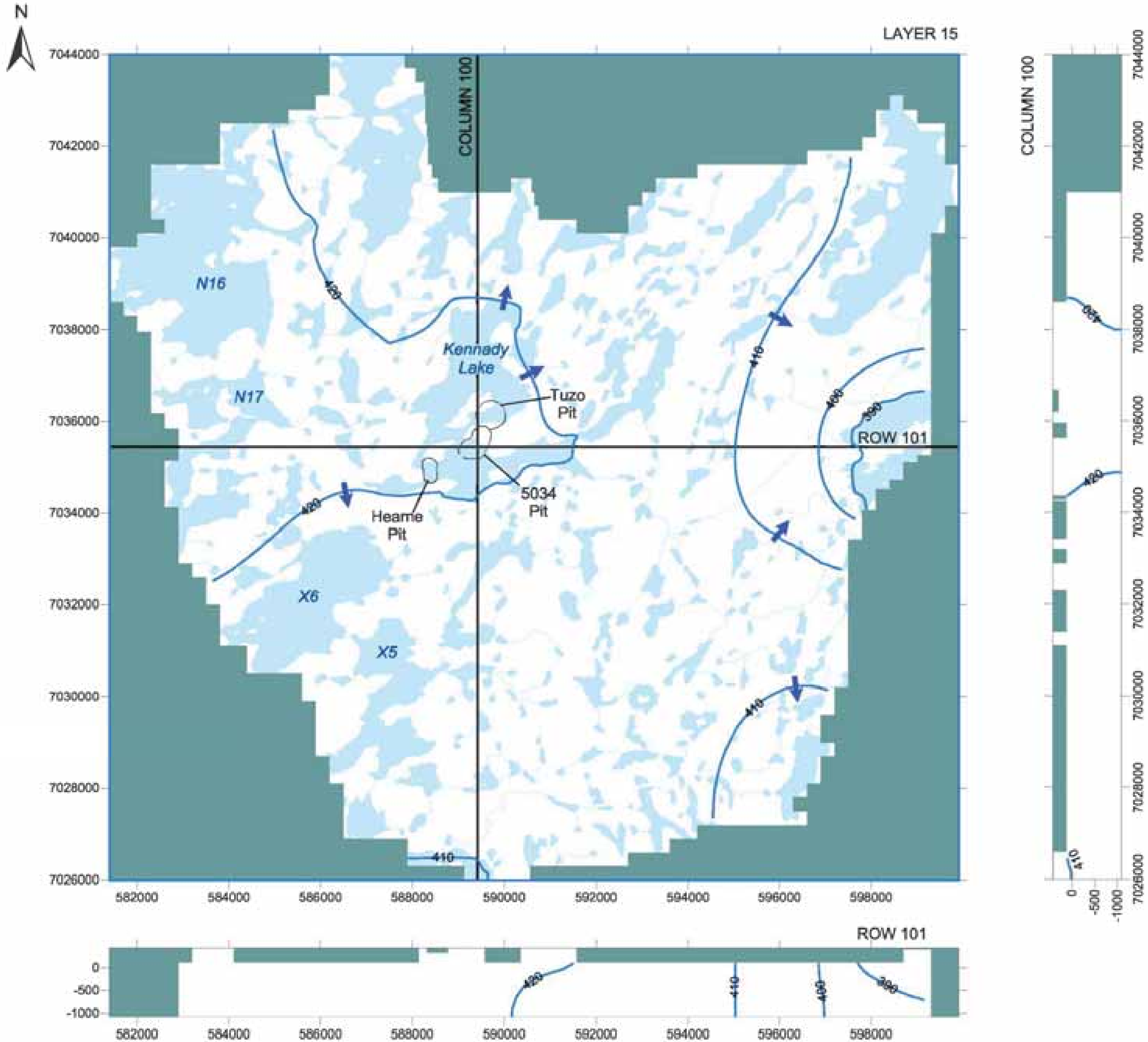
Boundary and Initial Conditions - Solute Transport

PROJECTION: UTM Zone 12	DATUM: NAD83	DE BEERS CANADA
SCALE 2 0 2 KILOMETRES		
FILE No: SON-11.6-004-CAD		DATE: August 20, 2010
JOB No: 09-1365-1004	REVISION No: 0	**Figure 11.6.I-8**
OFFICE: GOLD - CAL	DRAWN: KJM / CHECK: DC	

11.6.I.3.5 MODEL PREDICTIONS

The model-predicted hydrogeologic conditions for the pre-mining flow field are presented in Figure 11.6.I-9. The predominant groundwater flow direction in the deep groundwater flow regime is to the southeast. Kennady Lake is a groundwater recharge zone prior to mining, with water discharging from the lake to several lower elevation lakes with open taliks to the north, south and east of Kennady Lake. Two large lakes with open taliks with higher lake elevations than Kennady Lake are located to the west of Kennady Lake: however, these lakes are predicted to discharge to lakes to the north and south of Kennady Lake that are located at lower elevations. Therefore, a groundwater flow divide is predicted to be present to the west of Kennady Lake.

The three open pits and water levels in the diked off areas were simulated based on the mine schedule of pit bottom elevations, and surface water levels provided in the Project Description (Section 3). According to this mine schedule, pre-stripping of the 5034 Pit begins in Year -1, and mining in the pit continues to Year 5; the pit is then backfilled with mine rock, and the water level in the pit is maintained at about 300 m above mean sea level (amsl) (120 mbgl). Mining in the Hearne Pit is planned to begin in Year 4, and to continue until Year 7; the pit is then gradually filled with fine processed kimberlite (PK), and the water level gradually fills to the pre-mining level by the end of the mine life in Year 11. Mining in the Tuzo Pit is planned to begin in Year 5, and to proceed until the end of mine life in Year 11. After mining in this pit is complete, the pit is planned to be filled with surface water from the diked off areas of Kennady Lake to about 310 m amsl (110 mbgl); thereafter it is allowed to passively fill with groundwater and surface water.



LEGEND

- Hydraulic Head Contour (m)
- Predicted Groundwater Flow Direction
- Water Course
- Water Body

NOTES

1. Hydraulic Heads plotted at approximately 100 m above sea level near the bottom of permafrost.
2. Base Data source: National Topographic Base Data (NTDB) 1:250,000. All distances in metres.

GAHCHO KUÉ PROJECT

Predicted Hydraulic Heads Pre-Mining Conditions

PROJECTION: UTM Zone 12	DATUM: NAD83
SCALE: 2 0 2 KILOMETRES	
FILE No: SON-11.6-006-CAD	DATE: August 20, 2010
JOB No: 09-1365-1004	REVISION No: 0
OFFICE: GOLD - CAL	DRAWN: RFM / CHECK: DC

