DOMINION DIAMOND

ANNEX IX

HYDROGEOLOGY BASELINE REPORT FOR THE JAY PROJECT

HYDROGEOLOGY BASELINE REPORT FOR THE JAY PROJECT

Prepared for: Dominion Diamond Ekati Corporation

Prepared by: Golder Associates Ltd.

September 2014

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Abbreviations

Abbreviation	Definition
BSA	baseline study area
Ca	calcium
ca.	circa (about)
Cl	chlorine
Dominion Diamond	Dominion Diamond Ekati Corporation
e.g.,	for example
Ekati Mine	Ekati Diamond Mine
EPZ	enhanced permeability zone
et al.	and more than one additional author
$HC0_3$	bicarbonate
ID	identification
K	hydraulic conductivity
Mg	magnesium
Na+K	sodium + potassium
NE	northeast
NW	northwest
NWT	Northwest Territories
Project	Jay Project
RQD	rock quality designation
SE	southeast
SO_4	sulphate
SW	southwest
TDS	total dissolved solids

Units of Measure

Unit	Definition
%	percent
<	less than
°C	degrees Celsius
cm	centimetre
km	kilometre
km^2	square kilometre
m	metre
m^2	square metre
m/d	metres per day
m^3/d	cubic metres per day
m/m	metres per minute
m/s	metres per second
m^2/s	square metres per second
mah	metres along hole
masl	metres above sea level
mbgs	metres below ground surface
mg/L	milligrams per litre
mm	millimetre
ppb	parts per billion

1 INTRODUCTION

1.1 Background and Scope

Dominion Diamond Ekati Corporation (Dominion Diamond) is a Canadian-owned and Northwest Territories (NWT) based mining company that mines, processes, and markets Canadian diamonds from its Ekati Diamond Mine (Ekati Mine). The existing Ekati Mine is located approximately 200 kilometres (km) south of the Arctic Circle and 300 km northeast of Yellowknife, NWT (Map 1.1-1).

Dominion Diamond is proposing to develop the Jay kimberlite pipe (Jay pipe) located beneath Lac du Sauvage. The proposed Jay Project (Project) will be an extension of the Ekati Mine, which is a large, stable, and successful mining operation that has been operating for 16 years. Most of the facilities required to support the development of the Jay pipe and to process the kimberlite currently exist at the Ekati Mine. The Project is located in the southeastern portion of the Ekati claim block approximately 25 km from the main facilities and approximately 7 km to the northeast of the Misery Pit, in the Lac de Gras watershed (Map 1.1-2).

This hydrogeology baseline report is one component of a comprehensive environmental and socio-economic baseline program to collect information about the natural and socio-economic environment near the Project.

1.2 Objectives

The purpose of the hydrogeology baseline report is to describe the existing hydrogeological conditions at the Project site before development. The objectives are to provide the following:

- spatial and temporal variation in groundwater quantity;
- groundwater flow regimes associated with the Project site;
- the relationship between the groundwater regime and permafrost and active layer conditions;
- current and historical data on groundwater quality for the Project site and surrounding area; and,
- an assessment of the baseline data set.

150 0 150

SCALE 1:6,000,000 KILOMETRES

LEGEND

- JAY PROJECT
- EXISTING MINE OR PROJECT
- TERRITORIAL CAPITAL
- POPULATED PLACE
- HIGHWAY
- ALL-SEASON ROAD
- WINTER ROAD
- TIBBITT TO CONTWOYTO WINTER ROAD
- NORTHERN PORTION OF TIBBITT TO CONTWOYTO WINTER ROAD
- TERRITORIAL/PROVINCIAL BOUNDARY
- TREELINE
- WATERCOURSE
- WATERBODY

REFERENCE

WATER OBTAINED FROM ATLAS OF CANADA
NATURAL RESOURCES CANADA, CENTRE FOR TOPOGRAPHIC INFORMATION, 2012
PROJECTION: CANADA LAMBERT CONFORMAL CONIC

DOCUMENT

HYDROGEOLOGY BASELINE REPORT

PROJECT

DOMINION DIAMOND

JAY PROJECT
NORTHWEST TERRITORIES, CANADA

TITLE

LOCATION OF THE JAY PROJECT

Golder Associates

PROJECT		13-1328-0041	FILE No. B_JC_Hydgeo_005_GIS	
DESIGN	RK	19/03/14	SCALE AS SHOWN	REV. 0
GIS	ANK	11/09/14	MAP 1.1-1	
CHECK	CG	11/09/14		
REVIEW	SM	11/09/14		

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LEGEND

- EKATI MINE FOOTPRINT
- DIAVIK MINE FOOTPRINT
- PROPOSED JAY FOOTPRINT
- KIMBERLITE PIPE
- WINTER ROAD
- TIBBITT TO CONTWOYTO WINTER ROAD
- NORTHERN PORTION OF TIBBITT TO CONTWOYTO WINTER ROAD
- ELEVATION CONTOUR (10 m INTERVAL)
- ESKER
- WATERCOURSE
- WATERBODY

REFERENCE

CANVEC © NATURAL RESOURCES CANADA, 2012
NATURAL RESOURCES CANADA, CENTRE FOR TOPOGRAPHIC INFORMATION, 2012
DATUM: NAD83 PROJECTION: UTM ZONE 12N

DOCUMENT

HYDROGEOLOGY BASELINE REPORT

3 0 3
SCALE 1:150,000 KILOMETRES

PROJECT

DOMINION DIAMOND

JAY PROJECT
NORTHWEST TERRITORIES, CANADA

TITLE

EKATI PROPERTY MAP

Golder Associates

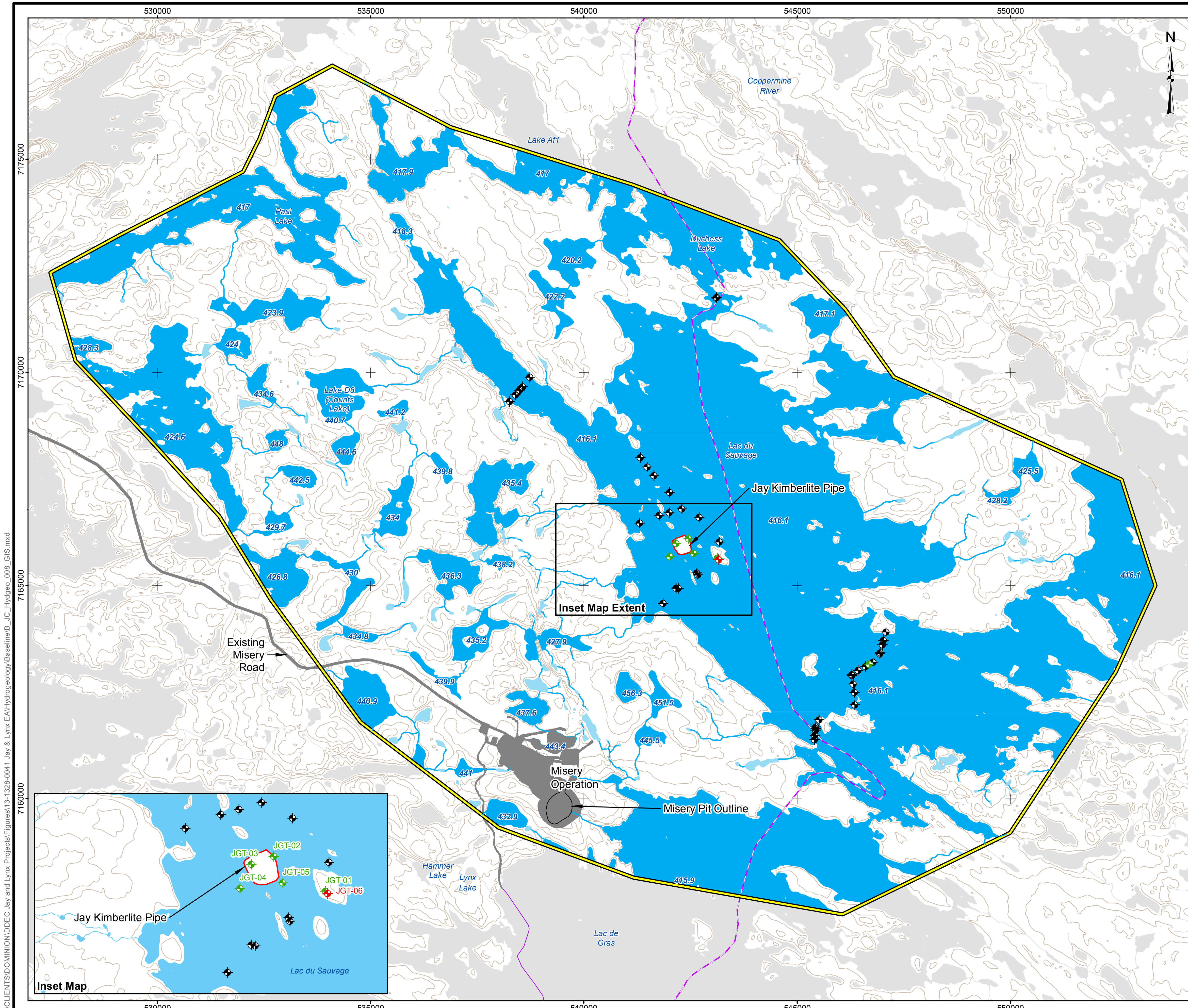
PROJECT		13-1328-0041	FILE No. B_JC_Hydgeo_009_GIS	
DESIGN	SM	12/08/14	SCALE AS SHOWN	REV 0
GIS	ANK	11/09/14	MAP 1.1-2	
CHECK	CG	11/09/14		
REVIEW	SM	11/09/14		

G:\CLIENTS\DOMINION\DDEC Jay and Lynx Projects\Figures\13-1328-0041 Jay & Lynx EA\Hydrogeology\Baseline\B_JC_Hydgeo_009_GIS.mxd

1.3 Baseline Study Area

The hydrogeology baseline study area (BSA) forms an irregular polygon approximately 15 by 25 km in size. Lac du Savage and the site of the proposed Project are located in the central part of the BSA, which covers an area of 300 square kilometres (km^2) (Map 1.3-1). The area encompasses the majority of the Lac du Sauvage sub-basin, which ultimately drains to Lac de Gras. The elevations of large lakes (greater than 133,000 square metres [m^2]) within the BSA range from approximately 415.9 metres above sea level (masl) at Lac de Gras to 456 masl at a small lake approximately 3 km south of the Jay pipe. The two largest lakes within the BSA are Lac du Sauvage and Lac de Gras, which have the lowest lake elevations in the area at 416.1 and 415.9 masl, respectively.

The existing Misery Pit is located within the BSA, approximately 7 km to the southwest of the Project area while the Lynx pipe is located outside the BSA, approximately 8.6 km south of the Project area. The existing Panda, Koala, Koala North, and Fox pits are located outside of the BSA, approximately 25 km to the northwest of the Project area. The Diavik Diamond Mine (Diavik Mine) A154 and A418 pits are also located outside of the BSA approximately 12 km southwest of the Project area.



LEGEND

- EKATI MINE FOOTPRINT
- KIMBERLITE PIPE
- WINTER ROAD
- NORTHERN PORTION OF TIBBITT TO CONTWOYTO WINTER ROAD
- ELEVATION CONTOUR (10 m INTERVAL)
- WATERCOURSE OUTSIDE THE BSA
- WATERBODY OUTSIDE THE BSA
- BASELINE STUDY AREA (BSA)
- WATERCOURSE INSIDE THE BSA
- LAKE INSIDE THE BSA WITH INFERRED OPEN TALIK
- LAKE INSIDE THE BSA WITHOUT INFERRED OPEN TALIK
- DEEP BEDROCK HYDRAULIC TESTING BOREHOLE
- OVERBURDEN OR SHALLOW HYDRAULIC TESTING BOREHOLE
- WESTBAY MULTI-LEVEL MONITORING WELL
- 416.2 LAKE ELEVATION (masl)

REFERENCE

CANVEC © NATURAL RESOURCES CANADA, 2012
NATURAL RESOURCES CANADA, CENTRE FOR TOPOGRAPHIC INFORMATION, 2012
DATUM: NAD83 PROJECTION: UTM ZONE 12N

DOCUMENT

HYDROGEOLOGY BASELINE REPORT

2 0 2
SCALE 1:90,000 KILOMETRES

PROJECT
DOMINION DIAMOND
JAY PROJECT
NORTHWEST TERRITORIES, CANADA

TITLE

BASELINE STUDY AREA

Golder Associates

PROJECT		13-1328-0041	FILE No. B_JC_Hydgeo_008_GIS	
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GIS	ANK	11/09/14		
CHECK	CG	11/09/14		
REVIEW	SM	11/09/14		

MAP 1.3-1

2 METHODS

The baseline study presents the hydrogeological conditions before Project initiation. Baseline conditions are also used for future reference in identifying environmental changes, and for qualitative and quantitative evaluation of potential changes to groundwater regimes. The methods used to characterize the baseline conditions consisted of the following:

- compilation and review of hydrogeologic testing and of groundwater sampling data collected near the Jay pipe during the 2014 field season;
- review of pertinent studies published in the literature;
- review of existing baseline studies;
- review of available data collected during operations at the current Ekati Mine and nearby Diavik Mine because these operations provide relevant site analogues; and,
- interpretation of information to develop the conceptual hydrogeological model of the area surrounding the Jay pipe.

2.1 Jay Project Data Review

Hydrogeological field programs were carried out between February and June 2014 from the ice surface of Lac du Sauvage. These investigations included 95 single-well hydraulic tests conducted in 59 boreholes. Sixty-six of these hydraulic tests were conducted in surficial soils or shallow bedrock located along the proposed dike alignments, and 29 tests were conducted in deep bedrock (approximately 25 to 400 m depth) within the footprint of the proposed dike. Three groundwater samples were collected in a Westbay multi-level monitoring well from approximately 300 to 420 m depth. Hydrogeologic testing locations, and the location of the Westbay multi-level monitoring well are presented in Map 1.3-1. These field programs are summarized below, and fully documented in Appendices A and B.

2.1.1 Westbay Multi-Level Monitoring Well

The Westbay multi-level monitoring well was completed in Borehole JGT-06 which was one of six deep boreholes completed in the Jay pipe area. The borehole was advanced from an island to the southwest of the Jay pipe that is along the proposed dike alignment. During the drilling of JGT-06, the drill fluid was tagged with fluorescence to allow for accurate identification of well development volumes required to remove drill fluid during purging. The development purging target was set at approximately 5 percent (%) of the concentration of tagged drill fluid.

