9.2 HYDROGEOLOGY

9.2.1 Baseline Setting

9.2.1.1 Introduction

The hydrology component describes the groundwater quantity and quality

This section is the hydrogeology component of the environmental assessment (EA) of the De Beers Canada Mining Inc. (De Beers) Snap Lake Diamond Project. The purpose of this section, as identified in the EA Terms of Reference (Table 9.1-1 in Section 9.1), is to describe, clearly and succinctly, the existing groundwater quality, quantity, and use. This section includes a discussion of the groundwater quality, hydrostratigraphy and groundwater flow patterns prior to development of the Snap Lake Diamond Project.

Local and regional study areas are defined

A local study area (LSA) and a regional study area (RSA) were developed for the hydrogeological baseline and the assessment. The LSA is presented in Figure 9.2-1. Although the LSA was defined primarily on surface water divides, it includes the area in which groundwater may be directly affected by surface facilities and the underground mine. The LSA includes the mine site surface facilities, the underground mine, Snap Lake, six small lakes north of Snap Lake (NL1 to NL6), and two larger lakes to the north: the north lake and the northeast lake. The north lake is connected to the northeast lake through NL5 and NL6. The RSA defines the area where the cumulative effects assessment (Section 12.6) will be focused and includes areas that may be indirectly affected by the project. The RSA is comprised of the Lockhart River drainage basin.

9.2.1.2 General Setting

Snap Lake Diamond Project is within the zone of continuous permafrost

The Snap Lake Diamond Project lies within the Canadian Shield approximately 70 kilometres (km) north of the east arm of Great Slave Lake. According to the International Permafrost Association (1997), the project site is located just north of the border between the zones of discontinuous and continuous permafrost. A talik (unfrozen ground surrounding permafrost) exists beneath Snap Lake with permafrost (permanently frozen layer) becoming thicker with distance from the lake. From observations and analyses described in Section 10.2, permafrost appears to be at least 100 metres (m) thick over much of the northwest peninsula of Snap Lake and beneath the land between Snap Lake and nearby lakes. The “thaw” or “active” layer beneath the project site has been observed to be up to 8 m thick. Permafrost is described in more detail in Section 10.2.1.5.

Figure 9.2-1 Local Study Area for Hydrology

Groundwater both in the active layer and in the deep groundwater beneath the permafrost is not presently utilized and will not likely be utilized in the future

Groundwater sources from both the active layer and from the deep groundwater below the permafrost are not presently utilized for drinking water. This is likely due to the presence of deep permafrost, the seasonal nature of the active layer, and the availability of good quality surface drinking water sources in the vicinity of the project site. Furthermore, it is unlikely that the groundwater in the shallow active layer, because of its seasonal nature, would be utilized in the future. Deep groundwater may be utilized in the future, but the likelihood of this is considered low because supply wells would need to be installed through deep permafrost and because there are abundant sources of good quality surface water.

9.2.1.3 Groundwater Quality

Baseline groundwater quality assessment is based on samples collected from ports and seeps in 2001

The baseline (existing) groundwater quality was assessed from the results of the water-sampling program completed as part of the 2001 hydrogeology and geochemistry program. Samples used in the assessment of baseline water quality conditions were those collected from ports and seeps. The data are subdivided according to lithology (kimberlite, granite, or metavolcanic). A discussion of the groundwater quality measured from each of these units is provided below.

A summary of results is provided below

The groundwater quality of each unit is summarized in Table 9.2-1. General trends in the major ion distribution of the groundwater from the three main units are shown in the piper plot provided in Figure 9.2-2. The plot expresses the relative concentration as percentages of the major cations (calcium, magnesium, and sodium plus potassium), and major anions (bicarbonate, sulphate, and chloride) on the two triangular portions of the diagram. Data from these portions are then projected onto a grid to aid in the identification of water quality groups and trends. Detailed results from the groundwater sampling program are provided in Appendix IX.1.

Groundwater shows weak to moderate mineralization generally increasing with depth in the metavolcanics and granite

In general, the groundwater samples show weak to moderate mineralization with total dissolved solids (TDS) ranging from 5 milligrams per litre (mg/L) to 1,630 mg/L. The mineralization is weakest in the upper metavolcanic units and increases with depth in the metavolcanics and with transition to granitic material. The data indicate that calcium and chloride are dominant in the granite groundwater, whereas bicarbonate, calcium, and magnesium are predominant in the kimberlite and metavolcanics. The predominance of calcium and chloride in granite groundwaters is consistent with observations made by Pearson (1987) regarding deep groundwaters of the Canadian Shield.