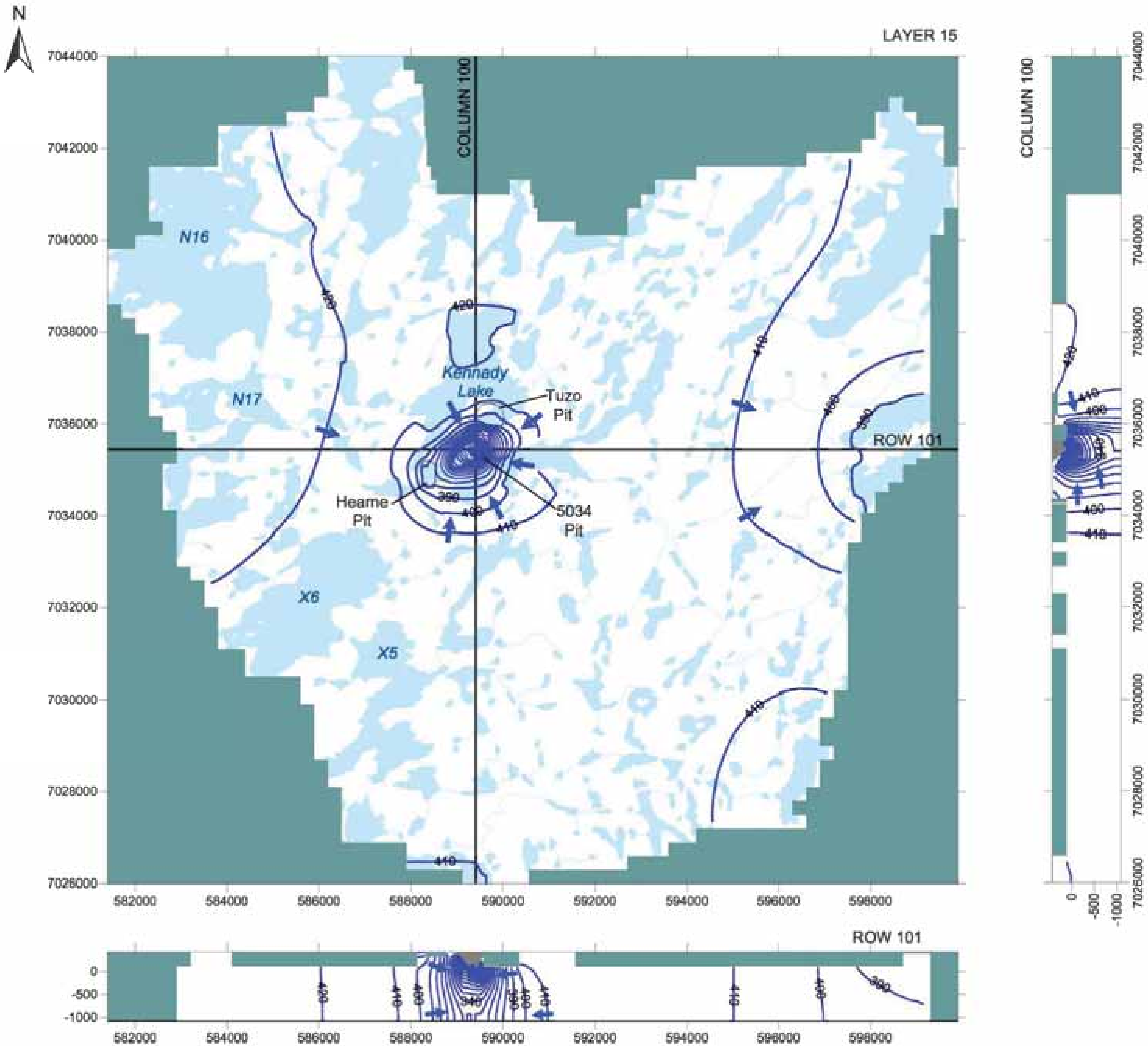
DE BEERS CANADA

Figure 11.6.I-9

Predicted hydrogeologic conditions in 2019 when the 5034 Pit reaches its ultimate depth are presented in Figure s 11.6.I-10 and 11.6.I-11. Table 11.6.I-3 and Figure s 11.6.I-12 to 11.6.I-17 present predicted groundwater inflow quantity and quality over the mine life. In 2019, groundwater flow in the deep groundwater flow regime beneath Kennady Lake and the adjacent permafrost is directed toward the 5034 Pit. Groundwater inflow to the 5034 Pit is predicted to be fairly constant throughout the time this pit is being developed, varying from 2,100 cubic metres per day (m^3/d) in Year -1 to 2,500 m^3/d in Year 5. In the initial stages of mining when the pit depth is relatively shallow, much of the groundwater inflow is attributed to water released from storage in the shallow tills beneath Kennady Lake. In the later stages of mining, this unit has been dewatered, and groundwater inflow to the pit is through the enhanced permeability zone and surrounding bedrock.

When mining of the pit is complete, and the pit is partially backfilled with mine rock, groundwater inflow is predicted to be less than 1,400 m^3/d at the end of mining. The TDS level in the groundwater inflow to the 5034 Pit is predicted to increase from 300 milligrams per litre (mg/L) in Year -1 to 4,000 mg/L in Year 5. The predicted increase in TDS concentration over the life of the pit occurs due to the higher salinity of the groundwater in the deep bedrock encountered as the pit extends to greater depths and the upwelling of saline water from beneath the pit. Initially, up to 70 percent (%) of the total pit inflow is expected to originate from the shallow groundwater system (i.e., consist of lake water or water released from storage in the shallow tills). This percentage is predicted to decline to between about 25% to 50% as the pit depth advances. As the pit is backfilled and the water level rises after Year 5, the contribution from lake water is predicted to increase to between 70% to 75%. These variations in the contribution to the TDS of pit inflow from surface water inputs are accounted for separately in the Site Wide Water Quality model described in Appendix 8.I.

Groundwater inflow to the Hearne Pit is predicted to be much lower initially than at its ultimate depth, as the shallow till near the Hearne Pit has already been depressurized as a result of mining in the 5034 Pit. Therefore, much less water is expected to be released from storage during initial mining of the Hearne Pit than during initial mining in the 5034 pit. At the start of mining in the Hearne Pit in Year 4, predicted groundwater inflow is about 400 m^3/d while predicted groundwater inflow when the pit reaches its ultimate depth in Year 7 is 1,400 m^3/d. Groundwater inflow to the pit is predicted to gradually decrease as the pit is backfilled with fine PK, and is predicted to be about 50 m^3/d in Year 11. Predicted groundwater inflows to this pit are approximately 40% lower than those predicted to the other pits, because the Hearne Pit is smaller and shallower than with the 5034 or Tuzo Pits. The TDS level in the groundwater inflow to the Hearne Pit is predicted to vary from 100 mg/L in Year 4 to 1,800 mg/L in Year 7.



LEGEND

- Hydraulic Head Contour (m)
- Predicted Groundwater Flow Direction
- Water Course
- Water Body

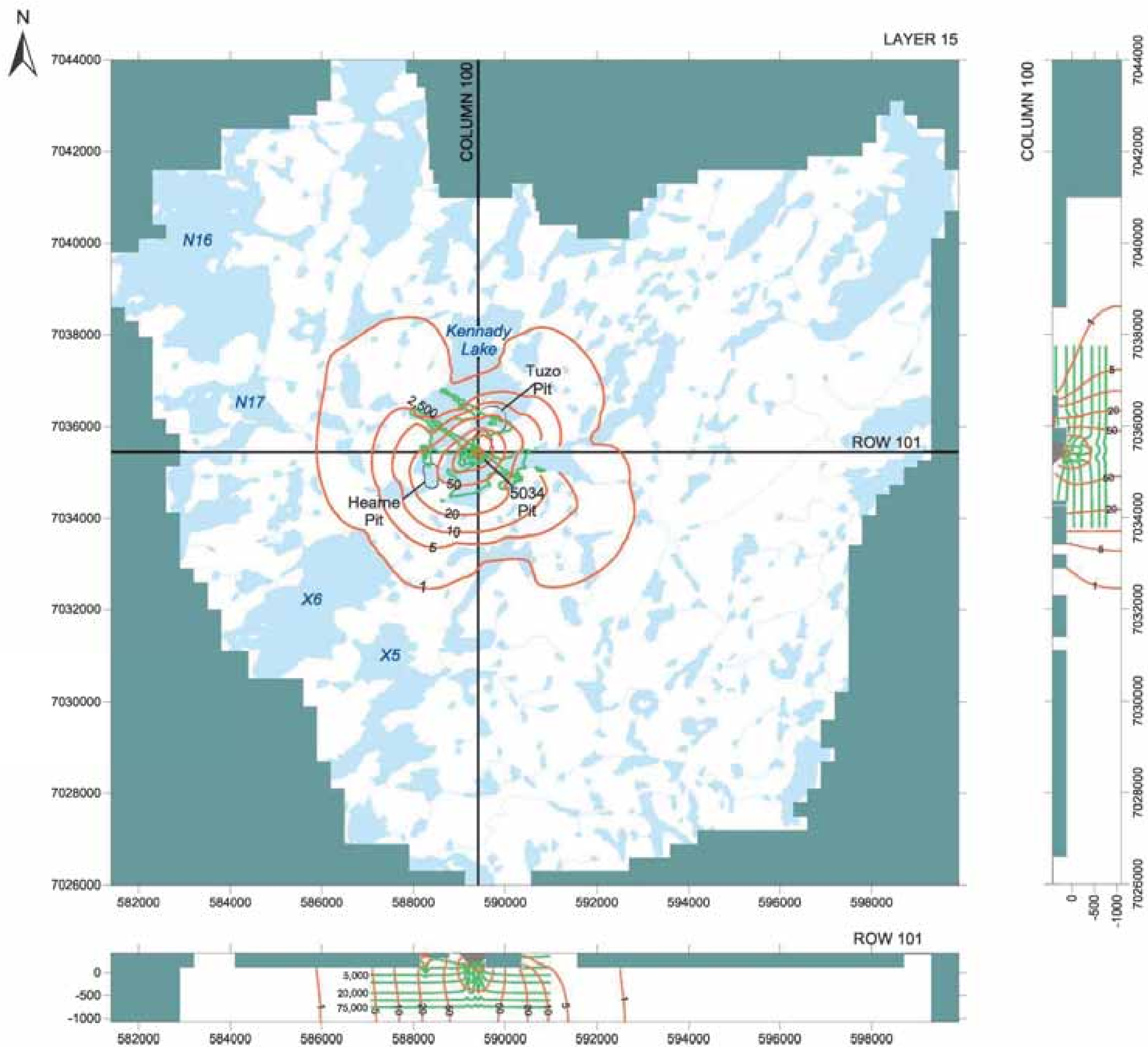
NOTES

1. Hydraulic Heads plotted at approximately 100 m above sea level near the bottom of permafrost.
2. Base Data source: National Topographic Base Data (NTDB) 1:250,000. All distances in metres.

GAHCHO KUÉ PROJECT

Predicted Hydraulic Heads Year 5 Ultimate 5034 Pit

PROJECTION: UTM Zone 12	DATUM: NAD83		
SCALE 2 0 2 KILOMETRES			DE BEERS CANADA
FILE No: SON-11.6-006-CAD			DATE: August 20, 2010
JOB No: 09-1365-1004	REVISION No: 0		**Figure 11.6.I-10**
OFFICE: GOLD - CAL	DRAWN: RFM	CHECK: DC	



LEGEND

- 1000 TDS Concentration Contour (mg/L)
- 1 Drawdown Contour (m)
- Water Course
- Water Body

NOTES

1. Drawdown and TDS plotted at approximately 100 m above sea level near the bottom of permafrost
2. Drawdown is displayed with a non-linear contour interval (1 m, 5 m, 10 m, 20 m, 50 m, 100 m , 200 m)
3. TDS is displayed with a non-linear contour interval (1000 mg/L, 2500 mg/L, 5000 mg/L, 10,000 mg/L, 20,000 mg/L, 50,000 mg/L, 75,000 mg/L)
4. Base Data source: National Topographic Base Data (NTDB) 1:250,000.
   All distances in metres.