Upon completion of drilling, Borehole JGT-06 was instrumented with a Westbay multi-level monitoring well. The Westbay allows for multi-level monitoring of hydraulic heads, testing of hydraulic conductivity, and collection of groundwater samples from nine different depth intervals, which are all located in the portion of the borehole located below permafrost. The Westbay multi-level monitoring well interval depths are provided in Table 2.1-1. Testing and sampling ports were installed in each isolated interval to measure the corresponding hydraulic heads, and to allow collection of groundwater samples. Pumping ports were placed at the base and halfway through the permafrost zone to allow injection of propylene glycol mixture into the annulus of the borehole within the extent of the permafrost zone to prevent freezing of the well. The Westbay multi-level monitoring well installation is fully documented in the *Geotechnical and Hydrogeological Field Investigations Factual Report Vol. 3* (Appendix A).

Table 2.1-1 Westbay Monitoring Interval Depths

Interval Number	Depth Along Hole			Vertical Depth		
	From (mah)	To (mah)	Magnetic Collar Depth (mah)	From (mbgs)	To (mbgs)	Magnetic Collar Depth (mbgs)
1	174.0	209.2	174.6	169.5	203.8	170.1
2	210.7	238.2	211.3	205.3	232.0	205.9
3	239.7	268.7	240.3	233.5	261.7	234.1
4	270.2	308.4	270.8	263.2	300.4	263.8
5	309.9	338.9	310.5	301.9	330.0	302.5
6	340.4	367.9	341.0	331.5	358.3	332.1
7	369.4	398.4	370.0	359.8	387.9	360.4
8	399.9	429.0	400.5	389.4	417.7	390.0
9	430.5	460.5	431.1	419.2	449.0	419.8

Note: Values based on "Casing Installation Log," included as part of Completion Report Westbay System Monitoring Wells: JGT-06 – Jay Project, NWT. May 28, 2014 (appended to Appendix A).
mah = metres along hole; mbgs = metres below ground surface.

Based on the hydraulic conductivities derived from the hydrogeological tests carried out in JGT-06 (Appendix A), three different methods were used to develop the intervals selected for groundwater sampling:

- the high yield airlifting method (Intervals 7 and 9);
- the low yield airlifting method (Interval 5); and,
- the Westbay sampler method (Interval 3).

Additional information on development procedures is presented in Table 2.1-2 and Appendix A.

Table 2.1-2 Estimated Extraction Volumes From Westbay Well JGT-06

Interval ID	Zone Volume (L)	Number of Well Volumes Removed	Actual Volume Removed (L)	Number of Days of Development	Final Dye Concentration
3[(a)]	156.5	0.3	45	n/a	n/a
5	156.5	2.8	446	11	15 ppb
7	156.5	5,901.6	923,600	28	43 ppb
9	162.0	2,061.5	333,960	13	41 ppb

a) The development of Interval 3 was not completed.
ID = identification; L = litre; n/a = not applicable; ppb = parts per billion.

After the completion of the development, groundwater samples were collected for Intervals 5, 7, and 9, and subsequently shipped to ALS Environmental in Edmonton for analysis. A duplicate for Interval 5 and blank control samples were collected for quality assurance / quality control purposes. The results of the analyses are presented in Appendix A.

2.1.2 Hydrogeologic Testing Programs

Hydrogeologic testing undertaken for the Project consisted of the following:

- single-well response testing in six deep boreholes drilled in the area of the proposed open pit to vertical depths of between 200 and 400 m (two of these boreholes were used to support installation of a Westbay multi-level well system);
- single-well response testing in 42 shallow boreholes drilled along the proposed dike alignments; and,
- two pumping tests carried out during development of two intervals of the Westbay multi-level monitoring well installation.

The locations of all the boreholes are presented in Map 1.3-1. Detailed borehole information such as collar coordinates, borehole azimuth and inclination, top of lake sediment and bedrock, and total drilled depth is presented in the *Factual Memorandum on 2014 Hydrogeological Testing Program* (Appendix B).

Single-well response tests were carried out in the selected boreholes to obtain information on the bulk hydraulic conductivity of the soil and rock mass. Testing was conducted using two different methods. The preferred method was the use of a pneumatic packer system in a single packer configuration. However, in eight shallow testing locations, due to poor borehole stability, temporary standpipe piezometers were installed and used during hydrogeologic testing as described in Appendix B.

The quality assurance / quality control of packer testing equipment was completed at the beginning of the program and at the beginning of testing at each borehole. In addition to the testing of the equipment, core recovered during drilling was inspected before each test to confirm that packer placement was over a solid rock. Following packer inflation, water was added to the borehole annulus while monitoring the water level inside the drill/test rods to confirm proper packer inflation and seal. The surface casing was also monitored during the constant rate injection tests to confirm that no water was flowing out of the casing. Following the test completion, the pressure history recorded within the test interval was inspected for any inconsistencies in expected pressure response.

In addition to single-well response testing, sustained airlifting rates during development of Intervals 7 and 9 were used to estimate hydraulic conductivity of the bedrock. These rates, together with other information such as the diameter of the Westbay multi-level monitoring well, hydraulic head in the Westbay multi-level monitoring well interval before testing and during airlifting, and the effective testing interval, were used to estimate a large-scale hydraulic conductivity for both of these intervals.

Results of all hydrogeologic testing are summarized in Appendix B.

2.2 Literature Review

Published information from other mine sites located in the Canadian Shield was reviewed to characterize the groundwater conditions for the hydrogeological conceptual model at the Project. Several relevant environmental assessments that were previously submitted to the Mackenzie Valley Review Board or Nunavut Impact Review Board (Agnico Eagle Mines 2013; Areva 2011; Cumberland [now Agnico Eagle Mines] 2005; De Beers 2002, 2010) were reviewed. Where data collected in the course of these assessments could be used to refine the hydrogeological conceptual model at the Project, these data were incorporated. In addition, available publications that could also be used to build the baseline dataset and conceptual understanding of the site were reviewed (Négrel and Casanova 2005; Douglas et al. 2000; Frape and Fritz 1987; Green et al. 2008; Holden et al. 2009; Martin et al. 2013; Stober and Bucher 2007; Stotler et al. 2009, 2012; Woo 2011). This information was integrated with information gathered at the Project, existing Ekati Mine operations, and the nearby Diavik Mine operations.

2.3 Diavik Mine Data Review

The Diavik Mine is an operating diamond mine located approximately 12 km to the southwest of the Project. The Diavik Mine is located on East Island, which is a 20 km^2 island in Lac de Gras. Open pit and underground mining in three kimberlite pipes (A154N, A154S, and A418) has been undertaken to date (Rio Tinto 2012). The Diavik kimberlites are hosted in similar rocks as the Jay pipe and before mining were located beneath the lakebed of Lac de Gras. Similar to the planned Jay operations, which will be located in the talik (unfrozen zones that occur beneath waterbodies) beneath Lac du Sauvage, the open pit and underground mines at Diavik are currently being operated within the large open talik underlying Lac de Gras, with the open pit / underground operations located within a diked off portion of the lake bed. Therefore, Diavik Mine is considered an appropriate site analogue, although not as relevant or representative as data collected in the Project area.

Several public documents, which discuss the hydrogeology at Diavik Mine, were reviewed (Kuchling et al. 2000; Golder 2004; Bieber et al. 2006, 2007). These documents include the results of field investigations to characterize the hydrogeology of the Diavik Mine site, and the site conceptual and numerical hydrogeological model. The results of a targeted field program conducted to characterize a substantial enhanced permeability zone associated with Dewey's Fault, a sub-vertical northeast–southwest (NE–SW) structure that passes through the two A154 pipes is also included in Bieber et al. (2006). In addition to the publicly available documents, permission was obtained from Diavik Diamond Mines Inc. to use the data and interpretations resulting from the geochemistry baseline program conducted by Blowes and Logsdon (1998).

Prior to mining at Diavik Mine, hydrogeological investigations were conducted in boreholes and in the 1,000 m long bulk sample decline, which was advanced in the bedrock beneath Lac de Gras into the A154S pipe (Kuchling et al. 2000). Hydrogeological field investigations consisted of approximately 600 single-well hydraulic (packer) tests, as well as borehole flowmeter testing, borehole temperature logging, and borehole video imaging in selected boreholes (Kuchling et al. 2000).

The geochemistry baseline dataset included 183 sets of water quality samples collected over the period of late 1996 to early 1997, from depths ranging between approximately 10 and 400 metres below ground surface (mbgs). Analytical methods and quality assurance / quality control of these samples are described in Blowes and Logsdon (1998). The resulting Diavik Mine groundwater quality data set is tabulated in Diavik Groundwater Quality Data (Appendix C).

Based on the results of the hydrogeological investigations conducted before mining, a numerical groundwater model was prepared for Diavik Mine to measure pit inflow quantity and quality. This model was later updated and calibrated to data collected during mining including observed pit inflow quantity and quality in the A154N/S Pit, and to open pit seepage mapping (Golder 2004). During calibration of the model to hydrogeological data collected during mining, the enhanced permeability zone (EPZ) identified during mining was incorporated into the model, and the hydraulic conductivity of the bedrock was increased slightly from the value assumed in the pre-mining model (Golder 2004). Following this calibration, the model was found to provide accurate predictions of groundwater inflow quantity and quality to the A154N/S Pit to the end of 2005 (Bieber et al. 2006).

2.4 Ekati Mine Data Review

With the exception of the Misery Pit, the existing Ekati mining operations are located outside the BSA, approximately 25 km to the northwest of the Jay pipe. The existing Ekati mining operations provide another relevant site analogue. Numerous historical hydrogeological reports prepared for the Ekati Mine were reviewed (Table 2.4-1), and relevant data were incorporated into the hydrogeological conceptual model for the Project.

Table 2.4-1 Summary of Hydrogeological Reports from the Existing Ekati Mines

Report Title	Author/Year	Description	Data Utilized
Phase II Hydrogeological Evaluation of the Panda Pit	Klohn Crippen 2001	presents results of hydrogeological investigations to predict groundwater quality, hydraulic heads, and groundwater inflow to the Panda Pit	hydrogeologic testing and water quality results in the area of the Panda Pit
Hydrogeological Evaluation of Misery Pit and Underground	Klohn Crippen 2004	presents the results of hydrogeological investigations at the Misery Pit	hydrogeologic testing results in the area of the Misery Pit
Ekati Mine 2004 Hydrogeological Investigation of Fox Pit	Klohn Crippen 2005	presents results of packer testing, a pumping test, and development of a numerical groundwater model for the Fox Pit	hydrogeologic testing results, and inferred values of hydraulic parameters in the area of the Fox Pit
Underground Water Quality Assessment	Rescan Environmental Services 2006	presents the results of comparison of historical data at the Panda and Koala mines with the results of sampling in the mine sumps	compiled groundwater quality data

Table 2.4-1 Summary of Hydrogeological Reports from the Existing Ekati Mines

Report Title	Author/Year	Description	Data Utilized
2005 Koala Feasibility Report Underground Mine Dewatering Final Report	Klohn Crippen 2006	presents the results of a feasibility level hydrogeological and hydrologic study of the Koala Underground Mine including the development of a numerical groundwater model	hydrogeologic testing, water quality, and predictions of groundwater inflows in the area of the Koala Underground Mine
Koala Underground Project Underground Water Management Review	WMC 2006	provides a review of previous hydrogeological characterizations, and operational water management recommendations	additional predictions of groundwater inflow to the Koala Underground Mine
Misery Resource Development Definition Study – Feasibility Hydrology and Hydrogeology	SWS 2010	presents the results of a hydrogeological assessment of the Misery mine area	open pit seepage mapping in the Misery Pit

2.4.1 Panda Open Pit and Underground Mine

The Panda Mine is situated in the talik beneath the former lakebed of Panda Lake. The talik was inferred to be open and extend through permafrost and into the deep regional groundwater regime beneath the lake (Klohn Crippen 2001). Hydrogeological characterization for the Panda Mine, which included single-well hydraulic (packer) testing in four boreholes and installation of a Westbay multi-level groundwater monitoring well, was carried out in the talik underlying the former lakebed of Panda Lake (Klohn Crippen 2001). Water quality samples were collected from the Westbay MP38 (PGT-27) monitoring well installed from Bench 270 (elevation 270 masl). Groundwater samples were collected in October 2001, March 2002, October 2002, and September 2003. The resulting Panda groundwater quality data set is tabulated in Ekati Panda Groundwater Quality Data (Appendix D).

2.4.2 Koala Open Pit and Underground Mine

The Koala Mine is located both in permafrost and in the talik extending beneath the lakebed of the former Koala Lake. This talik is inferred to be open and extending to the base of permafrost, and to be connected to the deep groundwater regime (Klohn Crippen 2006). At the Koala Underground Mine, a program of hydrogeologic testing focused on water-bearing structures identified in the Koala underground workings. This program consisted of single-well hydraulic (packer) testing in seven boreholes and installation of piezometers in six boreholes (Klohn Crippen 2006). Hydrogeologic testing carried out at the Koala Mine also included two monitored multi-day discharge tests carried out in the spring of 2005. These tests consisted of monitoring passive discharge from a single hole and monitoring the hydraulic response in several other holes (14 to 16 locations). Water samples were also collected during packer tests and from flowing boreholes.

Groundwater models constructed based on the results of hydrogeologic testing predicted that the average groundwater inflows to the underground mine were generally expected to range from 1,000 to 1,700 cubic metres per day (m^3/d) (Klohn Crippen 2006; WMC 2006). Comparison of these predictions with the annual average mine water reporting to the Panda and Koala underground mines of approximately 1,200 m^3/d (Dominion Diamond 2012) indicates that actual groundwater inflow volumes are within the range of predicted values. This comparison provides evidence to support the conceptual and numerical hydrogeological models previously presented for the Koala Underground Mine (Klohn Crippen 2006).

2.4.3 Fox Pit

Hydrogeological studies were carried out at the Fox Pit in support of the evaluation of slope stability in the walls of the open pit and for management of water (Klohn Crippen 2005). Dewatering of Fox Lake began in 2003, and mining of kimberlite within an inferred open talik, which had underlain Fox Lake, began in 2005. Single-well hydraulic (packer) testing was conducted at seven boreholes with three of the holes angled to test the kimberlite/granite contact. A pumping test was conducted at one flowing artesian hole with three additional boreholes equipped with vibrating wire piezometers or transducers used as observation wells.

A numerical groundwater model that was constructed based on the results of hydrogeologic testing predicted that groundwater inflow to the Fox Pit could range from approximately 400 to 4,300 m^3/d (Klohn Crippen 2005). In 2012, an average of approximately 1,000 m^3/d of mine water reported to the Fox Pit, indicating that actual groundwater inflow volumes are within the range of predicted values.