Table 9.2-1 Summary of Baseline Groundwater Quality

Parameter	Units[g]	Groundwater Baseline[a]												Guidelines
		Metavolcanic (n = 16)[c]			Kimberlite (n = 4)[d]			Granite (n = 9)[e]			All (n = 29)[f]			Drinking Water[b]
		min	max	median	min	max	median	min	max	median	min	max	median	
Conventional Parameters														
pH	pH	7.7	**8.7**	8.0	7.8	8.1	8.0	7.5	**11.8**	**9.2**	7.5	**11.8**	8.1	6.5-8.5
Alkalinity	mg/L	34	132	108	85	89	87	47	356	80	34	356	90	-
Total Dissolved Solids	mg/L	70	**1420**	270	120	**660**	425	360	**1630**	**920**	70	**1630**	345	≤500[h]
Total Hardness	mg/L	36.0	567.0	124.0	55.0	325.0	256.5	189.0	756.0	286.0	36.0	756.0	181.0	-
Total Organic Carbon	mg/L	2.0	6.0	3.0	2.0	3.0	2.5	3.0	7.0	4.0	2.0	7.0	3.0	-
Dissolved Organic Carbon	mg/L	2.0	5.0	3.0	-	-	-	2.0	6.0	4.0	2.0	6.0	4.0	-
Conductivity	µS/cm	174.0	1580.0	485.0	198.0	1050.0	889.0	646.0	2900.0	1130.0	174.0	2900.0	661.0	-
Nutrients														
Ammonia	mg/L	0.2	2.0	0.7	0.01	0.5	0.4	0.7	25.4	4.1	0.01	25.4	0.8	-
Nitrate + Nitrite	mg/L	<0.006	0.193	0.019	0.007	0.187	0.017	0.009	**22.2**	2.4	<0.006	**22.2**	0.06	-
Total Phosphorus	mg/L	0.008	0.181	0.099	0.022	0.279	0.076	0.013	0.3	0.1	0.008	0.29	0.09	-
Dissolved Phosphorus	mg/L	0.003	0.182	0.078	0.022	0.279	0.073	0.003	0.1	0.035	0.003	0.28	0.07	-
Orthophosphate	mg/L	<0.001	0.159	0.098	0.021	0.203	0.057	0.002	0.1	0.003	<0.001	0.20	0.02	-
Total Kjeldahl Nitrogen	mg/L	0.4	2.7	0.6	0.1	0.6	0.4	0.7	14.6	3.2	0.1	14.6	0.7	-
Major Ions														
Bicarbonate	$mgCO_3/L$	40.0	155.0	134.0	104.0	108.0	106.0	5.0	148.0	83.5	5.0	155.0	117.0	-
Carbonate	mg/L	<5	13.0	<5	<5	<5	<5	<5	75.0	29.0	<5	75.0	27.5	-
Calcium	mg/L	12.0	137.0	39.2	17.7	74.4	57.8	62.9	274.0	110.0	12.0	274.0	58.7	-
Chloride	mg/L	4.0	**431.0**	77.0	6.0	**261.0**	208.0	121.0	**599.0**	248.0	4.0	**599.0**	138.0	≤250[h]
Fluoride	mg/L	0.6	1.0	0.8	0.8	1.0	0.9	0.3	0.9	0.6	0.3	1.0	0.8	1.5
Hydroxide	mg/L	<5	<5	<5	<5	<5	<5	<5	78.0	<5	<5	78.0	<5	-
Magnesium	mg/L	1.6	54.4	6.4	2.7	33.7	27.3	0.2	27.7	7.8	0.2	54.4	7.6	-
Potassium	mg/L	1.6	6.1	3.1	1.9	3.2	3.1	3.3	18.9	9.3	1.6	18.9	3.3	-
Silica	mg/L	9.8	16.2	15.8	13.6	16.4	15.0	3.6	16.9	12.5	3.6	16.9	15.2	-
Sodium	mg/L	16.8	88.8	37.6	24.6	56.9	51.1	25.5	127.0	76.7	16.8	127.0	48.2	≤200[h]
Sulphate	mg/L	1.3	21.2	3.0	16.1	23.1	19.2	6.2	78.6	10.0	1.3	78.6	8.4	≤500[h]
Dissolved Metals														
Aluminum	µg/L	0.4	<30	1.4	0.8	30.0	1.8	1.2	40.2	7.2	0.4	40.2	3.7	-
Antimony	µg/L	<0.03	0.7	0.2	0.1	0.1	0.1	0.1	1.0	0.2	<0.03	1.0	0.2	-
Arsenic	µg/L	0.1	0.8	0.4	0.1	1.6	1.2	0.4	3.3	1.1	0.1	3.3	0.7	25[i]
Barium	µg/L	3.1	93.3	11.6	6.1	39.5	35.3	21.6	238	55.4	3.1	238	20.0	1,000[i]
Beryllium	µg/L	<0.2	<0.5	<0.2	<0.2	<0.5	<0.2	<0.2	<0.5	<0.2	<0.2	<0.5	<0.2	-