GAHCHO KUÉ PROJECT

Predicted Drawdown and TDS - Year 5 Ultimate 5034 Pit

PROJECTION: UTM Zone 12	DATUM: NAD83

SCALE 2 0 2 KILOMETRES

DE BEERS CANADA

FILE No: SON-11.6-007-CAD			DATE: September 16, 2010
JOB No: 09-1365-1004	REVISION No: 0		
OFFICE: GOLD - CAL	DRAWN: RFM	CHECK: DC	**Figure 11.6.I-11**

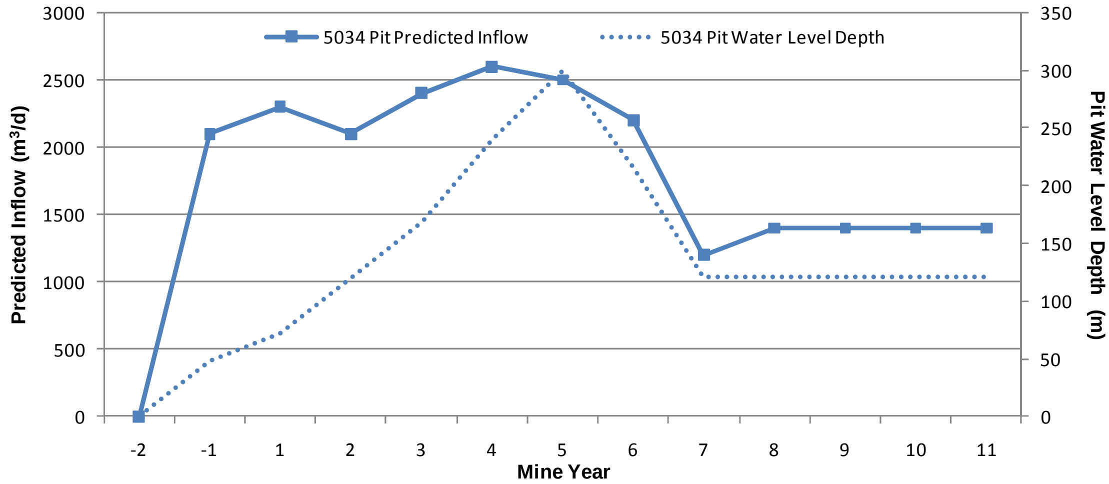
Table 11.6.I-3 Predicted Groundwater Inflow Quantity and Quality During Mining

Calendar Year	Mine Year	Inflow (m^3/d)			Total Dissolved Solids (mg/L)			Lake Water Contribution (%)			Pit Elevation (masl)		
		5034	Hearne	Tuzo	5034	Hearne	Tuzo	5034	Hearne	Tuzo	5034	Hearne	Tuzo
2013	-2	-	-	-	-	-	-	-	-	-	421	-	-
2014	-1	2,100	-	-	300	-	-	67	-	-	373	-	-
2015	1	2,300	-	-	1,100	-	-	29	-	-	349	-	-
2016	2	2,100	-	-	2,000	-	-	24	-	-	301	-	-
2017	3	2,400	-	-	2,500	-	-	32	-	-	253	-	-
2018	4	2,600	400	-	3,300	100	-	39	83	-	181	409	-
2019	5	2,500	800	600	4,000	600	200	46	44	74	121	361	397
2020	6	2,200	1,200	800	4,000	1,400	700	53	34	38	205[a]	301	361
2021	7	1,200	1,400	1,100	2,500	1,800	1,100	71	42	32	300[a]	217	325
2022	8	1,400	700	1,800	2,600	1,100	2,000	70	70	29	300[a]	337[a]	253
2023	9	1,400	300	2,100	2,600	400	3,100	72	89	35	300[a]	376[a]	193
2024	10	1,400	100	2,200	2,500	50	4,000	74	90	40	300[a]	410[a]	157
2025	11	1,400	50	2,400	2,400	50	5,200	75	90	43	300[a]	421[a]	121

(a) Elevation of the water level in the backfilled or flooded pit.

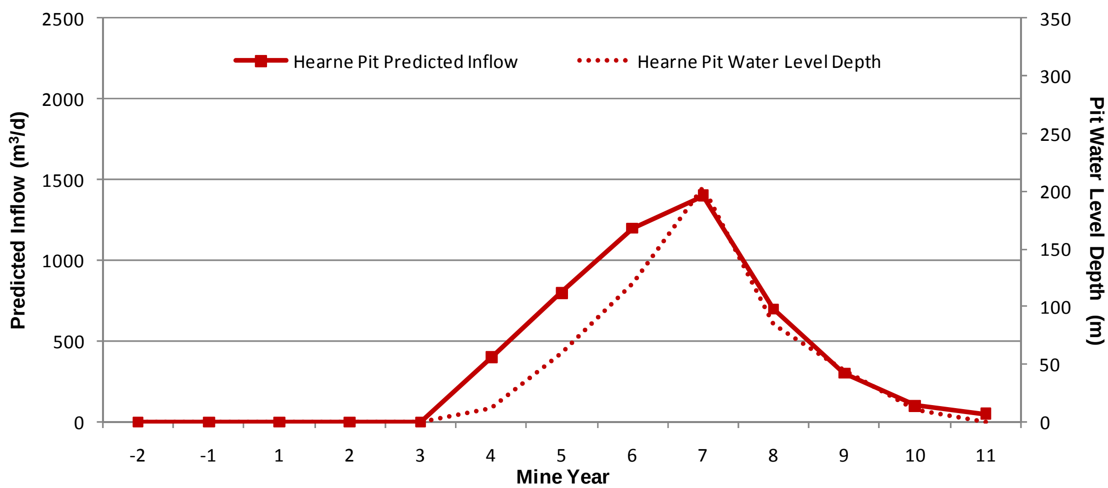
m^3/d = cubic metres per day; mg/L = milligrams per litre; % = percent; masl = metres above sea level; - = zero.

Figure 11.6.I-12 Predicted Groundwater Inflow Rate to the 5034 Pit



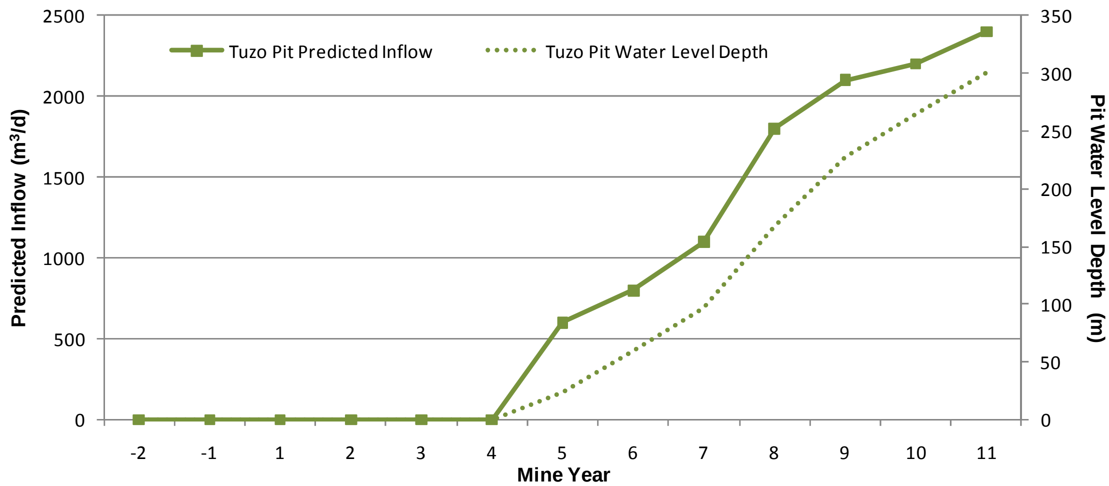
m = metres; m^3/d = cubic metres per day.

Figure 11.6.I-13 Predicted Groundwater Inflow Rate to the Hearne Pit



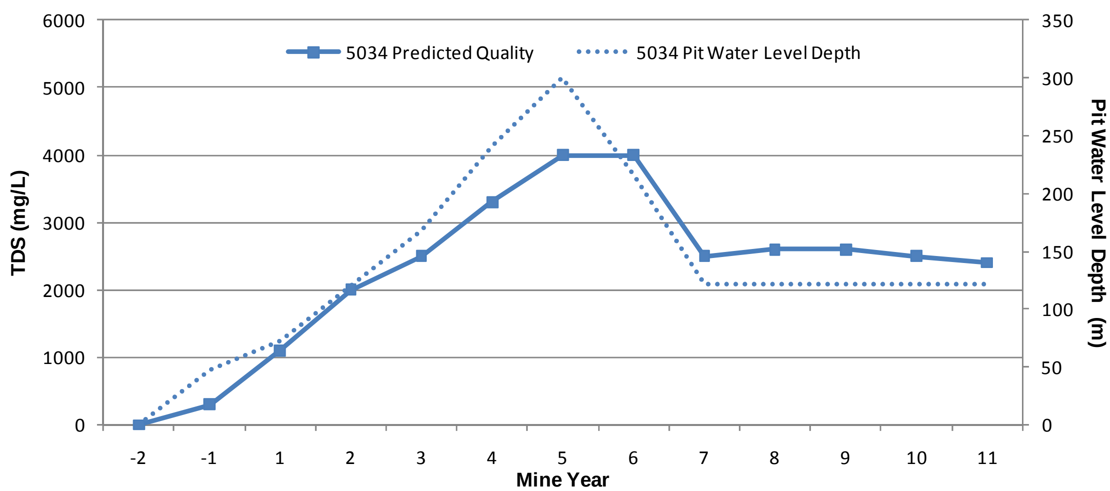
m = metres; m^3/d = cubic metres per day.