2.4.4 Misery Pit

At the Misery Pit, an open talik was present beneath Misery Lake before mining, and this talik likely provides connection to the deep groundwater flow regime (SWS 2010). Misery Lake was dewatered and excavated during mining of the Misery Pit, which began in 2001. In 2004, hydrogeologic testing was conducted in six boreholes in the Misery Pit area within the remaining Misery Lake talik. Groundwater sampling was planned but could not be undertaken due to the low permeability of the bedrock and difficulties with freezing of the drill rods (Klohn Crippen 2004). During mining, minor groundwater inflows were reported and during a 2010 site visit, pit inflow was observed to range between 200 and 300 m^3/d and was interpreted to originate primarily from the active zone (SWS 2010).

3 HYDROGEOLOGICAL SETTING

The information presented in this section is summarized from the Permafrost Baseline Report (Annex IV).

3.1 Permafrost

The Project is located within a region of continuous permafrost. In this region, the layer of permanently frozen subsoil and rock is generally deep and overlain by an active layer that thaws during summer. The depth of the active layer in the Misery Pit area ranges from approximately 1.0 to 2.7 m. Permafrost thickness (defined by the depth to the zero degree isotherm) is expected to vary between 320 m in the area of the Panda Pit and 485 m in the area of the Misery Pit based on thermistor data. The average thickness of the permafrost within the baseline study area is assumed to be approximately 400 m. Taliks (areas of unfrozen ground) may be present in the permafrost. Depending on lake size, depth, and thermal storage capacity, the talik beneath lakes may fully penetrate the permafrost layer resulting in an open talik.

In areas of continuous permafrost, there are 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 deep layer of low permeability permafrost, there is little to no hydraulic connection between these two flow regimes in areas where there are no open taliks.

Based on groundwater chemistry data from other sites in the Canadian Shield, the salinity of groundwater increases with depth (Frape and Fritz 1987). The salinity of the groundwater will result in freezing point depression and the formation of a layer of perennially cryotic (less than 0 degrees Celsius [°C]) but unfrozen ground at the base of the permafrost. This is termed the basal cryopeg. Although the basal cryopeg is part of the permafrost, it may contain unfrozen water, and groundwater flow may occur even though ground temperature is less than 0°C. The thickness of this layer is related to the salinity of the deep groundwater, the geothermal gradient, and the depth below ground surface (freezing point depression due to pressure effects). Based on the total dissolved solids (TDS) data for the Panda and Koala underground mines (Klohn Crippen 2005; Rescan 2006), freezing point depression could be between -1°C and -2°C at 300 m and 400 m depth, respectively. Considering -1°C to -2°C freezing point depression for the Ekati Mine, the depth to the basal cryopeg where unfrozen groundwater may first be encountered may be in the range of 185 to 415 mbgs.

3.2 Shallow Groundwater Regime

The shallow groundwater flow regime is active only seasonally during summer, and the magnitude of flow in this layer is expected to be several times less than runoff from snowmelt (Woo 2011). The water table in the active layer is a subdued replica of the topography. Hydraulic gradients in the Project area range from approximately 0.002 to 0.02 metres per minute (m/m), and annual groundwater velocities are in the order of 0.001 to 0.1 metres per day (m/d) (1×10^{-7} to 1×10^{-6} metres per second [m/s]). During winter, land is underlain by seasonal frost, which is in turn underlain by permafrost. From late spring to early autumn, when temperatures are above 0°C, the seasonal frost in the active layer becomes thawed. Water in the active layer is stored in ground ice during the cold season, and then released when it thaws in late spring or early summer, thus providing flow to surface waterbodies (Woo 2011). During the warm season, groundwater in the active layer is recharged primarily by precipitation.

The thickness of the active layer is variable and depends on several factors. The most important factors are the thaw index, thermal resistance of the vegetation cover, moisture content, and composition of soil or rock. In general, the active layer thickness at the end of summer season would range from 1 to 2.7 m of the ground surface.

Permafrost reduces the hydraulic conductivity of the bedrock by several orders of magnitude (Burt and Williams 1976; McCauley et al. 2002). Consequently, the permafrost in the rock would be virtually impermeable to groundwater flow. The shallow groundwater flow regime, therefore, has little to no hydraulic connection with the groundwater regime underlain by massive and continuous permafrost.

3.3 Deep Groundwater Regime

Water levels in lakes overlying open taliks provide the driving force for groundwater flow in the deep groundwater regime. Taliks exist beneath lakes that have sufficient depth so that they do not freeze to the bottom over the winter. If the lake is sufficiently large and deep, the talik can extend down to the deep groundwater regime. These taliks are referred to as open taliks. If the talik does not extend down to the deep groundwater, it is referred to as a closed or an isolated talik. Recharge to the deep groundwater flow regime is predominantly limited to open taliks.

Generally, deep groundwater will flow from higher-elevation lakes with open taliks to lower-elevation lakes with open taliks. To a lesser degree, groundwater beneath the permafrost is influenced by density differences in salinity (density-driven flow).

Lac du Sauvage is a large lake, which is up to 36 m deep in the area of the Jay pipe (Aurora 2013). Because of its size and areal extent, Lac du Sauvage is underlain by an open talik. Other major lakes inferred to be underlain by open taliks within the BSA include Paul Lake, Duchess Lake, and Lac de Gras.

Based on results for Lac de Gras, average late winter ice thicknesses at the Project are expected to range from 1.3 to 1.9 m, with an average thickness of 1.7 m. Taliks beneath lakes are assumed to extend vertically beneath the 1 m depth contour (60% of the mean ice thickness of 1.7 m) of the lakes for which bathymetry is available. For all lakes for which bathymetry is unavailable, the 1 m depth contour is assumed to correspond to the shoreline.

Results of the application of analytical models (MacKay 1962; Burn 2002) to determine temperature profiles for lakes at the Project indicate that open taliks may underlie circular lakes with a minimum radius of approximately 206 m, and elongate lakes with a minimum half width of approximately 99 m assuming that the lakes have sufficient depth. Based on these criteria, all lakes in the BSA with an area of 133,000 m^2 or greater are assumed to be underlain by open taliks that connect these lakes to the deep groundwater flow regime (Map 1.3-1). This assumption is conservative as some lakes in the BSA with sufficient area may be shallow and, therefore, may not be underlain by taliks.

3.4 Groundwater Usage

Groundwater sources from the active layer and from the deep groundwater below the permafrost are not currently used for drinking water or any project-related use in the Project area, nor are they currently used in other continuous permafrost regions in Canada. 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.

4 HYDROSTRATIGRAPHY

The Project is underlain by five main hydrostratigraphic units composed of overburden, weathered rock, competent rock, kimberlite, and an enhanced permeability zone (EPZ) associated with sub-vertical structures. 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 enhanced permeability associated with fault zones are assumed to have greater hydraulic conductivity than the surrounding less-disturbed rock mass.

4.1 Overburden

The thickness of the unconsolidated sediments that underlie Lac du Sauvage has been characterized in areas pertinent to the engineering design during the 2014 field season (Golder 2014). Lakebed sediments that underlie Lac du Sauvage are in turn underlain by a till layer which directly overlies the bedrock. In the area of the proposed JP5 Option 2 dike, the combined thickness of the lakebed sediments and the glacial till ranges from 0.5 m to 14.6 m with an average thickness of 6.5 m.

In situ hydraulic conductivity testing has been conducted in the overburden unit beneath the lake, and results of this testing are presented in Appendix B. The hydraulic conductivity of the shallow overburden beneath Lac du Sauvage estimated from the hydrogeologic testing ranges from 4×10^{-9} to 4×10^{-4} m/s. The geometric mean of hydrogeologic testing in this unit is 2×10^{-6} m/s, which is greater than the underlying bedrock and, therefore, will not restrict groundwater flow from the overlying lakes. These results are similar to the Diavik Mine, where measurements of the hydraulic conductivity of lakebed sediments have ranged from 2×10^{-8} m/s to 7×10^{-3} with an average of 4×10^{-5} m/s, which is more than two orders of magnitude greater than the underlying bedrock (Kuchling et al. 2000).

4.2 Shallow Bedrock

In the Canadian shield, the uppermost 10 to 30 m of bedrock is generally more highly fractured and correspondingly has greater hydraulic conductivity than the deeper underlying more competent rock, as has been observed at other sites where hydrogeologic testing data have been collected in shallow unfrozen bedrock (De Beers 2010; Golder 2004). This greater level of fracturing in the shallow rock is present as a result of the formation of stress relief joints due to isostatic rebound following glacial retreat. These stress relief joints are preferentially oriented horizontally, likely resulting in greater horizontal than vertical hydraulic conductivity in the shallow rock. Due to the preferential orientation of fracturing within this unit and the nearby source of water flow (Lac du Sauvage), the arithmetic mean of single-well response testing within the unit is considered to be the most representative measure of its horizontal hydraulic conductivity on the scale of the proposed mine.

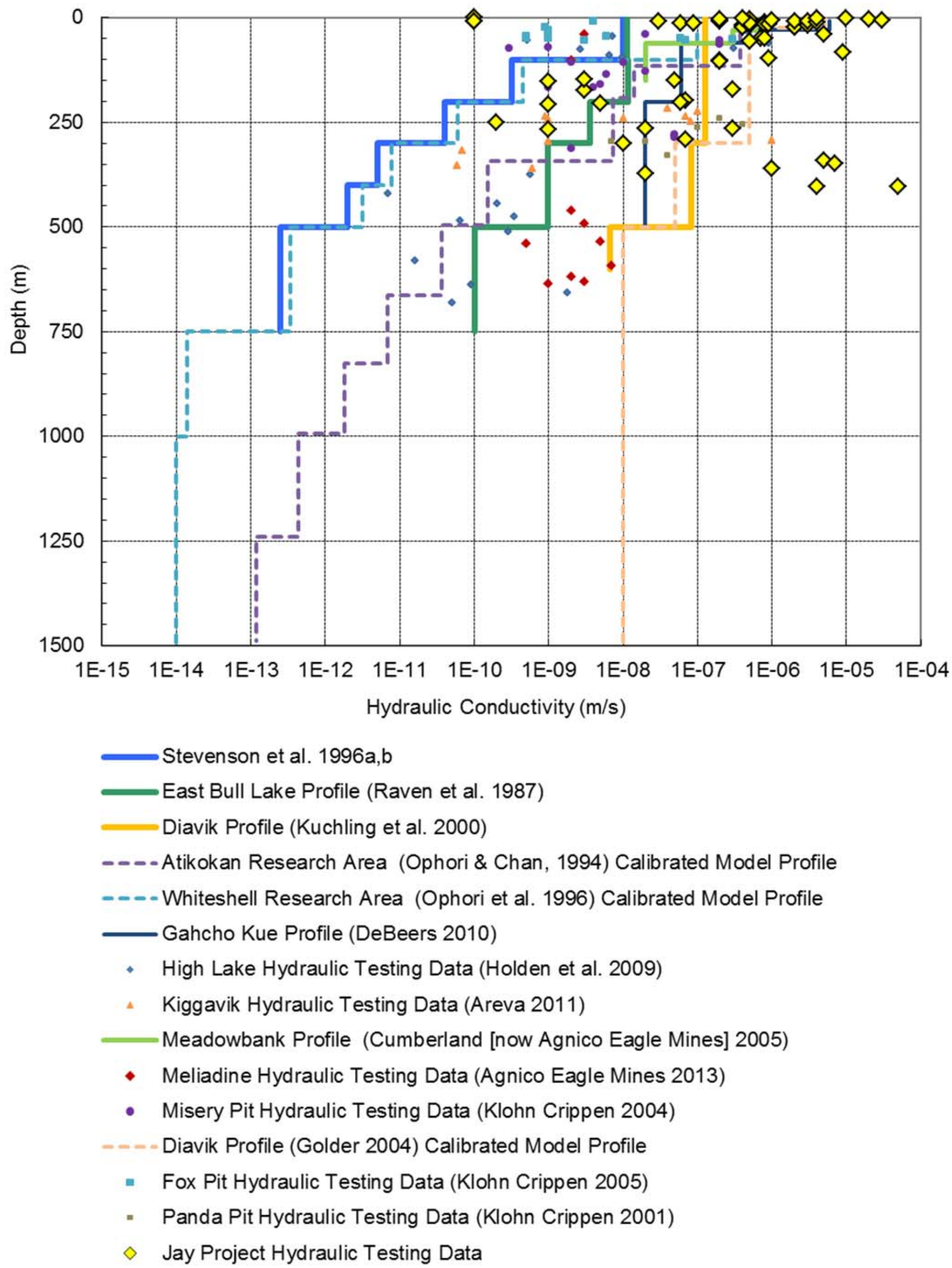
The arithmetic mean of the 26 single-well response tests conducted in bedrock at less than 30 m depth is approximately 4×10^{-6} m/s and is considered to be representative of the hydraulic conductivity of the shallow bedrock. This average excludes four single-well response tests that are considered to likely have been conducted in permafrost as the hydraulic conductivity was anomalously low (less than 1×10^{-10} m/s), and two single-well response tests conducted in temporary monitoring wells that may have had incompletely hydrated seals as the hydraulic conductivity was anomalously high (greater than 1×10^{-4} m/s). The estimated hydraulic conductivity of shallow bedrock is consistent with other diamond mines in the Canadian Shield (De Beers 2010; Golder 2004).

4.3 Competent Bedrock

At depths greater than 30 m, the bedrock is generally less permeable and the hydraulic conductivity is expected to decrease further with greater depth (Stober and Bucher 2007). Hydraulic conductivity depth data for 12 different sites located in the bedrock of the Canadian Shield including the Project is presented in Figure 4.3-1. Single-well response tests investigate a small-scale volume of rock near the well screen and, typically, in the bedrock of the Canadian Shield, when a large number of single-well response tests are conducted, the hydraulic conductivities inferred from individual tests will be log-normally distributed and range over several orders of magnitude (Kuchling et al. 2000). At mine sites in the Canadian Shield where there has been sufficient data to define a probability distribution, the results of single-well response testing in the bedrock vary between individual tests and generally range from 10^{-9} to 10^{-4} m/s (De Beers 2010; Kuchling et al. 2000). However, a hydraulic conductivity depth profile can be determined from the geometric mean of testing results calculated over depth intervals or from calibration of site-scale numerical models to groundwater inflows observed during mining.