Figure 11.6.I-14 Predicted Groundwater Inflow Rate to the Tuzo Pit



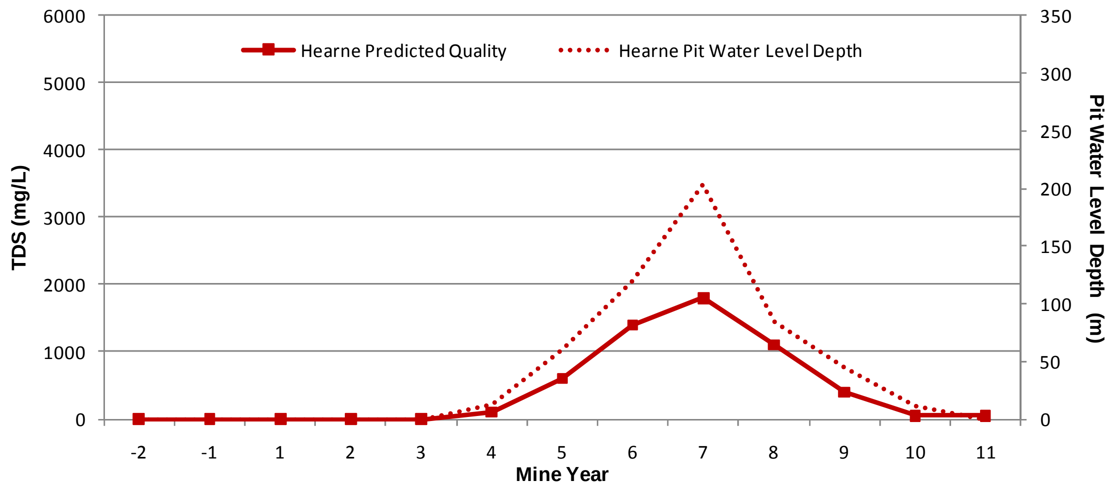
m = metres; m^3/d = cubic metres per day.

Figure 11.6.I-15 Predicted Groundwater Inflow Quality to the 5034 Pit



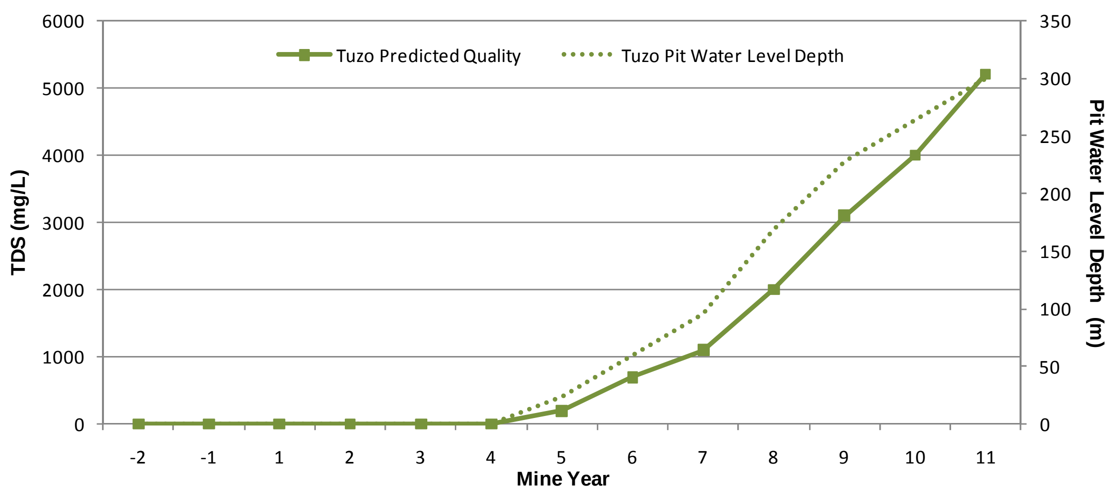
m = metres; mg/L = milligrams per litre.

Figure 11.6.I-16 Predicted Groundwater Inflow Quality to the Hearne Pit



m = metres; mg/L = milligrams per litre.

Figure 11.6.I-17 Predicted Groundwater Inflow Quality to the Tuzo Pit



m = metres; mg/L = milligrams per litre.

The percentage contribution of groundwater inflow originating from lake water or from storage in the shallow tills is predicted to be initially high at about 80%, but this percentage is predicted to decline to about 35% to 45% as the pit advances. During backfilling, the percentage contribution from lake water is predicted to increase to 90%. These variations in the contribution to the TDS of pit inflow from surface water inputs are accounted for separately in the Site Wide Water Quality model described in Appendix 8.I.

Groundwater inflow to the Tuzo Pit is predicted to increase from 600 m^3/d in Year 5, when mining of this pit is planned to begin, to 2,400 m^3/d at the end of mining (Year 11). The TDS level in the groundwater inflow is predicted to increase from 200 mg/L in Year 5 to 5,200 mg/L in Year 11 at the end of mine life. The initial predicted percentage contribution of inflow originating from lake water or from storage in the shallow tills is about 75%. As mining in the Tuzo Pit advances, the percentage contribution for lake water is predicted to vary from about 30% to 45%. These variations in the contribution to the TDS of pit inflow from surface water inputs are accounted for separately in the Site Wide Water Quality model described in Appendix 8.I.

Predicted groundwater inflows to the refilled, combined 5034 and Tuzo Pits from Year 12 to Year 17 are summarized in Table 11.6.I-4. Groundwater inflow to the combined pits is predicted to vary from 1,700 m^3/d to 300 m^3/d from Year 12 to Year 17 of mine life, respectively. The TDS level in the inflow to the combined pits during the refilling period is predicted to gradually decline from 2,100 mg/L in Year 12 to 400 mg/L in Year 17. Approximately 70% to 80% of the total pit inflow is expected to originate from the shallow groundwater system (i.e., consist of lake water), as the water level in the combined pits rises. These variations in the contribution to the TDS of pit inflow from surface water inputs are accounted for separately in the Site Wide Water Quality model described in Appendix 8.I.

After Year 17, the hydraulic gradient between the flooded pits and surrounding surface water is expected to be negligible. Groundwater inflows after this time were assessed using a post-closure model discussed in Appendix 11.6.II.

The groundwater inflow predictions outlined herein do not account for overland surface flow that may also enter the mine pits. Pit dewatering rates may, therefore, be higher than the groundwater inflow rates described herein.

Table 11.6.I-4 Predicted Groundwater Inflow Rate and Quality During Pit Refilling

Calendar Year	Mine Year	Combined 5034 and Tuzo Mine Pits			
		Inflow (m^3/d)	Total Dissolved Solids (mg/L)	Lake Water Contibution (%)	Combined Pit Elevation (masl)[(a)]
2026	12	1,700	2,100	75	318
2027	13	1,700	2,100	75	335
2028	14	1,500	2,000	76	351
2029	15	1,100	1,600	77	368
2030	16	800	1,100	78	384
2031	17	300	400	79	401

(a) Elevation of the water level in the backfilled or flooded pit.

m^3/d = cubic metres per day, mg/L = milligrams per litre; % = percent; masl = metres above sea level.

11.6.I.3.6 SENSITIVITY ANALYSIS

The following section provides a discussion and results of sensitivity simulations that were undertaken using the hydrogeological model. These simulations were developed in consideration of the following:

- In the Base Case scenario, it is assumed that enhanced permeability zones are present and associated with the geologic faults that intersect the proposed open pits. However, their presence has not yet been confirmed and it is possible that the structures are less permeable, thinner and/or less laterally extensive than the ones represented in the Base Case hydrogeological model.
- Based on past experiences at other mines in the north, increases in the overall mine inflow result in increased mass loading as more groundwater is moving upwards from the region where the deep-seated saline groundwater is present. At the Project site, this phenomenon is expected to be more pronounced, because of the presence of permafrost that nearly surrounds all three of the planned open pits (which will limit the dilution of the deep-seated saline groundwater by shallow fresher groundwater). The average model-predicted percentage of groundwater inflow that originates from the freshwater lakes at the Project site is about 40% to 50%. At the Diavik Lac De Gras Diamond Mine, there is a continuous source of freshwater, and the percentage of groundwater inflow that originates from the lake is estimated to be greater than 70%.
- Because the inflow and TDS mass are interdependent, it is likely that if reasonably highly conservative values of bedrock hydraulic conductivity were simulated together with a reasonably highly conservative TDS/depth profile the result would be an overly conservative groundwater inflow and TDS mass. Therefore, in a model sensitivity

which employs a more conservative TDS/depth profile, less conservative values of bedrock hydraulic conductivity are considered to be appropriate.

As a consequence of the above, two model sensitivities were undertaken; they were as follows:

- Sensitivity Run #1: In this model simulation, the enhanced permeability zones were removed from the model. All other parameters, including the TDS/depth profile, remained the same as the Base Case model. This simulation resulted in a lower bound estimate of inflow and TDS mass.
- Sensitivity Run #2: In this model simulation, the enhanced permeability zones were removed, but a conservative TDS/depth profile was used. The TDS concentrations in this profile are twice that used in the Base Case model. All other hydrogeologic parameters remain the same as those in the Base Case model.