At five of the sites shown in Figure 4.3-1, hydraulic conductivity depth profiles developed from the mean of hydrogeologic testing results are presented. These sites are as follows: Diavik Mine (Kuchling et al. 2000; Golder 2004), Gahcho Kué Project (De Beers 2010), Meadowbank Mine (Cumberland [now Agnico Eagle Mines] 2005), the Whiteshell Research Area (Stevenson et al. 1996a,b), and East Bull Lake (Raven et al. 1987). At all other sites (including the Jay Project), High Lake (Holden et al. 2009), Kiggavik (Areva 2011), Meliadine (Agnico Eagle Mines 2013), Misery Pit (Klohn Crippen 2004), Fox Pit (Klohn Crippen 2005), and Panda Pit (Klohn Crippen 2001), individual hydrogeologic testing results are shown. Profiles resulting from calibration of flow and transport models are also shown in Figure 4.3-1 for the Diavik Mine, the Whiteshell Research Area in Manitoba (Stevenson et al. 1996a,b), and the East Bull Lake area in Ontario (Raven et al. 1987). This figure demonstrates that the results of single-well response (packer) testing at the Project are generally within the range observed in bedrock within the Canadian Shield. However, five single-well response (packer) tests conducted between approximately 340 m depth and 400 m depth are anomalously high (greater than 1 x 10^{-6} m/s) (Figure 4.3-1). These tests are substantially higher than the Diavik Mine hydraulic conductivity profile, which was obtained from calibration of the site numerical hydrogeological model to inflows observed during the early stages of mining (Golder 2004), and which provides the most conservatively high hydraulic conductivity versus depth profile for bedrock in the Canadian Shield. Therefore, these tests are assumed to be representative of an enhanced permeability zone, and are discussed in more detail in Section 4.4. The geometric mean of the remaining 22 single-well response tests conducted in bedrock more than 30 m below the lake bottom is 3 x 10^{-8} m/s.

Figure 4.3-1 Hydraulic Conductivity Versus Depth in Bedrock of the Canadian Shield



m = metre; m/s = metres per second.

The hydraulic conductivity of the competent bedrock at Diavik Mine estimated from model calibration was approximately three times greater than that estimated primarily from the results of single-well hydrogeologic testing. This result is expected because hydraulic conductivity values determined from single-well response tests have been found to generally underestimate large-scale hydraulic conductivity by a factor of 2 to 5 times, depending on the relative scale of the disturbance to the scale of the hydrogeological regime (Illman and Tartakovsky 2006; Niemann and Rovey 2008). This effect is observed since single-well response tests are conducted over a small-scale volume of rock near the well screen and are more often representative of the lower-permeability rock composed of poorly connected and small aperture discontinuities (e.g., fractures). Where hydrostratigraphic units are heterogeneous, the hydraulic conductivity of the bedrock on the scale of the open pit is likely to be greater than tested. Testing of a larger volume of rock generally will include better-connected and larger aperture discontinuities and, hence, a higher permeability. For this reason, the hydraulic conductivity of bedrock derived from model calibration to observed mine inflow is considered to provide a more reliable estimate of hydraulic conductivity on the scale of the open pit mines. Therefore, the hydraulic conductivity of the bedrock at the Project on the scale of the proposed mine could be three times higher than that estimated from the geometric mean of response testing described above.

The Jay pipe is emplaced within two-mica granite, near the contact of the two mica granite and the metasediments (Geology Baseline Report [Annex III]). The contact between the two-mica granite and the metasediments is expected to be steeply dipping approaching the pipe area, and can be defined by an intermixing zone over a substantial depth interval (Annex III). Results of single-well hydraulic (packer) testing in the area of the Misery Pit suggest that metasedimentary bedrock (schist) has lower hydraulic conductivity than granite within the BSA. The metasedimentary rocks to the west of the Jay pipe were tested in three of the single-well response tests presented in Figure 4.3-1. The results of these tests ranged from 2×10^{-8} to 9×10^{-7} m/s and were generally within the range observed for the two-mica granite. Therefore, the metasediments are expected to have similar or lower hydraulic conductivity than the granitic bedrock.

Because the Diavik Mine is near the Project and is located in similar bedrock geology, the profile provides a reasonably conservative estimate of the hydraulic conductivity depth profile that would be encountered at the Project. Comparison of the Diavik Mine hydraulic conductivity profile obtained from calibration with packer testing results from the Ekati and Diavik mines is presented in Table 4.3-1.

Table 4.3-1 Estimated Hydraulic Conductivity of Competent Bedrock

Mine	Predominant Bedrock Type	Estimated K (m/s)
Ekati Jay[(a)]	granite and metasediments	3×10^{-8} to 9×10^{-8}
Ekati Panda[(b)]	granite	1×10^{-7}
Ekati Misery[(c)]	granite and schist	2×10^{-9} for schist to 5×10^{-8} for granite
Ekati Koala[(d)]	granite	1×10^{-8}
Ekati Fox[(e)]	granite	1×10^{-8}
Diavik hydrogeologic testing[(f)]	granite	2×10^{-7}
Diavik calibrated model[(g)]	granite	6×10^{-7}

a) The value for competent rock up to 300 m depth was derived from the mean of single-well response (packer testing). However, due to scale effects, the value could be three times higher than that estimated from single-well response tests.

b) The value for competent rock was derived from the geometric mean of single-well response (packer testing) (Klohn Crippen 2005).

c) The values for competent rock (granite and schist) were derived from the geometric mean of single-well response (packer testing) (Klohn Crippen 2004).

d) The value for competent rock assumed in the site hydrogeological model (Klohn Crippen 2006).

e) The value for competent rock were inferred from the results of single-well response (packer) testing, and assumed in the calibrated site hydrogeological model (Klohn Crippen 2005).

f) The value for competent bedrock up to 570 m depth below the lake bottom was determined from the average of hydrogeologic testing results (Kuchling et al. 2000).

g) The value for competent bedrock from 25 to 300 m depth below the lake bottom was determined from model calibration (Golder 2004).

K = hydraulic conductivity; m/s = metres per second.

4.4 Enhanced Permeability Zones

Enhanced permeability zones (EPZs), which are zones of greater fracturing and good hydraulic connectivity, related to structures such as faults, have been found to be present at operating diamond mines in crystalline rock of the Canadian Shield. Such zones may be present at the Project site, because these zones have been found at both the Diavik and Ekati mines (Table 4.4-1). Although multiple EPZs associated with structural features may be present near the Jay pipe, it is expected that the hydrogeologic importance of each individual EPZ will be variable. Multiple EPZs have been identified at the Panda, and Koala mines; however, for each mine one EPZ, with much greater hydrogeologic significance than all other EPZs, is present (Klohn Crippen 2001, 2006). This is also the case at Diavik where Dewey's Fault is the dominant structural and hydrogeologic feature.

The interpretation of structural geology (Annex III) in the Lac du Sauvage area, together with the results of hydrogeologic testing (as described above), were used to identify a potential well-connected EPZ that could be associated with structural features near the Jay pipe (Annex III). As discussed above, the results of five single-well response (packer) tests conducted in bedrock were anomalously high when compared to other representative data in the Canadian Shield (Figure 8.2-1). In addition, the results of two pumping tests conducted in the intervals of the Westbay multi-level monitoring well also indicated anomalously high hydraulic conductivity (1×10^{-5} m/s) at greater than 360 m depth. Because the scale of these tests is much smaller than the scale of the open pit, these results could indicate several isolated zones of enhanced permeability, but the results could also indicate the presence of a larger feature that is well connected on the scale of the mine. The presence of a large well-connected EPZ would result in greater mine inflow, and greater migration of saline groundwater water from depth; therefore, the assumption of such a feature is considered conservative.

Because groundwater inflow along a planar zone with enhanced permeability would be preferentially oriented along the dip and strike of the feature, the arithmetic mean of single-well response tests is expected to be representative of the hydraulic conductivity of a feature that is well-connected on the scale of the mine. This hydraulic conductivity of the assumed Jay EPZ is based on structural geology and on the hydraulic conductivities measured in five anomalously high single-well response tests in three boreholes (JGT-03, JGT- 05, and JGT-06) which have an arithmetic mean of 1×10^{-5} m/s. The mean of these single-well response tests agrees well with the estimated hydraulic conductivity derived from pumping tests in two of the ports in the Westbay multi-level monitoring well system (also 1×10^{-5} m/s). Moreover, the observation that these ports provided continuous flow over extended periods of time during interval development suggests that the tested zones may be permeable and laterally extensive.

Rock quality designation (RQD) is a method to quantify the percentage of "good" rock in a borehole. It is calculated by summing the lengths of all core pieces in a drill run or geotechnical interval that are greater than 10 centimetres (cm) in length, and presenting the summed length as a percentage of the total length of the interval or drill run. High-quality rock typically has an RQD greater than 75%, and low quality rock typically has an RQD less than 50%. In each of the intervals that are assumed to have intersected the Jay EPZ, at least one zone of very low RQD (0%) was logged within the interval or very near the interval.

The Jay EPZ is conservatively assumed to have a thickness of 60 to 100 m. This assumption is considered to be conservative based on experience at the Ekati and Diavik mines. Although the presently available data suggest that an EPZ could be oriented along the alignment of the boreholes with measured high hydraulic conductivity values, experience at other mines in the Canadian Shield (Bieber et al. 2006; De Beers 2004) demonstrates EPZs that are extensive on the scale of a mine can be challenging to identify in advance of mining on the basis of single-well response tests that examine a relatively small volume of rock. However, experience at the Snap Lake and Diavik mines (De Beers 2004; Golder 2004) also shows that in situations where mining occurs beneath a major lake, in a large open talik and far away from permafrost, the hydraulic connection that these EPZs provide to the lake can be substantial. Thus, although there is uncertainty as to the orientation and extent, or even the number of potential EPZs, the interpretation of a sub-vertical EPZ with a width of 60 to 100 m and a hydraulic conductivity of 1×10^{-5} m/s is consistent with the available data, and this assumption is considered to be conservative and prudent.

EPZs encountered at the existing Ekati and Diavik mines are presented in Section 4.4.1 and 4.4.2, and summarized in Table 4.4-1 to provide additional context on the presence, prevalence, and hydraulic properties of EPZs that may be encountered at the Project site during operations.

Table 4.4-1 Hydraulically Significant Enhanced Permeability Zones

Mine	Enhanced Permeability Zones	Hydraulic Conductivity (m/s)	Width (m)	Orientation	Identification/Characterization
Ekati Jay[(a)]	Jay EPZ	1×10^{-5}	60 to 100	sub-vertical NW–SE	satellite imagery and hydrogeologic testing
Ekati Koala[(b)]	Giant and Giant en-echelon	1×10^{-6}	50	sub-vertical NE–SW	aerial photographs, aeromagnetic surveys, underground mapping, hydrogeologic testing, and core logging
Ekati Misery[(c)]	Fracture Zones 1 to 4	-	-	SE–NW and NE–SW	satellite imagery, multiple types of core logging, and open pit mapping
Ekati Panda[(d)]	Dagger Fault	4×10^{-6}	20	NE–SW	core logging and hydrogeologic testing
Diavik A154[(e)]	Dewey's Fault Zone	1×10^{-5}	100	sub-vertical NE–SW	open pit seepage mapping, multiple types of borehole logging data, and targeted hydrogeologic testing

a) Width conservatively estimated from the range observed at other sites.
b) Klohn Crippen (2006); Water Management Consultants (WMC) (2006).
c) WMC (2010).
d) Klohn Crippen (2001).
e) Golder (2004); Bieber et al. (2007).
m/s = metres per second; m = metre; NE = northeast; NW = northwest; SE = southeast; SW = southwest; - = not available.

4.4.1 Diavik Mine

At Diavik Mine, a sub-vertical EPZ trending NE–SW referred to as Dewey's Fault was not identified in hydrogeological investigations conducted before mining (Kuchling et al. 2000). However, once mining began this feature was found to be the source of substantial groundwater inflow to the A154N/S Pit (Bieber et al. 2006). Dewey's Fault has been the subject of extensive hydrogeological characterization carried out during mining of the A154N/S Pit, including the collection of multiple types of borehole logging data such as fluid temperature, electrical conductivity, caliper, optical, and acoustic televiewer for holes drilled to investigate the feature. In addition, open pit seepage surveys and targeted hydrogeologic testing, including single-well response (packer) tests and a pumping test, were performed in this EPZ resulting in an estimated transmissivity of 1×10^{-3} m/s, assuming a width of 100 m and hydraulic conductivity of 1×10^{-5} m/s (Bieber et al. 2007). The width of the EPZ associated with Dewey's Fault has been found to become narrower with depth. For example, at approximately 400 m depth it is estimated to be approximately 60 m wide.

Additional EPZs have been found at Diavik Mine, but these zones have lower hydraulic conductivities or are thinner; therefore, they do not contribute as much flow to the mine as the EPZ associated with Dewey's Fault.

4.4.2 Ekati Mine

4.4.2.1 Panda Pit

In the area of the Panda Pit, approximately 25 EPZs associated with fault zones were identified within the predominantly granitic bedrock. Results of hydrogeologic testing within these zones ranged up to 1×10^{-5} m/s with an arithmetic mean of 4×10^{-6} m/s and geometric mean of 1×10^{-6} m/s (Klohn Crippen 2001). The dominant zone in the Panda Pit area is the Dagger Fault, which strikes NE–SW and possesses a broken zone of 10 to 20 m wide.

4.4.2.2 Koala Underground Mine

The EPZs associated with water-bearing faults within the granitic host rock provide the majority of groundwater inflow to the Koala Underground Mine. Several fault zones are present; however, the Giant Fault and its associated fractured rock zone, which trend NE–SW and bound the Koala Pipe on the north, have been identified as the most hydraulically significant (WMC 2006). The Giant Fault and EPZ have an estimated transmissivity of 5×10^{-5} m/s and hydraulic conductivity of 1×10^{-6} m/s, assuming a width of 50 m (WMC 2006). Other EPZs near this pipe are expected to be of lesser hydrogeological significance. These zones include the Lake Fault, the Masked Rider, and the Burwash Fault (Klohn Crippen 2006).

4.4.2.3 Fox Pit

At the Fox Pit, groundwater flow within the granite bedrock was identified as primarily through joints, fractures, and faults (Klohn Crippen 2005). However, the hydrogeologic testing program, and subsequent development of the conceptual model of hydrogeology for the Fox Pit, did not focus on the identification of specific areas of enhanced fracturing due to structural features. Instead, a holistic approach was taken by assuming that the vertical hydraulic conductivity of the granite bedrock was 10 times greater than the horizontal hydraulic conductivity of this unit to account for likely EPZs along sub-vertical features.

4.4.2.4 Misery Pit

Four potential EPZs associated with fractured rock zones, referred to as zones 1, 2, 3, and 4, have been identified at the Misery Pit (SWS 2010). Fracture zone 4, which trends NE–SW, is expected to be of the greatest hydraulic significance (SWS 2010). However, groundwater inflows to the Misery Pit were moderately low in 2010 and measured to be between 200 m^3/d and 300 m^3/d (SWS 2010). Although the fractured rock zones identified may have enhanced hydraulic conductivity, there is currently no substantial hydraulic connection to a source of water as only the bottom of the pit is connected through an open talik to the deep groundwater regime; permafrost is present surrounding the walls of the pit.