11.6.I.3.6.1 Sensitivity Run #1

Results of Sensitivity Run #1 are summarized in Tables 11.6.I-5 and 11.6.I-6. These results indicate that groundwater inflows to the mine pits would be, on average, approximately 40% lower than predicted in the Base Case, if the enhanced permeability zones were not present. Generally, predicted groundwater inflows in this sensitivity simulation are close to those predicted in the Base Case when the pits are shallow and groundwater inflow occurs primarily through the till and exfoliated rock units; however, for the ultimate pit configurations, predicted groundwater inflows are between 50% and 70% lower than in the Base Case predictions. Predicted groundwater inflow to the 5034 Pit in Year 5 is about 1,400 m^3/day in this scenario, while predicted groundwater inflow to the ultimate Hearne Pit in Year 7 is about 900 m^3/day. Predicted groundwater inflow for the ultimate Tuzo Pit in Year 13 is 1,100 m^3/day in this scenario.

Predicted groundwater quality in this simulation is generally less than that predicted for the Base Case. Predicted TDS level in the groundwater inflow to the ultimate 5034 Pit, before refilling, is equal to that predicted for the Base Case at approximately 4,000 mg/L, while predicted TDS of groundwater inflow to the ultimate Hearne Pit is approximately 1,700 mg/L. Predicted TDS of groundwater inflow to the ultimate Tuzo Pit in this scenario is 4,600 mg/L.

Table 11.6.I-5 Predicted Groundwater Inflow Rates and Quality During Mining –Sensitivity Run #1

	Mine Year	Predicted Inflow (m^3/d)			Total Dissolved Solids (mg/L)			Lake Water Contribution (%)			Pit Bottom Elevation (masl)		
		5034	Hearne	Tuzo	5034	Hearne	Tuzo	5034	Hearne	Tuzo	5034	Hearne	Tuzo
2013	-2	-	-	-	-	-	-	-	-	-	421	-	-
2014	-1	2,100	-	-	300	-	-	68	-	-	373	-	-
2015	1	1,900	-	-	800	-	-	33	-	-	349	-	-
2016	2	1,600	-	-	1,400	-	-	28	-	-	301	-	-
2017	3	1,700	-	-	2,100	-	-	28	-	-	253	-	-
2018	4	1,600	400	-	3,000	100	-	30	83	-	181	409	-
2019	5	1,400	700	600	4,000	500	200	32	52	74	121	361	397
2020	6	1,200	800	600	4,200	1,200	500	37	23	45	205[(a)]	301	361
2021	7	400	900	700	2,000	1,700	700	68	24	41	300[(a)]	217	325
2022	8	800	200	1,000	2,700	800	1,200	61	72	27	300[(a)]	337[(a)]	253
2023	9	800	100	1,000	2,800	50	2,100	62	90	29	300[(a)]	376[(a)]	193
2024	10	900	50	1,000	2,800	50	3,200	64	90	31	300[(a)]	410[(a)]	157
2025	11	900	50	1,100	2,700	50	4,600	65	90	31	300[(a)]	421[(a)]	121

(a) Elevation of the water level in the backfilled or flooded pit.

m^3/d = cubic metres per day; mg/L = milligrams per litre; % = percent; masl = metres above sea level; - = zero

Table 11.6.I-6 Predicted Groundwater Inflow Rates and Quality During Refilling – Sensitivity Run #1

Calendar Year	Mine Year	5034 and Tuzo Combined			
		Inflow (m^3/d)	Total Dissolved Solids (mg/L)	Lake Water Contribution (%)	Pit Bottom Elevation (masl)[(a)]
2026	12	900	1,800	72	318
2027	13	900	1,800	72	335
2028	14	800	1,500	73	351
2029	15	700	900	76	368
2030	16	500	400	78	384
2031	17	200	50	79	401

(a) Elevation of the water level in the backfilled or flooded pit.

m^3/d = cubic metres per day; mg/L = milligrams per litre; % = percent; masl = metres above sea level.

11.6.I.3.6.2 Sensitivity Run #2

In Sensitivity Run #2, the enhanced permeability zones were removed from the model and the TDS concentrations in the TDS/depth profile were increased by a factor of two. Results of this simulation (Table 11.6.I-7 and 11.6.I-8) indicate that if TDS levels in groundwater are two times greater than assumed in the Base Case, the TDS concentrations in groundwater inflow will be approximately two times greater then in Sensitivity Run #1.

Predicted TDS concentrations for Sensitivity Run #2 are, on average, 1.5 to 2 times greater than those predicted for the Base Case. However, because predicted groundwater inflow rates in this scenario are lower than those under the Base Case, the overall mass loading to the pits is similar between the two scenarios (i.e., Sensitivity Run #2 and the Base Case). This result demonstrates that the model parameters used in the Base Case scenario provide a reasonable upper bound of mass loading to the pits over the mine life.

Table 11.6.I-7 Predicted Groundwater Inflow Quantity and Quality During Mining –Sensitivity Run #2

Calendar Year	Mine Year	Predicted Inflow (m^3/d)			Total Dissolved Solids (mg/L)			Lake Water Contribution (%)			Pit Bottom Elevation (masl)		
		5034	Hearne	Tuzo	5034	Hearne	Tuzo	5034	Hearne	Tuzo	5034	Hearne	Tuzo
2013	-2	-	-	-	-	-	-	-	-	-	421	-	-
2014	-1	2,100	-	-	600	-	-	68	-	-	373	-	-
2015	1	1,900	-	-	1,600	-	-	33	-	-	349	-	-
2016	2	1,600	-	-	2,700	-	-	28	-	-	301	-	-
2017	3	1,700	-	-	4,100	-	-	28	-	-	253	-	-
2018	4	1,600	400	-	6,100	300	-	30	83	-	181	409	-
2019	5	1,400	700	600	7,900	1,000	400	32	52	74	121	361	397
2020	6	1,200	800	600	8,400	2,400	1,100	37	23	45	205[(a)]	301	361
2021	7	400	900	700	4,100	3,300	1,400	68	24	41	300[(a)]	217	325
2022	8	800	200	1,000	5,400	1,500	2,400	61	72	27	300[(a)]	337[(a)]	253
2023	9	800	100	1,000	5,500	100	4,200	62	90	29	300[(a)]	376[(a)]	193
2024	10	900	50	1,000	5,500	100	6,500	64	90	31	300[(a)]	410[(a)]	157
2025	11	900	50	1,100	5,500	100	9,200	65	90	31	300[(a)]	421[(a)]	121

(a) Elevation of the water level in the backfilled or flooded pit.

m^3/d = cubic metres per day; mg/L = milligrams per litre; % = percent; masl = metres above sea level; - = zero

Table 11.6.I-8 Predicted Groundwater Inflow Quantity and Quality During Refilling – Sensitivity Run #2

Calendar Year	Mine Year	5034 and Tuzo Combined			
		Inflow (m^3/day)	TDS (mg/L)	Lake Water Contribution (%)	Pit Bottom Elevation (masl)[(a)]
2026	12	900	3,700	72	318
2027	13	900	3,700	72	335
2028	14	800	3,000	73	351
2029	15	700	1,800	76	368
2030	16	500	800	78	384
2031	17	200	50	79	401

(a) Elevation of the water level in the backfilled or flooded pit.

m^3/d = cubic metres per day; mg/L = milligrams per litre; % = percent; masl = metres above sea level.

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11.6.I.5 ACRONYMS AND GLOSSARY

11.6.I.5.1 ABBREVIATIONS AND ACRONYMS

LSA	Local Study Area
PK	processed kimberlite
Project	Gahcho Kué Project
SON 11.6	Subject of Note: Permafrost, Groundwater, and Hydrogeology
TDS	total dissolved solids

11.6.I.5.2 UNITS OF MEASURE

%	percent
amsl	above mean sea level
km	kilometre
km bgl	kilometres below ground level
m	metre
m^3/d	cubic metres per day
masl	metres above sea level
mbgl	metres below ground level
mg/L	milligrams per litre

APPENDIX 11.6.II

HYDROGEOLOGIC MODEL FOR TUZO PIT – POST-CLOSURE

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11.6.II.1 INTRODUCTION

This appendix presents the results of a model study that was completed to assess the post-closure groundwater regime in the vicinity of the Tuzo Pit. The objectives of the model simulations were as follows:

- to evaluate the effects of higher total dissolved solids (TDS) water beneath the open pit on the groundwater flow system following closure of the mine workings; and
- to evaluate the influence of solute transport by groundwater flow on the movement of solutes from the bedrock into the flooded pit.

During mining operations, fresh water from nearby lakes will be drawn down into the bedrock, due to the hydraulic gradients that develop in response to mine dewatering and mine pit development. This fresh water will displace groundwater with higher TDS concentrations that was present under pre-mining conditions. Mining operations will also result in upward migration of higher TDS groundwater from depth in the region beneath the mine excavations. Consequently, the groundwater chemistry in the vicinity of the mine will be altered from pre-mining conditions. At closure, the Tuzo Pit will be gradually flooded over a period of eight to nine years. The intent of the modelling study outlined herein is to examine potential post-closure changes in the groundwater flow regime once the Tuzo Pit and Kennady Lake have been completely re-filled and to evaluate what, if any, influence these changes may have on water quality in the flooded pit. The results of this study are relevant to the following subject of note and key lines of inquiry:

- Permafrost, Groundwater and Hydrogeology (Section 11.6);
- Water Quality and Fish in Kennady Lake (Section 8); and
- Long-term Biophysical Effects, Closure, and Reclamation (Section 10).

11.6.II.1 CONCEPTUAL MODEL OF GROUNDWATER FLOW AND SOLUTE TRANSPORT AT POST-CLOSURE

Following flooding of the Tuzo Pit and the refilling of Kennady Lake, several different groundwater flow and solute transport processes will take place. They are as follows:

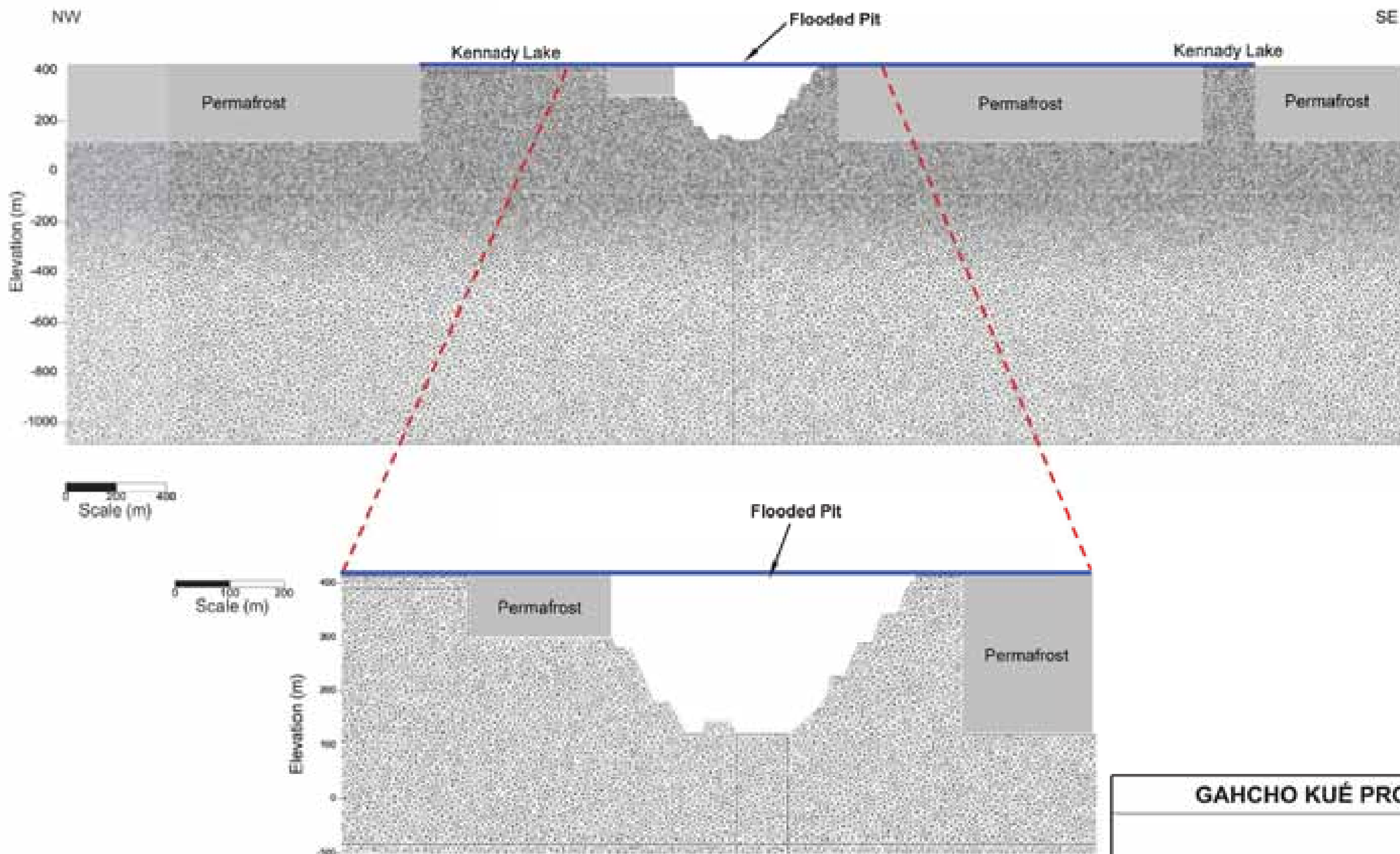
- Initially, lake water will flow from the flooded pit into the bedrock, re-saturating the partially de-watered bedrock near the pit walls, and dissipating the large hydraulic head differences that have become established during mine operation in the vicinity of the mine workings.
- With the dissipation of these hydraulic head differences, there are no significant regional gradients in hydraulic head that could results in the relatively rapid displacement of the fresh lake water that has infiltrated into the bedrock during mining operations. When the external hydraulic gradients are weak or absent, groundwater flow caused by lateral variations in fluid density (due to differences in TDS concentration) will likely dominate the groundwater flow system. The brackish groundwater with higher TDS concentrations that migrated upward during mining operations will begin to sink, because of its higher density relative to the surrounding fresher groundwater. This effect can create a slow-moving, convective circulation system in the bedrock. Changes in the TDS concentration of the groundwater and the TDS concentration of water discharging to the flooded pit will reflect the combined influence of this density-driven flow and solute transfer by diffusion.
- The TDS profile in the bedrock beneath the site is expected to eventually return to near pre-mining conditions as the fresh water that infiltrated the bedrock during mining operations is gradually displaced by higher TDS groundwater and as diffusion transfers dissolved mass into regions of lower solute concentrations.

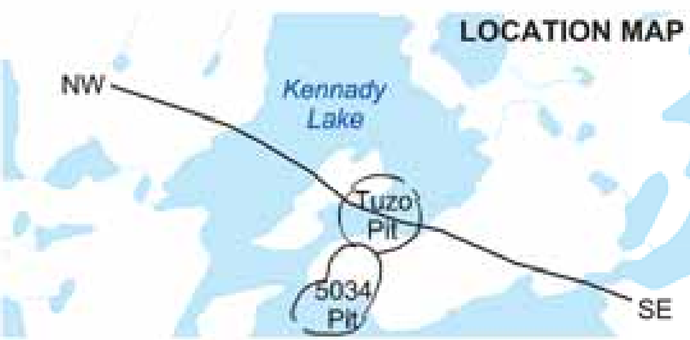
11.6.II.2 SIMULATION OF GROUNDWATER CONDITIONS AT POST-CLOSURE

The simulation of groundwater flow and solute transport prior to mining, during mining and at closure was carried out using the three-dimensional MODFLOW/MT3DMS model, as described in Appendix 11.6.I. Density-dependent transport of solutes was not included in these simulations, as the buoyancy effects were considered negligible in relation to the hydraulic head gradients associated with mine dewatering and pit development. It was concluded that hydraulic heads in the bedrock will recover to a near-equilibrium state approximately six years after the flooding of the Tuzo Pit is initiated. It was also concluded, as outlined in Appendix 11.6.I, that groundwater inflow to the refilled pit would be negligible when density-driven effects are not accounted for.

To analyze the hydrogeological conditions following mine closure (i.e., during the post-closure period), a two-dimensional model was developed that explicitly considered density-coupled groundwater flow and solute transport. This two-dimensional model, which was developed using FEFLOW (Diersch 2010), was oriented along the enhanced permeability zone that intersects the Tuzo Pit. This approach was considered reasonable, because the results of the three-dimensional modelling described in Appendix 11.6.I showed that the flow in this 30 metre (m) wide zone is primarily oriented along its alignment and that approximately 70 percent (%) of groundwater inflow to the Tuzo Pit could originate from this zone.

As presented in Figure 11.6.II-1, the two-dimensional model extends to a distance of approximately 2,700 m northwest and southeast from the center of the pit, a distance that is similar to the one adopted for the transport domain in the three-dimensional model. The finite element mesh consists of approximately 75,000 elements with the node spacing ranging from about 10 m near the ground surface to 20 m near the base of the model, which is sufficient to maintain stability of the numerical solution.