4.5 Kimberlite Pipes and Kimberlite Contact Zone

The kimberlite pipes are expected to have moderate hydraulic conductivity. Due to the presence of horizontal layering of interbeds in the kimberlite pipes (Annex III), the vertical hydraulic conductivity of the kimberlite is likely to be less than the horizontal hydraulic conductivity. The hydraulic conductivity of the kimberlite is expected to decrease with depth (Golder 2004). No hydraulic conductivity testing has been conducted in the Jay pipe; therefore, data collected at the Ekati and Diavik mines are discussed below. These data represent the range of hydraulic conductivity that could be expected in the Jay pipe.

Single-well response tests conducted in the Panda and Misery pipes yielded low hydraulic conductivity values ranging from 1×10^{-9} m/s to 2×10^{-8} m/s in four packer tests with a geometric mean of 2×10^{-9} m/s (Klohn Crippen 2001, 2004). As discussed above, due to scaling effects these results may provide lower bound estimates of hydraulic conductivity in the Panda and Misery pipes (Illman and Tartakovsky 2006; Niemann and Rovey 2008).

In the A154 North and South kimberlite pipes at Diavik Mine, the hydraulic conductivity estimated from inflows to cover holes was approximately 4×10^{-7} m/s. However, during calibration of numerical models in the A154 Pit, the calibrated values for hydraulic conductivity of these pipes were increased to between 3×10^{-6} m/s and 9×10^{-6} m/s for the A154 South and North kimberlite pipes (Bieber et al. 2007; Golder 2004).

The contact between kimberlite and competent rock is not expected to have substantially enhanced hydraulic conductivity. This has been the case at the Panda, Fox, and Koala pipes (Klohn Crippen 2001, 2005, 2006).

4.6 Summary

Based on the data collected at the Project discussed above, the hydraulic parameters for the key hydrostratigraphic units near the Jay pipe have been compiled and are summarized in Table 4.6-1. Where no site-specific information was available, data were supplemented by representative values from the literature or analogue sites (Maidment 1992; Guimerà and Carrera 2000; Golder 2004; Schulze-Makuch 2005; Stober and Bucher 2007).

All of the hydraulic conductivity values presented in Table 4.6-1 were derived from hydrogeologic testing results at the Project with the exception of the values for kimberlite (all depths), competent rock (greater than 400 m depth), and the Jay EPZ (greater than 400 m depth). Below 750 m depth, the hydraulic conductivity of both kimberlite and the Jay EPZ were decreased to 5 x 10^{-7} m/s. Below 1,000 m depth, the hydraulic conductivity of the Jay EPZ was reduced by to 1 x 10^{-7} m/s. These reductions are expected based on general trends of bedrock hydraulic conductivity with depth, as presented in Figure 4.3-1.

These values, summarized in Table 4.6-1, are considered conservative from the perspective of predicting mine inflows because the Jay EPZ, which provides a hydraulic connection between the un-diked portion of Lac du Sauvage and the open pit, has been assumed to be present and to have a width of up to 100 m. In addition, to account for scaling effects (Illman and Tartakovsky 2006; Niemann and Rovey 2008) in the conservative case, the hydraulic conductivity of competent rock has been increased by a factor of three from the values obtained from hydrogeologic testing.

Table 4.6-1 Summary of Hydrostratigraphic Units

Hydrostratigraphic Unit	Depth Interval (m)	Horizontal Hydraulic Conductivity (m/s)[a]	Ratio of Vertical to Horizontal Hydraulic Conductivity[b]	Specific Storage (1/m)[c]	Specific Yield (-)[c]	Effective Porosity (-)[c]	Longitudinal Dispersivity[d]	Transverse Dispersivity (m)[d]	Effective Diffusion Coefficient (m^2/s)
Overburden	0 to 5	2.E-06	1:1	1E-04	0.2	0.2	10	1	2E-10
Weathered bedrock	5 to 30	4.E-06	1:2	2E-04	0.03	0.03	10	1	2E-10
Competent bedrock	30 to 300	3.E-08 to 9.E-08	1:1	1E-05	0.0006	0.001	10	1	2E-10
Competent bedrock	300 to 500	1.E-08 to 3.E-08	1:1	1E-05	0.0006	0.001	10	1	2E-10
Competent bedrock	500 to 1,500	1.E-08 to 3.E-08	1:1	1E-05	0.0006	0.001	10	1	2E-10
Kimberlite (including contact zone)	25 to 500	3.E-06	1:2	1E-04	0.01	0.1	10	1	2E-10
Kimberlite (including contact zone)	500 to 750	3.E-07	1:2	1E-05	0.005	0.05	10	1	2E-10
Kimberlite (including contact zone)	750 to 1,500	3.E-08	1:2	1E-05	0.005	0.05	10	1	2E-10
EPZ[e]	25 to 400	1.E-05	1:1	1E-04	0.01	0.01	10	1	2E-10
EPZ[e]	400 to 750	5.E-06	1:1	1E-04	0.01	0.01	10	1	2E-10
EPZ[e]	750 to 1,000	5.E-07	1:1	1E-04	0.01	0.01	10	1	2E-10
EPZ[e]	1,000 to 1,500	1.E-07	1:1	1E-04	0.01	0.01	10	1	2E-10

a) Derived from hydrogeologic testing results at the Jay Project with the exception of the values for kimberlite (all depths), competent rock (greater than 400 m depth), and the Jay EPZ (greater than 40 m depth) which were derived from Golder (2004) supplemented by the data presented in Figure 4.3-1. The hydraulic conductivity of competent rock at all depths was assumed to be three times greater in the conservative case.

b) Vertical anisotropy assigned in both weathered rock and kimberlite based on the geological descriptions of these units.

c) Parameter values were conservatively derived from those used in the Diavik numerical model which was calibrated to inflow quantity and quality observed during mine operations (Golder 2004). These values are within the ranges documented in the literature (Maidment 1992; Stober and Bucher 2007).

d) These values were derived from Schulze-Makuch (2005).

e) Enhanced permeability zone (EPZ) assumed to be trending northwest-southeast, and to be 60 to 100 m wide based on hydrogeologic testing and geological evidence.

m = metre; m/s = metres per second; m^2/s = square metres per second; 1/m = per metre; - = no units; EPZ = enhanced permeability zone.

5 GROUNDWATER QUALITY

The results of analysis of groundwater quality samples collected from the Project in 2014 are presented in Appendix A. The Project groundwater quality is discussed in the context of the shallow groundwater flow regime and the deep groundwater flow regime at the Project site. Groundwater quality is discussed in the context of the total dissolved solids (TDS) and dissolved metal content of groundwater quality samples collected from the Project, Diavik Mine (Appendix C), Ekati Mine (Appendix D), and other project sites in the Canadian Shield.

Total dissolved solids (TDS) is the calculated sum of the dissolved concentrations of major ions in a water quality sample (Equation 1).

Equation 1

$$\text{TDS} = [\text{calcium}] + [\text{chloride}] + [\text{iron}] + [\text{potassium}] + [\text{magnesium}] + [\text{sodium}] + [\text{sulphate}] + [\text{fluoride}] + [\text{total alkalinity as } CaCO_3 * 0.6] + [4.427 \text{ x nitrate} + \text{nitrite as N}]$$

5.1 Shallow Groundwater Flow Regime

In the shallow groundwater flow regime, groundwater is expected to be low in TDS because the water in the shallow flow system is recharged seasonally from precipitation and from runoff during snowmelt. The TDS is expected to be less than 100 milligrams per litre (mg/L) with low concentrations of dissolved metals as has been observed at the Gahcho Kué Project located 136 km southeast of the Project (De Beers 2010).

5.2 Deep Groundwater Flow Regime

In the deep groundwater flow regime, the salinity of groundwater is expected to increase logarithmically with depth in the open taliks, and to further increase in the deep groundwater regime below the permafrost. Increasing TDS with depth in groundwater has been observed at numerous sites in the Canadian Shield (Blowes and Logsdon 1998; De Beers 2010; Frape and Fritz 1987; Greene et al. 2008). The origin of deep saline groundwater in the Canadian Shield has been the subject of substantial research at several mine sites, most notably at Lupin Mine (Stotler et al. 2009), Diavik Mine (Stotler et al. 2012), and Con Mine (Green et al. 2008). It was postulated that initially this high-salinity groundwater originated in response to rock-water interactions or as a result of infiltration of ancient seawater before and during glacial periods. In a recent comprehensive review of data compiled from numerous sites in the Canadian Shield, Stotler et al. (2012) concluded that the high salinity of groundwater may be the result of permafrost formation due to the concentration of solutes in residual fluids during freezing. This was the case at Diavik Mine where the relationship between chloride and oxygen isotopes (Stotler et al. 2012) indicates that the salinity of deep groundwater sampled in the talik beneath Lac de Gras was derived from a single in situ freezing process.

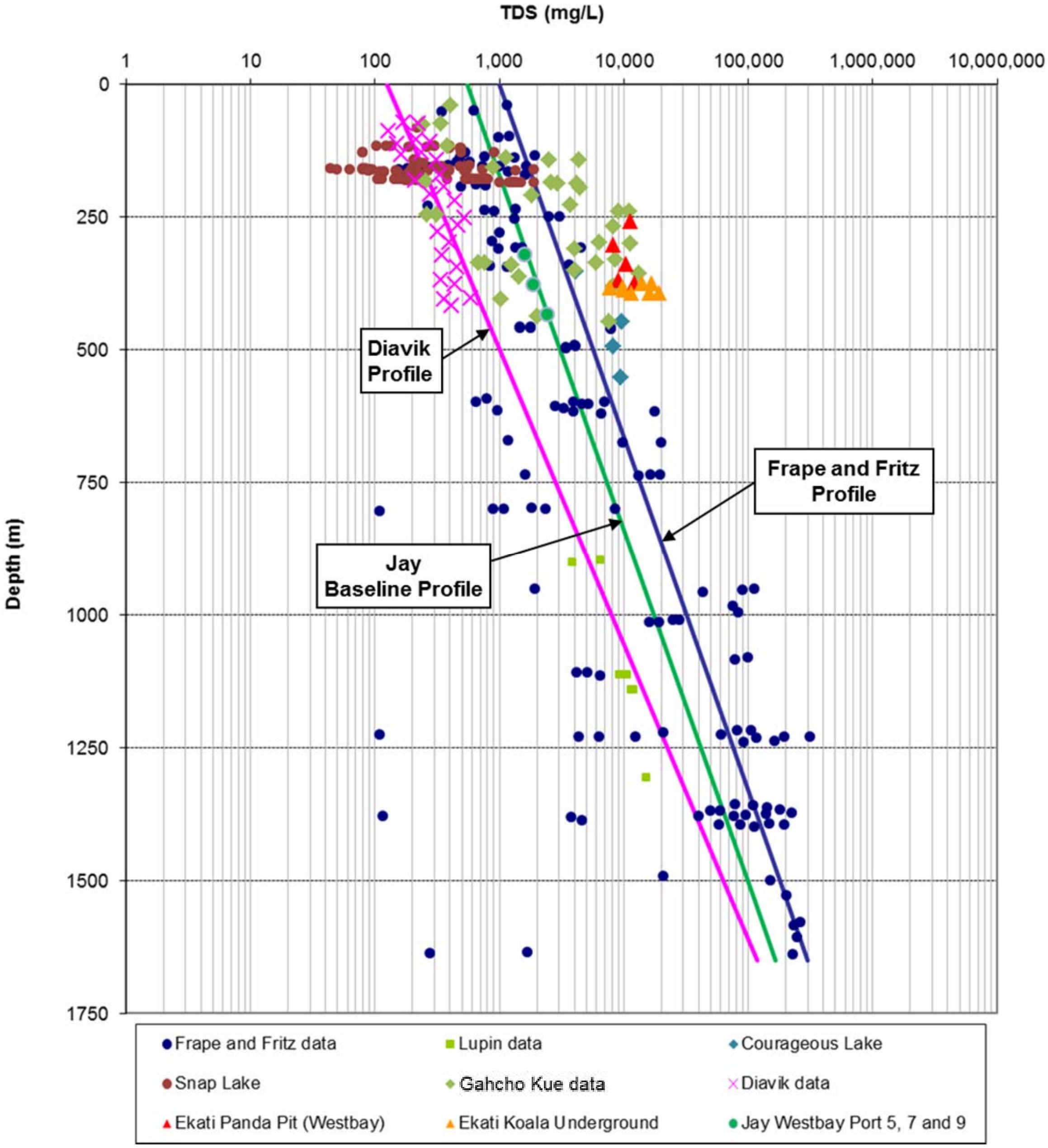
TDS concentrations measured in the Westbay monitoring well installation at the Project increased from 1,674 mg/L (approximately 320 m depth) to 2,390 mg/L (approximately 430 m depth), as presented in Figure 5.2-1. Figure 5.2-1 compares the TDS-depth profile from the Project to several project sites, including: Diavik Mine (Kuchling et al. 2000), Ekati Panda Pit (Klohn Crippen 2001), Ekati Koala Underground Mine (Klohn Crippen 2006), Snap Lake Mine (De Beers 2002), Gahcho Kué Project (De Beers 2010), Courageous Lake Project (Martin et al 2013) and other project sites in the Canadian Shield (Frape and Fritz 1987).

The results presented in Figure 5.2-1 demonstrate that the TDS concentrations observed at the Project follow a similar trend as other mines in the Canadian Shield. At 450 m depth, the TDS concentrations at the Project are assumed to be approximately three times greater than the Diavik Mine profile and approximately two times less than the Frape and Fritz profile. Data collected within the extensive taliks underlying Snap Lake, Kennady Lake (Gahcho Kué Project), Lac de Gras (Diavik Mine), and Lac du Sauvage (Jay Project) are generally lower TDS than those that have been observed in the Ekati Panda and Koala mines at comparable depths. The TDS concentrations measured in samples collected from depth at the Ekati Panda and Koala mines are similar to the TDS concentrations in samples collected at the Lupin Mine (Stotler et al. 2009). At the Lupin mine, TDS concentrations measured in deep groundwater in bedrock overlain by a talik were lower than those measured at equivalent depths overlain by undisturbed permafrost. This result suggests that deep groundwater in open (penetrating) talik areas may have lower TDS concentrations than beneath permafrost due to the hydraulic connection with the overlying lake. However, this evidence is not conclusive because samples collected at the Lupin Mine may have been contaminated by drilling fluids or affected by the hydraulic influence of mining (Stotler et al. 2009)

Figure 5.2-1 presents a TDS profile for the Project. The Project TDS profile was developed using the results of groundwater quality analysis from the Project (Appendix A); data from other projects in the Canadian Shield was used to supplement the Project TDS profile. The Project TDS profile assumes that TDS in the Project area increases with depth from a TDS concentration of approximately 800 mg/L at 100 m depth to approximately 98,000 mg/L at 1.5 km depth. The profile previously derived for the Diavik Mine is shown for comparison (Kuchling et al. 2000). The Diavik profile was derived from site-specific data from Diavik Mine, supplemented by information from the Lupin Mine site located approximately 200 km north of Diavik Mine. In the Diavik profile, TDS at 100 m depth is approximately 200 mg/L and at 1.5 km depth, it is approximately 63,000 mg/L. The Frape and Fritz profile (1987) is also shown for comparison. This profile results in predicted TDS of 1,400 mg/L at 100 m depth, and predicted TDS of approximately 180,000 mg/L at 1.5 km depth. Therefore, the Project profile is considered to provide a reasonable representation of the TDS concentrations expected at the Project.

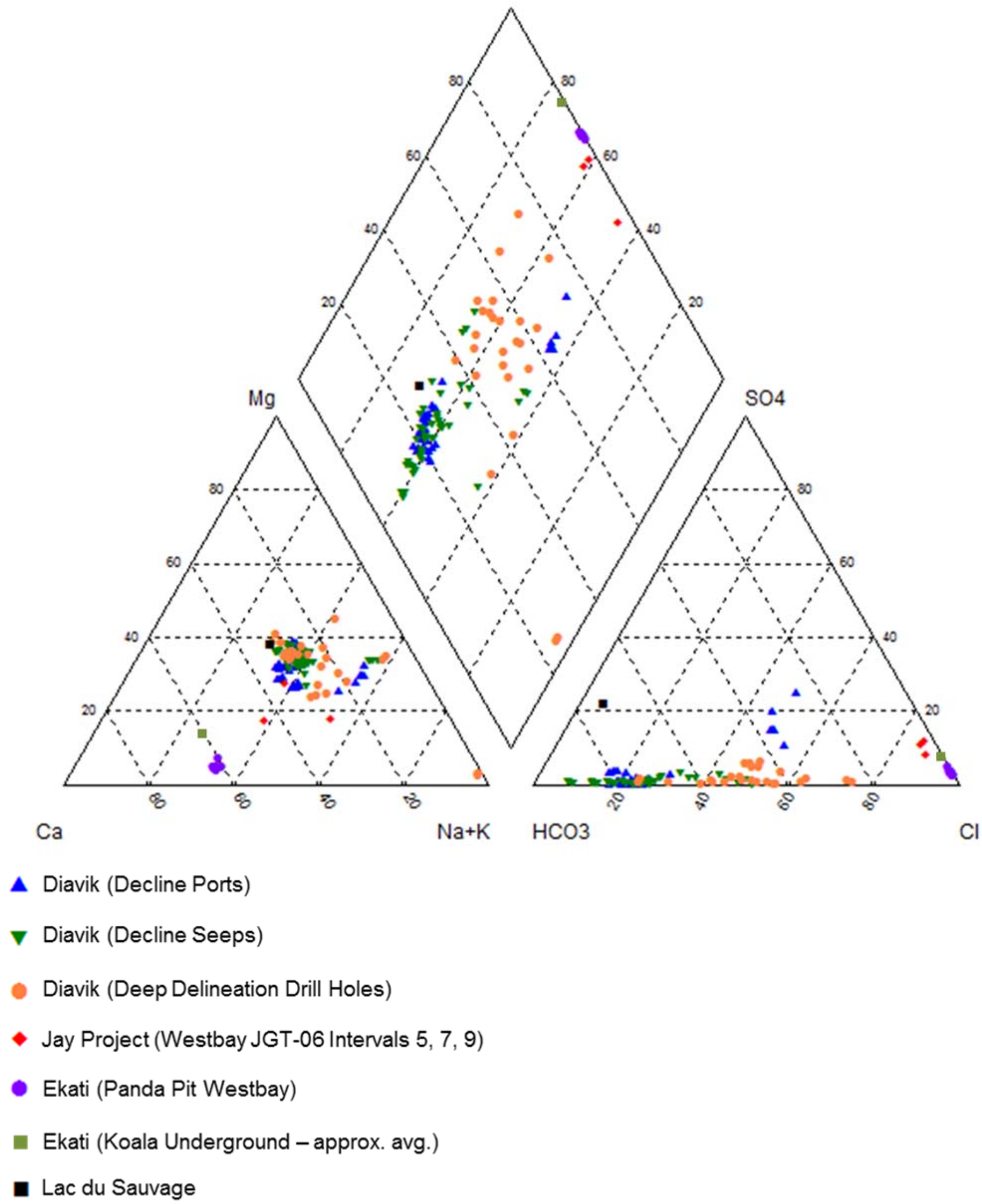
Figure 5.2-2 compares the major ion composition of water quality samples collected within the deep groundwater flow regime (within open taliks or beneath permafrost) at the Project to data from the Diavik Mine (Blowes and Logsdon 1998), the Panda Pit Westbay installation (Ekati Jay and Panda Groundwater Quality Versus Depth Plots [Appendix E]), and the Koala Underground Mine (Klohn Crippen 2006). The results of water quality sampling in Lac du Sauvage collected in 2013 are also presented on this plot for comparison; this information is presented as the average of lake water data from the four monitoring stations closest to the Project (AC-1, AC-2, AC-7, and AC-8).

Figure 5.2-1 Total Dissolved Solids Versus Depth in the Canadian Shield



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

Figure 5.2-2 Piper Plot of Groundwater at Diavik and Ekati Mines



Mg =magnesium; SO_4 = sulphate; Ca = calcium; Na+K = sodium + potassium; Cl = chlorine; $HC0_3$ = bicarbonate.

Groundwater at the Project is generally sodium-calcium-chloride (Na-Ca-Cl) type water with moderately high TDS (up to 2,390 mg/L at approximately 430 m depth). In comparison, groundwater at Diavik Mine to the southwest of the Jay pipe is generally sodium-magnesium-calcium – bicarbonate-(chloride) (Na-Mg-Ca-HCO_3-[Cl]) type water with moderate TDS generally less than 500 mg/L down to 420 mbgs depth (Blowes and Logsdon 1998). Lac du Sauvage has low TDS concentrations (average TDS of 16 mg/L), which are similar to other lakes in the region. Blowes and Logsdon (1998) found that the stable isotope and tritium signatures at Diavik Mine were distinct from Lac de Gras signatures. They also concluded that the groundwater samples had a general chemistry consistent with moderate to long residence time in granitic terrain that had recharged under a cold climate. In contrast, groundwater at the Ekati mining operations (Panda Pit and Koala Underground Mine) is generally calcium-sodium-chloride (Ca-Na-Cl) type water with greater TDS ranging up to 20,000 mg/L at similar depths (down to 390 mbgs).

Trends in concentrations of major ions with depth are presented for the Project, together with the Panda Westbay data set, in Appendix E. Trends in concentrations of major ions with depth at the Diavik Mine are also presented in Diavik Groundwater Quality Versus Depth Plots (Appendix F). Both Ekati Jay/Panda and Diavik data sets show concentrations of calcium, magnesium, sodium, and chloride increasing with depth. Metals concentrations in both data sets are low and often below lab detection limits. A correlation with depth is observed for strontium in the Ekati Jay/Panda and Diavik data sets, as has been observed at other sites in the Canadian Shield (Négrel and Casanova 2005).

In the Jay Westbay dataset, nitrate and ammonia are low (generally less than 0.3 mg/L). Similarly, nitrite concentrations are all less than 0.0053 mg/L, while all total dissolved phosphorus concentrations are less than 0.036 mg/L. In the Diavik dataset, these nutrients were generally at similar levels with the exception of total phosphorus, which was higher in the Diavik dataset (ranging from less than 0.01 to 0.9 mg/L). The higher levels of phosphorus (greater than 0.5 mg/L) were generally observed in data collected from the 10 m long boreholes drilled into bedrock along the decline developed during exploration.

In the Ekati/Panda Westbay dataset, concentrations of the nutrients were also generally at similar levels with the exception of ammonia which ranged from less than 0.005 to 1.13 mg/L, and nitrate which ranged up to 39.5 mg/L in a small number of samples in the Panda Westbay dataset. The Panda Westbay was installed from a bench within the Panda open pit during mining of that pit, and the highest nitrate and ammonia concentrations were observed in shallowest samples, which were closest to the wall of the open pit; therefore, these high concentrations are likely due to the influence of mining related to blasting. Of the three datasets, only the Jay groundwater quality samples were collected prior to the advance of an exploratory decline or open pit mining; therefore, the lower concentrations of these nutrients collected at the Jay Project are considered the most representative of baseline conditions at the Jay Project.

The lab pH of the samples in the Project dataset was narrow, ranging from 7.6 to 7.7. The field pH of the Diavik Mine groundwater samples varies between 7.24 and 10.7 with a mean value of 8.0. In the Ekati Panda Westbay data, field pH generally varies from 6.1 to 7.3 with a mean of 6.7.

The presence of a strong hydrogen sulphide odour was noted and confirmed using air monitoring equipment during the well development of the Jay Westbay multi-level monitoring well. The presence of hydrogen sulphide is attributed to volatilization of dissolved sulphide from the groundwater during the well development procedures which involved injection of air to displace water from the well pipe (air lifting). A strong hydrogen sulphide odour has also been noted in groundwater samples taken at the Ekati Koala Underground Mine (Klohn Crippen 2006). The source of hydrogen sulphide at the Jay and Koala mines is hypothesized to be the decomposition of zones of organic material within the kimberlite pipes.

6 GROUNDWATER FLOW

6.1 Shallow Groundwater Flow Regime

Within the active layer, the water table is expected to be generally a subdued replica of topography and roughly parallel to the topographic surface. Therefore, groundwater gradients during months when this flow system is active would generally be similar to topographic gradients. Groundwater in the active layer primarily flows to local depressions and ponds that drain to larger lakes; therefore, the total travel distance would generally extend only to the nearest pond, lake, or stream.

Although hydraulic gradients generally follow land topography, thickness of the active layer varies due to local climate conditions, vegetation cover, and soil properties (Geological Survey of Canada 1998). These variations, combined with variations in the hydraulic conductivity of the shallow subsurface materials, control the magnitude of flow in the shallow groundwater flow system, and can affect flow directions (Woo 2011). Where organic cryosols associated with ice-wedge polygons are present in more poorly drained areas and lowlands in the Project area (Aurora 2013), groundwater will be concentrated and will flow orders of magnitude more quickly than in areas where lower permeability bedrock is exposed at surface.

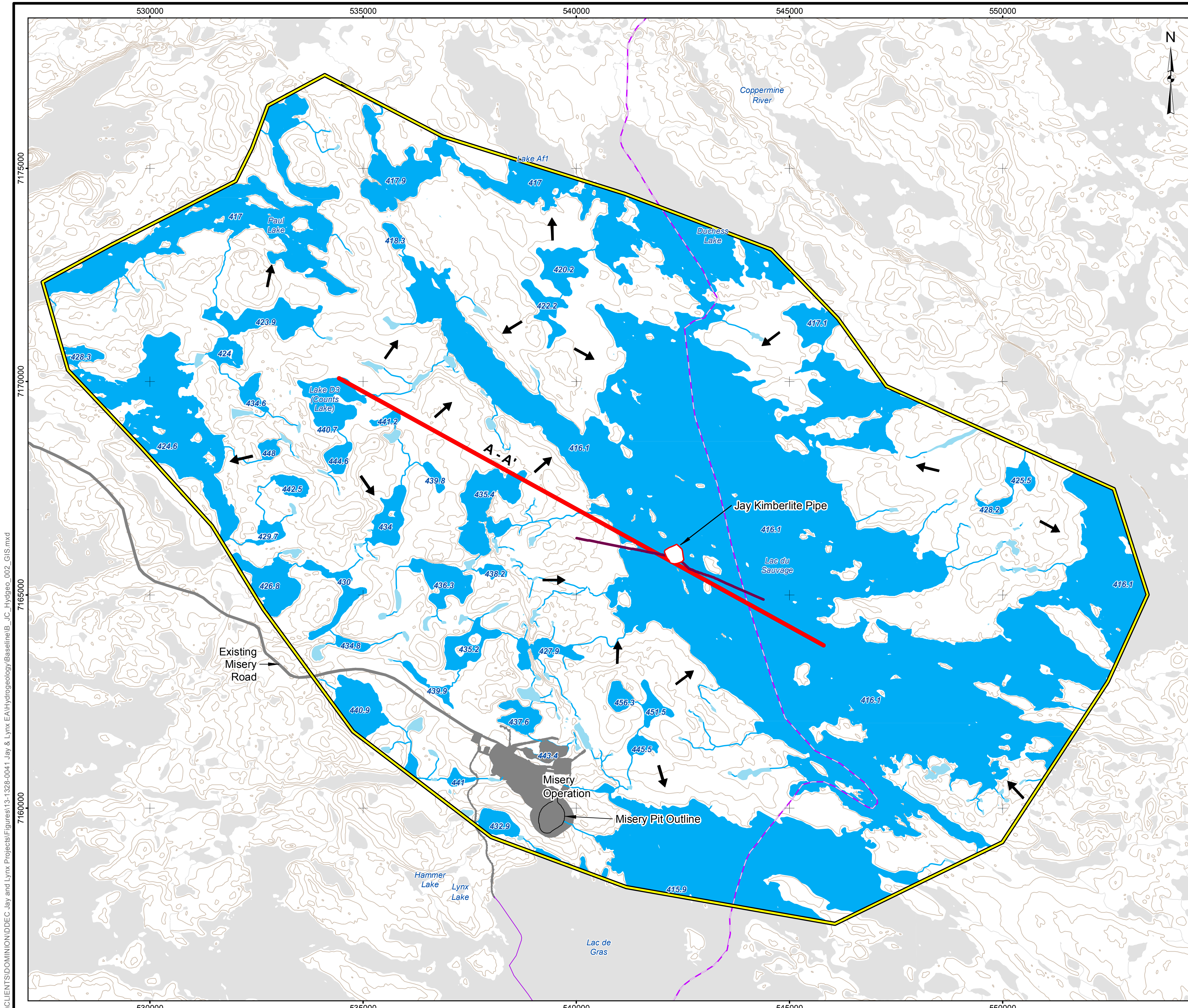
6.2 Deep Groundwater Flow Regime

Open taliks play a pivotal role in controlling the deep groundwater flow, because the lakes provide the driving head for the flow system beneath the zone of continuous permafrost. Generally, groundwater will flow via open taliks 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 Map 6.2-1.

The elevations of these lakes indicate that the groundwater flow direction in the deep groundwater flow regime is towards Lac du Sauvage. Lac du Sauvage is expected to be primarily a groundwater discharge zone with the exception of the southern extent of the lake where groundwater flow likely is directed towards Lac de Gras. Hydraulic gradients are expected to be near hydrostatic or weakly upward over most of the lake area. As discussed in Section 5, the TDS of groundwater (or salinity) is expected to increase with depth resulting in increased density of groundwater with depth. This increase in density with depth will result in fluid density gradients that counteract the upward gradient to Lac du Sauvage, as the less dense fresher water will have greater buoyancy than deeper saline groundwater (Post et al. 2007).