GAHCHO KUÉ PROJECT			
Finite Element Mesh			
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SCALE: AS SHOWN			
FILE No: SON-11.6.II-001-CAD.dwg			DATE: November 22, 2010
JOB No: 09-1365-1004	REVISION No: 0		**Figure 11.6.II-1**
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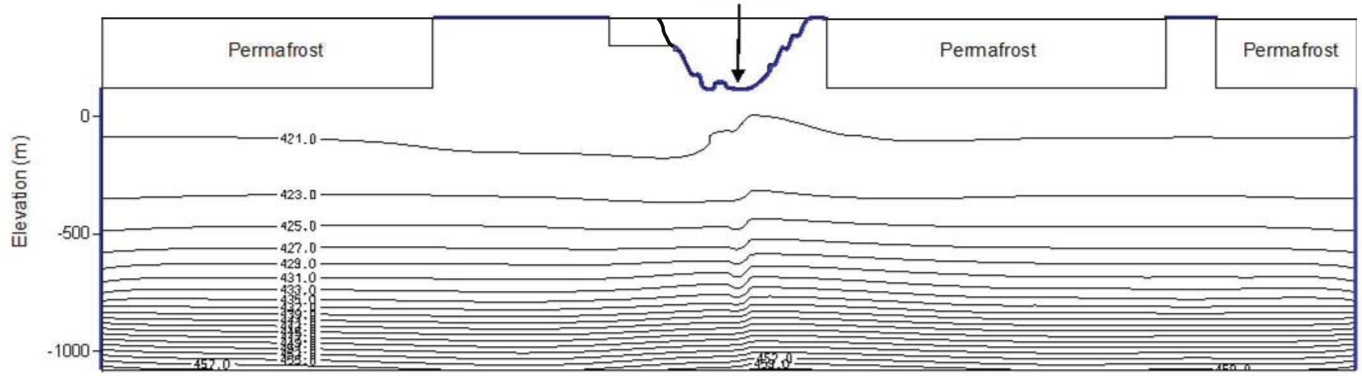
The model boundaries, extent of the hydrostratigraphic units and their parameters are the same as used in the three-dimensional model outlined in Appendix 11.6.I, except for the following modifications necessary to simulate density effects at post-closure:

- The initial conditions for the post-closure simulation were set to the TDS concentration profile generated using the three-dimensional model, which is shown in Figure 11.6.II-2. The equivalent freshwater heads corresponding to these concentrations were assumed to be hydrostatic.
- Specified concentration and specified head boundaries were assigned along the pit walls to represent the refilled area. The concentrations were set to 188 milligrams per litre (mg/L) to a depth of 354 m and to 670 mg/L below this depth. This lake profile was developed from the water quality modelling results discussed in Section 8. The equivalent freshwater heads assigned to these boundaries were calculated for individual mesh nodes based on their depth below the lake surface and the lake TDS profile. In addition, boundary constraints were used to automatically turn off the specified concentration boundaries at locations where groundwater inflow to the refilled pit was predicted to occur. This approach allowed for the proper representation of solute exchanges between the lake and the adjacent groundwater, as required for the simulation of density-driven convection flow (i.e., at locations where groundwater inflow to the lake was predicted, TDS mass was allowed to freely exit the model domain whereas at outflow locations recharge to groundwater was assigned a lake water TDS).
- Along the right and left boundary of the model domain specified head and specified concentration boundaries representing an undisturbed TDS vs. depth profile and hydrostatic conditions were assigned. The equivalent freshwater heads at these boundaries were calculated using the TDS vs. depth profile

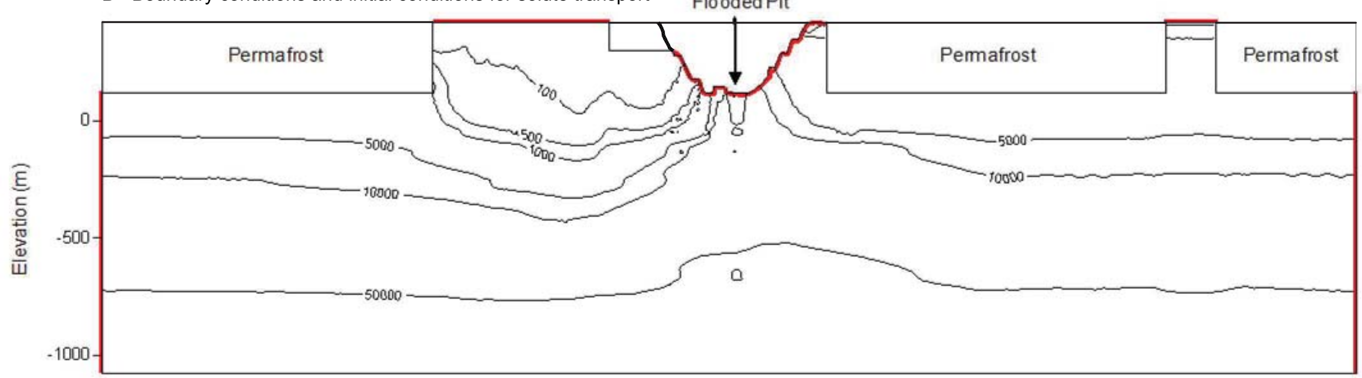
NW SE

A - Boundary conditions and initial conditions for groundwater flow



Blue lines represent specified head boundaries.
Contours depict initial distribution of equivalent freshwater head (m).

B - Boundary conditions and initial conditions for solute transport



Red lines represent specified concentration boundaries.
Contours depict initial TDS distribution (mg/L).

0 200 400
Scale (m)

GAHCHO KUÉ PROJECT

Boundary and Initial Conditions Used in the Post-Closure In-flow Groundwater Model

PROJECTION: N/A	DATUM: N/A	DE BEERS CANADA
SCALE: AS SHOWN		
FILE No: SON-11.6.II-002-CAD.dwg		DATE: November 26, 2010
JOB No: 09-1365-1004	REVISION No: 0	Figure 11.6.II-2
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11.6.II.3 RESULTS OF MODELLING

The FEFLOW model described above was used to simulate post-closure conditions for a 1,000 year time period. Predicted flow rates into and out of the refilled Tuzo Pit, along with predicted TDS mass fluxes into the refilled pit, are summarized in Table 11.6.II-1, expressed per unit width of the Tuzo Pit, and in. Figure 11.6.II-3.

Table 11.6.II-1 Predicted Flows into and out of the Refilled Tuzo Pit Post-Closure, along with TDS Mass Loading Rates, expressed per unit Width of the Refilled Pit

Time (years)	Groundwater Inflow (m^3/d/m)	Lake Outflow (m^3/d/m)	Mass Loading (g/d/m)
1	0.07	0.19	105
10	0.03	0.09	24
100	0.01	0.00	8
1,000	0.02	0.01	46

m^3/d/m = cubic meter per day per unit width; g/d/m = gram per day per unit width.

The values shown in Table 11.6.II-1 were adjusted to account for the full width of the Tuzo Pit. This adjustment was accomplished assuming that the enhanced permeability structure represented in the FEFLOW model is 30 m wide and that exchange across this structure accounts for 70% of the total exchange that occurs of the entire circumference of the pit. In other words, the values listed in Table 11.6.II-1 were multiplied by 30 and then divided by 0.7 to produce estimates of total inflow, outflow and TDS mass loading for the entire Tuzo Pit. These estimates are listed in Table 11.6.II-2.

Table 11.6.II-2 Predicted Flows into and out of the Refilled Tuzo Pit Post-Closure, along with TDS Mass Loading Rates

Time (years)	Groundwater Inflow (m^3/d)	Lake Outflow (m^3/d)	Mass Loading (g/d)
1	3.02	8.00	4,507
10	1.46	3.95	1,025
100	0.51	0.19	336
1,000	0.82	0.39	1,953

m^3/d = cubic meter per day; g/d = gram per day

The assumption that exchange across the enhanced permeability structure accounts for 70% of the total exchange is considered conservative, because flows are likely to be lower outside of the enhanced permeability feature. In addition, the exchange between the groundwater and refilled pit are also likely to occur more slowly, due to relatively low permeability of bedrock outside of the enhanced feature. These two mechanisms, acting together, would likely result in lower mass loading rates than those shown in Table 11.6.II-2.

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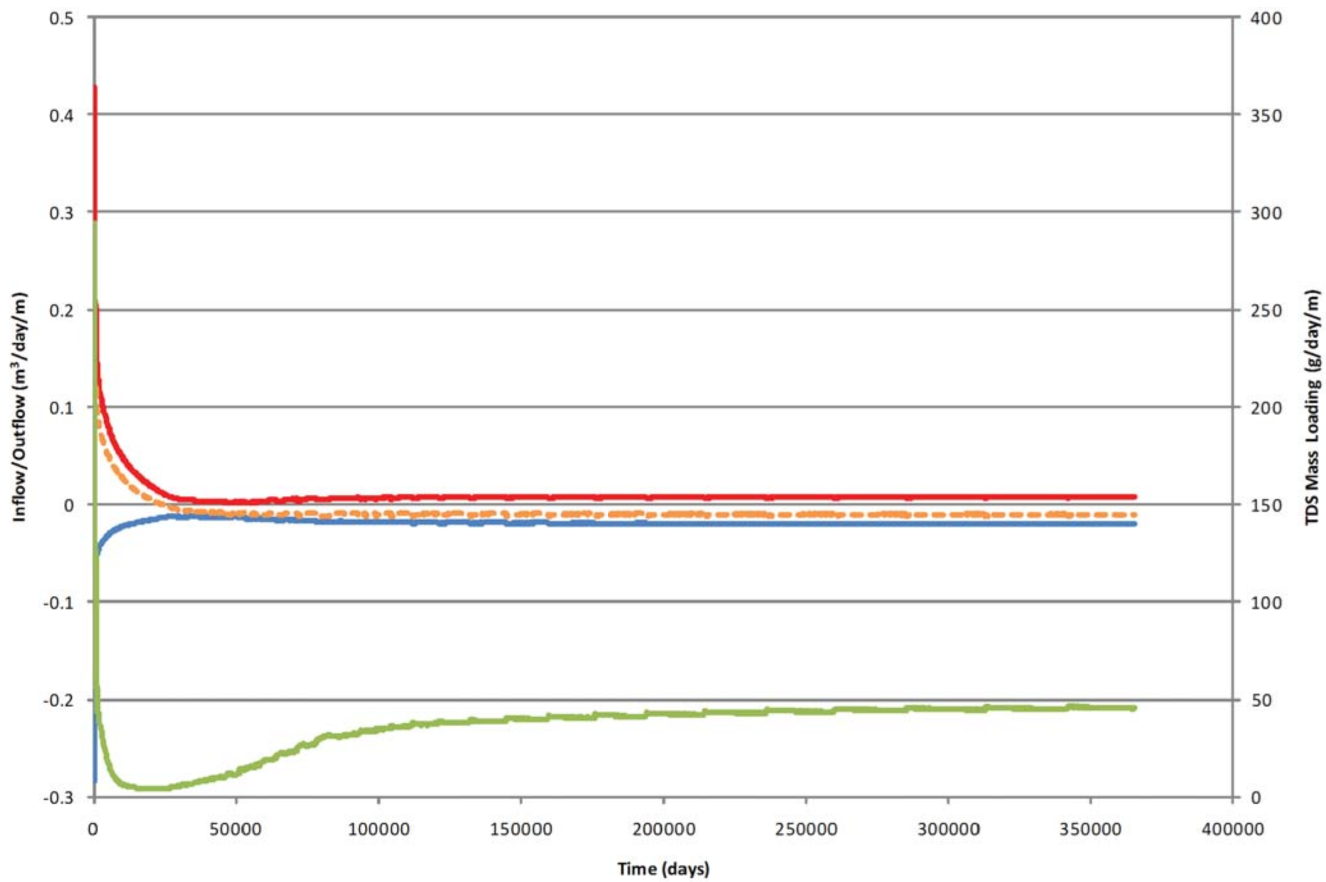