These groundwater flow directions were inferred assuming that open taliks exist beneath the lakes identified in Map 6.2-1. Also, on the regional scale, the hydraulic conductivity of the bedrock beneath the permafrost was assumed to be relatively homogeneous and isotropic.

The Misery Pit is currently in operation within the BSA; however, the ultimate depth of the Misery Pit will be limited to approximately 300 mbgs, and has been developed in low hydraulic conductivity rock (Klohn Crippen 2004). In addition, groundwater inflow during mining at the Misery Pit has been relatively low (less than 300 m^3/d); therefore, the hydrogeological influence of this mine is expected to be limited to the immediate area of the open pit mine. Similarly, the Lynx Pit is planned to extend to a depth of less than 150 mbgs. Therefore, dewatering of these open pit mines will have negligible effect on groundwater flow directions in the deep groundwater flow regime.



LEGEND

- EKATI MINE FOOTPRINT
- DIAVIK MINE FOOTPRINT
- KIMBERLITE PIPE
- TIBBITT TO CONTWOYTO WINTER ROAD
- NORTHERN PORTION OF TIBBITT TO CONTWOYTO WINTER ROAD
- HIGHWAY
- ALL-SEASON ROAD
- WINTER ROAD
- ELEVATION CONTOUR (10 m INTERVAL)
- WATERCOURSE OUTSIDE THE BSA
- WATERBODY OUTSIDE THE BSA
- BASELINE STUDY AREA (BSA)
- CONCEPTUAL CROSS-SECTION
- INFERRED GROUNDWATER FLOW DIRECTION
- WATERCOURSE INSIDE THE BSA
- LAKE INSIDE THE BSA WITH INFERRED OPEN TALIK
- LAKE INSIDE THE BSA WITHOUT INFERRED OPEN TALIK
- ENHANCED PERMEABILITY ZONE (LATERAL EXTENT INFERRED)
- *416.2* LAKE ELEVATION (masl)

REFERENCE

CANVEC © NATURAL RESOURCES CANADA, 2012
NATURAL RESOURCES CANADA, CENTRE FOR TOPOGRAPHIC INFORMATION, 2012
DATUM: NAD83 PROJECTION: UTM ZONE 12N

DOCUMENT

HYDROGEOLOGY BASELINE REPORT

2 0 2
SCALE 1:90,000 KILOMETRES

PROJECT
DOMINION DIAMOND
JAY PROJECT
NORTHWEST TERRITORIES, CANADA

TITLE

GROUNDWATER FLOW IN THE BASELINE STUDY AREA

Golder Associates

PROJECT	13-1328-0041		FILE No. B_JC_Hydgeo_002_GIS	
DESIGN	CB	06/01/14	SCALE AS SHOWN	REV 0
GIS	ANK	11/09/14	MAP 6.2-1	
CHECK	CG	11/09/14		
REVIEW	SM	11/09/14		

7 SUMMARY

7.1 Conceptual Hydrogeological Model

Available hydrogeological data collected at the site and at nearby mining facilities, together with the information collected elsewhere in the Canadian Shield, were used to develop conceptual understanding of groundwater conditions at the Project site. A conceptual hydrogeological model is a pictorial and descriptive representation of the groundwater regime that organizes and simplifies the site conditions so they can be readily modelled. The conceptual model must retain sufficient complexity so that the analytical or numerical models developed from it adequately reproduce or simulate the actual components of the groundwater flow system to the degree necessary to satisfy the objectives of the modelling study. The baseline conceptual model has been developed to describe key features of the hydrogeological regime in the BSA before mining. The key features include the groundwater flow, groundwater quality, and dominant groundwater flow direction, all of which are described in more detail below. The baseline conceptual model is presented in Figure 7.1-1, and described below.

7.2 Permafrost

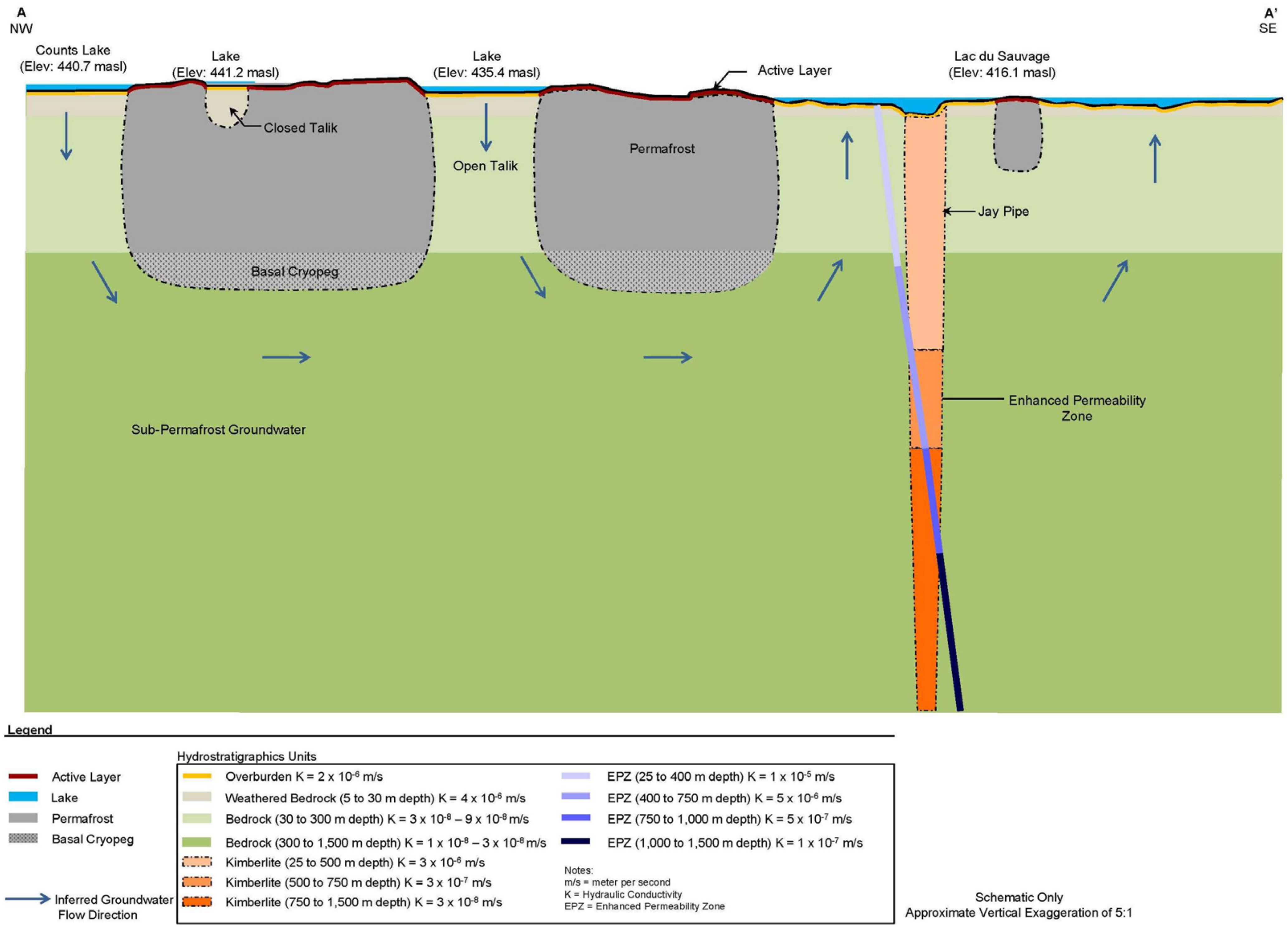
The Project site is located within a region of continuous permafrost. In this region, the layer of permanently frozen subsoil and rock is generally deep and overlain by an active layer that thaws during summer. The depth of the active layer in the Misery Pit area ranges from approximately 1.0 to 2.7 m (Annex IV). Permafrost thickness (defined by the depth to the zero degree isotherm) in the BSA is expected to vary between 320 m in the area of the Panda Pit and 485 m in the area of the Misery Pit. The average thickness of the permafrost within the BSA is assumed to be approximately 400 m. The average depth to the basal cryopeg (where the temperature of the ground surface is equal to the freezing point of the saline groundwater found at depth) is conservatively assumed to be at 300 m depth. Lakes with areas of 133,000 m^2 or larger are assumed to be connected to the deep groundwater flow regime through open taliks.

7.3 Hydrostratigraphy

The conceptual model for the site consists of five hydrostratigraphic units composed of overburden, weathered rock, competent rock, kimberlite, and enhanced permeability zones (EPZs) associated with sub-vertical faults. In developing the conceptual model of hydrostratigraphy for the site, a reasonably conservative approach was taken so that the actual magnitudes of groundwater inflows (quantity and quality) to the open pits during simulation of mining are expected to be less.

Overburden and weathered bedrock are limited to the near surface, while relatively competent bedrock is assumed to comprise the majority of the rock domain. The hydraulic conductivity of competent rock is assumed to decrease with depth. Areas of enhanced permeability may be associated with structures such as fault zones, and these are assumed to have greater hydraulic conductivity than the surrounding less-disturbed rock mass. Such EPZs have been found to be present at Diavik and Ekati mines. Based on the interpretation of structural geology (Annex III) and the results of hydrogeologic testing, a substantial EPZ is conservatively assumed to be present at the Jay pipe. This is referred to as the Jay EPZ. This zone is considered to be of potential importance for governing groundwater inflow quality and quantity to the planned open pit. The assumed hydraulic properties of hydrostratigraphic units near the Jay pipe are summarized in Table 4.6-1.

Figure 7.1-1 Conceptual Model of Deep Groundwater Flow Regime – Pre-mining Jay Pipe Cross-Section View



Permafrost is assumed to be essentially impermeable with the exception of the basal cryopeg (assumed to be at 300 mbgs). This portion of the permafrost that may contain unfrozen groundwater due to freezing point depression is assumed to be entirely unfrozen and have a hydraulic conductivity equivalent to the unfrozen rock at that depth. In reality, isolated pockets of groundwater within this zone may be frozen, resulting in a decrease in the hydraulic conductivity of the rock compared to that of the entirely unfrozen rock. However, the degree of this reduction is difficult to quantify. Therefore, it is conservatively assumed that there is no reduction in hydraulic conductivity over this portion of the permafrost.

7.4 Groundwater Quality

Groundwater is low in TDS in the shallow (active layer) zone, and in Lac du Sauvage. In the deep groundwater flow regime, the groundwater is expected to increase in TDS with depth. Groundwater at the Project is generally sodium-calcium-chloride (Na-Ca-Cl) type water with moderately high TDS (up to 2,390 mg/L at 430 m depth). The pH of the Project groundwater samples ranged from 7.6 to 7.7. The majority of total and dissolved metals concentrations (with concentrations above the detection limit) showed an increasing trend with depth in the three samples collected. Exceptions included barium, magnesium, manganese, and silicon, which showed no obvious trend. Based on this evidence, concentrations of solutes are likely to be moderate, and concentrations of major ions are expected to be between those in the Diavik Mine groundwater and the Ekati Mine groundwater.

Total dissolved solids (TDS) concentrations are expected to increase with depth as has been observed at other sites in the Canadian Shield (Frape and Fritz 1987; Kuchling et al. 2000; De Beers 2010). Based on trends in concentrations of major ions with depth observed in the Ekati Jay/Panda data and Diavik Mine data sets, concentrations of calcium, magnesium, sodium, potassium, and strontium are expected to increase with depth. Metals concentrations are expected to be low (Appendices A, C, and D).

7.5 Groundwater Flow Regimes

Two groundwater flow regimes occur at the Project: a deep groundwater flow regime beneath permafrost and a shallow groundwater flow regime located in the active (seasonally thawed) layer near the ground surface. With the exception of areas of taliks beneath lakes, the two groundwater regimes are isolated from one another by the thick permafrost.

The shallow groundwater regime is active only seasonally during the summer months, and the magnitude of flow in this layer is expected to be several times less than runoff from snowmelt (Woo 2011). Groundwater in the active layer primarily flows to local depressions and ponds that drain to larger lakes; therefore, the total travel distance would generally extend only to the nearest pond, lake, or stream. Water in the active layer is stored in ground ice during the cold season, and then released when the ice thaws in late spring or early summer, thus providing flow to surface waterbodies (Woo 2011). During the warm season, groundwater in the active layer is recharged primarily by precipitation.

Groundwater flow within the deep groundwater flow regime is limited to the sub-permafrost zone and potentially within the basal cryopeg. The deep groundwater flow regime is connected to the ground surface by open taliks underlying larger lakes. The elevations of these lakes are expected to control groundwater flow direction in the deep groundwater flow regime, along with density gradients.
The elevations of these lakes in the BSA indicate that Lac du Sauvage is primarily a groundwater discharge zone with the exception of the southern extent of the lake where groundwater flow likely is directed towards Lac de Gras. Hydraulic gradients are expected to be near hydrostatic or weakly upward over most of the lake area. The TDS of groundwater (or salinity) is expected to increase with depth, resulting in increased density of groundwater with depth. This increase in density with depth will result in fluid density gradients that counteract the upward gradient to Lac du Sauvage to an extent because the less dense fresher water will have greater buoyancy than deeper saline groundwater.

8 REFERENCES

Agnico Eagle Mines. 2013. Volume 7.0 Freshwater Environment and Impact Assessment – Environmental Impact Statement (DEIS) – Meliadine Gold Project, Nunavut. Prepared by Golder Associates Ltd.

Areva. 2011. Kiggavik Project Environmental Impact Statement Tier 3 Technical Appendix 5B Geology and Hydrogeology Baseline. December 2011.

Aurora (Aurora Geosciences Ltd.). 2013. Technical Report Lac du Sauvage – Northwest Territories, Canada.

Bieber C, Chorley D, Zawadzki W, Reinson J. 2006. Hydrogeologic Data Collection and Development of Conceptual Models to Predict Mine Inflow Quantity and Quality at Diavik Diamond Mine, NWT. 59th Canadian Geotechnical Conference and 7th Joint CGS/IAH-CNC Groundwater Specialty Conference, Vancouver, BC, Canada. M6-B Data Collection II.

Bieber C, Moffitt K, Chorley D, Zawadzki W, Greer S. 2007. Detailed Evaluation of Pit Slope Stability in Fractured Rock and Kimberlite Slope – Diavik Diamond Mine, NWT. OttawaGeo2007: The Diamond Jubilee Conference, Ottawa, ON, Canada.