GAHCHO KUÉ PROJECT			
Predicted Flow and Mass Flux Into and Out of the Refilled Tuzo Pit, Expressed per Unit Width of the Pit			
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SCALE: AS SHOWN			
FILE No: SON-11.6.II-003-CAD.dwg			DATE: November 10, 2010
JOB No: 09-1365-1004	REVISION No: 0		**Figure 11.6.II-3**
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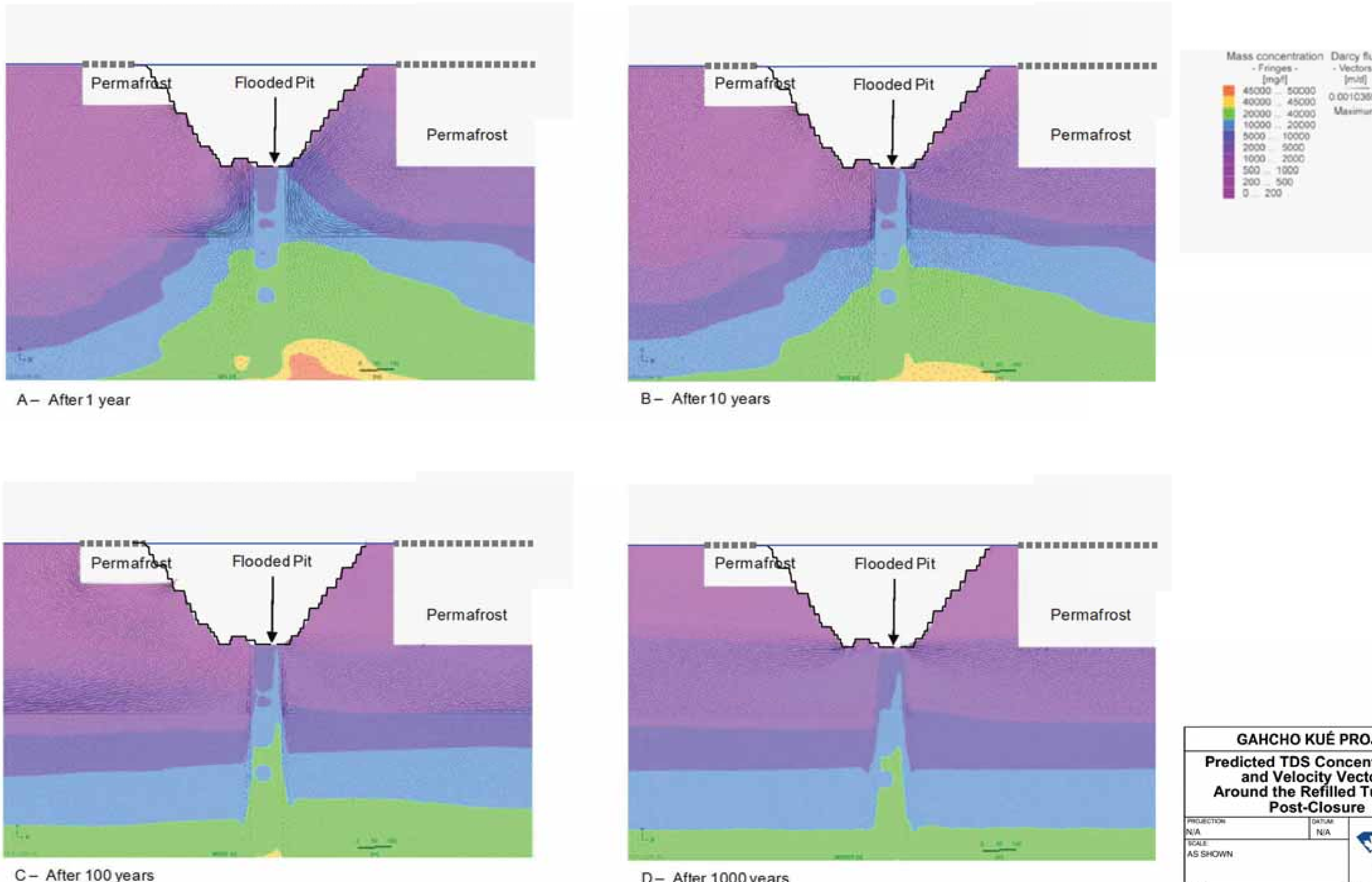
Groundwater velocity vectors and TDS concentration contours are presented in Figure 11.6.II-4 for 1, 10, 100, and 1,000 years after mine closure. The groundwater velocity vectors are scaled to a different maximum velocity in each plot. In addition, for illustrative purposes only, relatively large vectors are used in plotting these results, which may give the impression that the flow system is highly dynamic and fast flowing. These maximum velocities, however, are several orders of magnitude less than the velocities predicted for groundwater flow during mining operations (see Appendix 11.6.I).

The model results show that, once the hydraulic heads return to near equilibrium shortly after mine flooding, two convection cells form beneath the mine (Figure 11.6.II-4A). These convection cells are caused by sinking of high-TDS groundwater that has been upwelling towards the pit during mining operations. The high-TDS groundwater located near the pit sinks, because its density is higher relative to the density of groundwater located at the same depth, but at some distance away from the pit. As the convection cell develops, water from the refilled pit is drawn downwards from the bottom part of the pit into bedrock, while groundwater is flowing upward to the upper part of the pit. Over time, as the pre-mining fluid density profile is restored, the effects of density-driven flow are reduced, groundwater velocities decrease, and diffusion becomes the dominant transport process.

Predicted groundwater inflow to the flooded pit gradually decreases from approximately 3 cubic meters per day (m^3/d) one (1) year after mine closure to approximately 0.5 m^3/d 100 years later, with a subsequent increase to approximately 0.8 m^3/d 1,000 years after refilling. Water loss from the refilled pit to the surrounding groundwater system is predicted to gradually decrease from approximately 8 m^3/d in Year 1 to 0.2 m^3/d after 100 years and then gradually increase to approximately 0.4 m^3/d after 1,000 years.

The corresponding TDS mass flux into the flooded pit follows a similar pattern. It gradually decreases from approximately 4,500 grams per day (g/d) one (1) year after mine closure to approximately 300 g/d at 100 years and then increases to approximately 2,000 g/d at 1,000 years. These temporal changes in predicted TDS fluxes are considered reasonable, as they reflect gradual changes in the convective circulation patterns and groundwater quality along the pit walls that are presented in Figure 11.6.II-4.



GAHCHO KUÉ PROJECT			
Predicted TDS Concentrations and Velocity Vectors Around the Refilled Tuzo Pit Post-Closure			
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SCALE: AS SHOWN			
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JOB No: 09-1365-1004	REVISION No: 0		**Figure 11.6.II-4**
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11.6.II.4 DISCUSSION AND CONCLUSIONS

After flooding of the Tuzo Pit and dissipation of the large hydraulic head gradients around the flooded pit, the conditions that create the near-hydrostatic fluid pressures that characterize the pre-mining groundwater regime will be re-established. These conditions permit the development of a density-driven groundwater flow system in the vicinity of the mine workings, due to the high-TDS groundwater that upwelled during mining operations. This convective system will lead to groundwater discharge to the flooded pit and discharge of lake water to the surrounding bedrock. During the first 100 after pit refilling, groundwater inflow rates to the refilled pit are predicted to range between approximately 0.5 and 3 m^3/d, whereas predicted water losses to the groundwater system range from 0.2 and 8 m^3/d. The corresponding TDS mass flux into the flooded pit range from approximately 300 to 4,500 g/d.

11.6.II.5 REFERENCES

Diersch, H.G. 2010. *FEFLOW v. 6 Finite Element Subsurface Flow and Transport Simulation System*. DHI-WASY Institute for Water Resources Planning and System Research Ltd., Berlin, Germany.

11.6.II.6 ABBREVIATIONS, ACRONYMS, AND UNITS

11.6.II.6.1 ABBREVIATIONS AND ACRONYMS

TDS	total dissolved solids

11.6.II.6.2 UNITS OF MEASURE

%	percent
g/d	gram per day
g/d/m	gram per day per unit width
m	metre
m^3/d	cubic meter per day
m^3/d/m	cubic meter per day unit width
mg/L	milligrams per litre