Blowes DW, Logsdon MJ. 1998. Diavik Geochemistry Baseline Report. Prepared for Diavik Diamond Mines Inc.

Burt TP, Williams PJ. 1976. Hydraulic Conductivity in Frozen Soils, Earth Surface Processes. Volume 1, John Wiley, pp 349-360.

Burn CR. 2002. Tundra lakes and permafrost, Richards Island, western Arctic coast, Canada. Can J Earth Sci 39: 1281-1298.

Cumberland (Cumberland Resources Ltd.). 2005. Meadowbank Gold Project Mine Waste and Water Management. October 2005.

De Beers (De Beers Canada Inc.). 2002. Snap Lake Diamond Project: Environmental Assessment Report. Submitted to the Mackenzie Valley Review Board. February 2002.

De Beers. 2010. Environmental Impact Statement for the Gahcho Kué Project. Volumes 1, 2, 3a, 3b, 4, 5, 6a, 6b, 7, and Annexes A through N. Submitted to Mackenzie Valley Review Board. December 2010.

Dominion Diamond (Dominion Diamond Ekati Corporation). 2012. Environmental Agreement and Water License Annual Report 2012. Submitted in accordance with Article V, Section 5.1 of the Environmental Agreement Part B, Section 1 of Type A Water Licence W2009L2-0001. April 2013.

Douglas M, Clark ID, Raven K, Bottomley D. 2000. Groundwater mixing dynamics at a Canadian Shield mine. J Hydrol 235 (2000): 88-103.

Frape SK, Fritz P. 1987. Geochemical trends for groundwaters from the Canadian shield; in saline water and gases in crystalline rocks. Editors: Fritz, P. and Frape, S.K. Geological Association of Canada Special Paper 33.

Geological Survey of Canada. 1998. Living with Frozen Ground: A field guide to permafrost in Yellowknife, Northwest Territories. Miscellaneous Report 64.

Golder (Golder Associates Ltd.). 2004. Diavik Hydrogeologic Numerical Model December 2004 Re-Calibration. Submitted to Diavik Diamond Mines Inc.

Golder. 2014. Jay Project Geotechnical and Hydrogeological Field Investigation Factual Report Vol. 1 Proposed Dikes. Submitted to Dominion Diamond Ekati Corporation. Reference Number: 1313280041-E14041a-R-Rev0-2010. July 2014.

Greene S, Battye N, Clark I, Kotzer T, Bottemley D. 2008. Canadian Shield brine from the Con Mine, Yellowknife, NWT, Canada: Noble gas evidence for an evaporated Paleozoic seawater origin mixed with glacial meltwater and Holocene recharge. Geochimica et Cosmochimica Acta 72 (2008): 4008-4019.

Guimerà J, Carrera J. 2000. A comparison of hydraulic and transport parameters measured in low-permeability fractured media. J Contam Hydrol 41 (2000): 261-281.

Holden B, Stotler RL, Frape SK, Ruskeeniemi T, Talikka M, Freifeld BM. 2009. High Lake Permafrost Comparison Site: Permafrost Phase IV, NWMO TR-2009-11. June 2009.

Illman W, Tartakovsky D. 2006. Asymptotic analysis of cross-hole hydraulic tests in fractured granite. Ground Water 44 no. 4: 555-563.

Klohn Crippen. 2001. Phase II Hydrogeological Evaluation of Panda Pit. File: 878802

Klohn Crippen. 2004. Ekati Mine Hydrogeological Evaluation of Misery Pit and Underground. File: M08788 07.500.

Klohn Crippen. 2005. Ekati Mine 2004 Hydrogeological Investigation of Fox Pit. File: A0304A01.500.

Klohn Crippen. 2006. Ekati Mine 2005 Koala Feasibility Report Underground Mine Dewatering Final Report. File: A03040A02.500.

Kuchling K, Chorley D, Zawadzki W. 2000. Hydrogeological modelling of mining operations at the Diavik Diamonds Project. In Proceedings of the Sixth International Symposium on Environmental Issues and Waste Management in Energy and Mineral Production, University of Calgary, Calgary, AB, Canada.

Mackay JR. 1962. Pingos of the Pleistocene Mackenzie Delta Area. Geographical Bulletin 18:21-63.

Maidment DR. 1992. Handbook of Hydrology. McGraw-Hill, New York, USA.

Martin J, Clayton C, Murphy B. 2013. A method for deriving sub-permafrost groundwater salinity and total dissolved solids. Proceedings of the First International Conference on Mine Water Solutions in Extreme Environments. April 15-17, 2013 in Lima, Peru.

McCauley CA, White DM, Lilly MR, Nyman DM. 2002. A comparison of hydraulic conductivities, permeabilities and infiltration rates in frozen and unfrozen soils. Cold Reg Sci Technol 34: 117-125.

Négrel P, Casanova J. 2005. Comparison of the Sr isotopic signatures in brines of the Canadian and Fennoscandian shields. Appl Geochem 20 (2005): 749–766.

Niemann WL, Rovey CW. 2008. A systematic field-based testing program of hydraulic conductivity and dispersivity over a range of scales. Hydrogeol J. 17 no.2: 307-320.

Ophori DU, Chan T. 1994. Regional groundwater flow in the atikokan research area; Simulation of 18O and 3H Distributions. AECL-11083. MB, Canada.

Ophori DU, Brown A, Chan T, Davison CC, Gascoyne M, Scheier NW, Stanchell FW, Stevenson DR. 1996. Revised Model of Regional Groundwater Flow in the Whiteshell Research Area. AECL Whiteshell Laboratories, Pinawa, MB, Canada

Post V, Kooi H, Simmons C. 2007. Using hydraulic head measurements in variable-density ground water flow analyses. Ground Water—November-December 2007. Vol. 45, No. 6: 664–671.

Raven KG, Bottomley DG, Sweezey RA, Smedley JA, Ruttan TJ. 1987. Hydrogeological Characterization of the East Bull Lake Research Area. Environment Canada, IWD Sci. Series, No. 160; NHRI Paper No. 31, 77 pp.

Rescan Environmental Services Ltd. 2006. Ekati Diamond Mine Underground Water Quality Assessment. Project 770-1. Prepared for BHP Billiton Diamonds Inc. January 2006.

Rio Tinto. 2012. Diavik Diamond Mine 2011 Environmental Agreement Annual Report. Communities and External Relations Department. July 2012. CCOM-091-0712 R0.

Schulze-Makuch D. 2005. Longitudinal Dispersivity Data and Implications for Scaling Behaviour. GROUND WATER May/Jun 2005; 43, 3; ProQuest Science Journals p. 443.

SWS (Schlumberger Water Services). 2010. Misery Resource Development Definition Study – Feasibility Hydrology and Hydrogeology. Prepared for BHP Billiton Diamonds Inc. September 2010.

Stevenson DR, Brown A, Davison CC, Gascoyne M, McGregor RG, Ophori DU, Scheier NW, Stanchell FW, Thorne GA, Tomsons DK. 1996a. A revised conceptual hydrogeologic model of a crystalline rock environment, Whiteshell research area, southeastern Manitoba, Canada. AECL-11331, Whiteshell Laboratories, Pinawa, MB, Canada.

Stevenson DR, Kozak ET, Gascoyne M, Broadfoot RA. 1996b. Hydrogeologic characteristics of domains of sparsely fractured rock in the Granitic Lac du Bonnet Batholith, southeastern Manitoba, Canada. AECL-11558, Whiteshell Laboratories, Pinawa, MB, Canada.

Stober I, Bucher K. 2007. Hydraulic properties of the crystalline basement. Hydrogeol J. 15:213-224.

Stotler R, Frape S, Ruskeeniemi T, Ahonen L, Onstott TC, Hobbs MY. 2009. Hydrogeochemistry of groundwaters in and below the base of thick permafrost at Lupin, Nunavut. Can J Hydrol 373 (2009): 80–95.

Stotler R, Frape SK, Ruskeeniemi T, Pitkänen P, Blowes DW. 2012. The interglacial–glacial cycle and geochemical evolution of Canadian and Fennoscandian Shield groundwaters. Geochimica et Cosmochimica Acta 76 (2012): 45–67.

WMC (Water Management Consultants). 2006. Koala Underground Project Underground Water Management Review. June 2006. Prepared for BHP Billiton Diamonds Inc.

Woo MK. 2011. Linking Runoff to Groundwater in Permafrost Terrain. J.A.A. Jones (ed.), Sustaining Groundwater Resources, International Year of Planet Earth, 119 DOI 10.1007/978-90-481-3426-7_8, Springer Science+Business Media B.V. 2011. pp 119–129.

9 GLOSSARY

Term	Definition
Active layer	The top layer of ground in permafrost region where temperature fluctuates above and below 0°C during the year.
Artesian	A confined aquifer containing groundwater that will flow upwards out of a well without pumping.
Baseline	Describes the current environmental setting, against which changes in the environment from the Project could be measured.
Bathymetry	A measurement of water depth in a waterbody.
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.
Brittle structure	Planar features, which have experienced displacement, such as faults and fractures zones.
Contact zone	Zone where plutonic igneous rock intrude into the surrounding rock. Contact refers to the effect on rocks of conductive or convective heat transfer.
Craton	A portion of the Earth's crust that has been tectonically stable and not substantially deformed for a long period.
Cryopeg	The layer of perennially cryotic (T <0°C) ground with liquid saline or pressurized pore water that forms the base of permafrost. The thickness of this layer is related to the salinity of the groundwater regime, which can result in depression of the freezing point up to several degrees below zero.
Cryosol	An order of soils in the Canadian taxonomic system. Cryosolic soils are mineral or organic soils that have perennially frozen material within 1 m of the surface in part of the soil body, or pedon. The mean annual soil temperature is less than 0°C. Their maximum development occurs in organic and poorly drained, fine textured materials. The active layer of these soils is frequently saturated with water, especially near the frozen layers, and colours associated with gleying are therefore common in mineral soils, even those that occur on well-drained portions of the landscape. They may or may not be markedly affected by cryoturbation. The order has three great groups: Turbic Cryosol, Static Cryosol, and Organo Cryosol (q.v.).
Diatreme	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.
Discharge	The volumetric rate of flow of water in a watercourse at a specified point, expressed in units of cubic metres per second or equivalent.
Enhanced permeability zones (EPZs)	Zones of greater fracturing and good hydraulic connectivity, related to structures such as faults.
Esker	A long, winding ridge of stratified sand and gravel believed to form in ice-walled tunnels by streams which flowed within and under glaciers. After the retaining ice walls melt away, stream deposits remain as long, winding ridges.
Geology	The study of the Earth's crust, its structure, and the chemical composition and the physical properties of its components.
Granite	A coarsely crystalline igneous intrusive rock composed of quartz, potassium feldspar, mica, and hornblende.
Granitoid	Rocks with a composition the same as, or similar to, granite.
Groundwater	Water that is passing through or standing in the soil and the underlying strata in the zone of saturation. It is free to move by gravity.
Groundwater – shallow	Water that occupies pores and crevices in the rock and soil of the active layer above the permafrost layer.
Groundwater – deep	Ancient fossil or connate water that occupies pores and crevices in the bedrock below the permafrost layer.
Groundwater flow	The movement of water through interconnected voids in the phreatic zone.

Term	Definition
Hydraulic conductivity	The ability of a porous medium to conduct a fluid (e.g., water). It is the combined property of a porous medium and the fluid moving through it in saturated flow, which determines the relationship, called Darcy's Law, between the specific discharge and the head gradient causing it.
Hydraulic head	The level to which water will rise if a standpipe is installed.
Hydraulic gradient	A measure of the force of moving groundwater through soil or rock. It is measured as the rate of change in total head per unit distance of flow in a given direction. Hydraulic gradient is commonly shown as being dimensionless, since its units are metres/metre.
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.
In Situ	In place.
Isotherm	A line of equivalent temperature (not just in water).
Kimberlite	Igneous rocks that originate deep in the Earth's mantle and intrude the Earth's crust. These rocks typically form narrow pipe-like deposits that sometimes contain diamonds.
Kimberlite pipe	A more or less vertical, cylindrical body of kimberlite that resulted from the forcing of the kimberlite material to the Earth's surface.
Mean	Arithmetic average value in a distribution.
Metasediments	Sedimentary rocks that have been modified by metamorphic processes.
Overburden	Materials of any nature, consolidated or unconsolidated, that overlie a deposit of useful materials. In the present situation, overburden refers to the soil and rock strata that overlie kimberlite deposits.
Parameter	A particular physical, chemical, or biological property that is being measured in a groundwater system.
Permafrost	Ground (soil or rock and included ice and organic material) that remains at or below 0°C for at least two consecutive years. Permafrost is defined on the basis of temperature. It is not necessarily frozen, because the freezing point of the included water may be depressed several degrees below 0°C; moisture in the form of water or ice may or may not be present.
Permeability, soil	The ease with which gases and liquids penetrate or pass through a bulk mass of soil or a layer of soil. Because different soil horizons vary in permeability, the specific horizon should be designated.
Piezometer	A standpipe placed in the ground to measure water levels.
Plutonic	Pertaining to igneous rocks that are formed deep within the Earth. The process of intrusion of igneous rock formed at great depth into the Earth's crust.
Runoff	The portion of water from rain and snow that flows over land to streams, ponds or other surface waterbodies. It is the portion of water from precipitation that does not infiltrate into the ground, or evaporate.
Seepage	Slow water movement in subsurface. Flow of water from man-made retaining structures. A spot or zone, where water oozes from the ground, often forming the source of a small spring.
Talik	Zone of unfrozen ground that occurs beneath waterbodies. It originates mainly under deep lakes, rivers and other places where the mean annual soil temperature is above zero.
Tectonic	Pertaining to the internal forces involved in deforming the Earth's crust.
Thermistor	A device whose electrical resistance, or ability to conduct electricity, is controlled by temperature.
Till	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.

Term	Definition
Topography	The physical features of a district or region, such as those represented on a map, taken collectively; especially the relief and contours of the land. On most soil maps topography may also mean topography classes that describe slopes according to standard ranges of percent gradient.
Total dissolved solids	The total concentration of all dissolved materials found in a water sample.
Transmissivity	The product of the average coefficient of hydraulic conductivity (or permeability) and the thickness of the aquifer. Consequently, transmissivity is the rate of flow under a hydraulic gradient equal to unity through a cross-section of unit width over the whole thickness of the aquifer. It is designated by the symbol T. It has the dimension of: $Length^3/Time \times Length$ or $Length^2/Time$ (e.g., m^2/d).
Veneer	Unconsolidated materials too thin to mask the minor irregularities of the underlying unit surface. A veneer ranges from 10 cm to 1 m in thickness and possesses no form typical of the materials' genesis.
Water table	The upper surface of groundwater or that level below which the soil is saturated with water.