Table 9.2-1 Summary of Baseline Groundwater Quality (continued)

Parameter	Units[g]	Groundwater Baseline[a]												Guidelines Drinking Water[b]
		Metavolcanic (n = 16)[c]			Kimberlite (n = 4)[d]			Granite (n = 9)[e]			All (n = 29)[f]			
		min	max	median	min	max	median	min	max	median	min	max	median	
Bismuth	µg/L	<0.03	<5	<0.03	<0.03	<0.05	<0.03	<0.03	0.2	<0.03	<0.03	<5	<0.03	-
Boron	µg/L[g]	37.0	321.0	56.0	57.0	329.0	247.5	16.0	94.0	64.0	16.0	329.0	61.0	-
Cadmium	µg/L	<0.05	<0.1	<0.05	<0.05	<0.1	<0.05	<0.05	<0.1	<0.05	<0.05	<0.1	<0.05	5[i]
Cesium	µg/L	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	0.9	0.5	<0.1	0.9	0.4	-
Chromium	µg/L	<0.06	1.9	0.9	0.5	9.9	3.1	<0.06	3.5	0.1	<0.06	9.9	0.9	50[i]
Cobalt	µg/L	<0.1	0.4	<0.1	<0.1	0.6	0.4	<0.1	0.2	0.2	<0.1	0.6	0.2	-
Copper	µg/L	<0.6	2.8	1.1	<0.6	4.2	3.0	<0.6	24.6	2.8	<0.6	24.6	2.1	≤1,000[h,i]
Iron	µg/L	<5	56.0	43.0	<5	240.0	133.0	<5	3460.0	21.0	<5	3460.0	40.5	≤0.3[h,i]
Lead	µg/L	<0.05	1.8	0.5	<0.1	2.2	0.7	<0.05	1.4	0.2	<0.05	2.2	0.4	10[i]
Lithium	µg/L	13.3	57.2	22.7	24.9	42.1	35.0	18.0	86.6	45.2	13.3	86.6	29.1	-
Manganese	µg/L	1.5	37.4	8.9	3.1	12.0	9.3	0.1	252.0	7.1	0.1	252.0	8.7	≤50[h,i]
Mercury	µg/L	<0.01	0.1	0.0	<0.02	<0.02	<0.02	<0.02	0.5	0.1	<0.01	0.5	0.0	1[i]
Molybdenum	µg/L	1.8	7.1	3.8	2.0	2.6	2.3	2.6	11.0	5.6	1.8	11.0	3.8	-
Nickel	µg/L	<0.06	19.8	0.5	1.1	29.7	4.9	0.1	4.8	0.8	<0.06	29.7	0.8	-
Rubidium	µg/L	<1	8.0	2.0	1.0	2.0	1.5	2.0	44.0	23.0	<1	44.0	2.0	-
Selenium	µg/L	0.1	14[j]	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	0.1	14[j]	0.3	10[i]
Silver	µg/L	<0.1	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.2	<0.1	-
Strontium	µg/L	180	1570	436	230	1490	1295	879	3970	1760	180	3970	745	-
Thallium	µg/L	<0.03	<0.1	<0.03	<0.03	<0.05	<0.03	<0.03	0.1	<0.03	<0.03	0.1	<0.03	-
Titanium	µg/L	0.3	2.4	1.6	0.4	3.3	1.9	<0.1	2.1	1.3	<0.1	3.3	1.5	-
Uranium	µg/L	<0.05	1.2	<0.05	<0.05	<0.1	<0.05	<0.05	1.0	0.1	<0.05	1.2	0.1	20[i]
Vanadium	µg/L	0.3	2.4	0.8	0.1	2.8	1.8	0.6	4.5	1.8	0.1	4.5	1.0	-
Zinc	µg/L	0.8	2.1	1.3	<2	3.6	2.9	<0.8	9.3	3.4	<0.8	9.3	1.5	≤5,000[h,i]

< = less than detection limit (see glossary for definition).

[a] Numbers in bold exceed drinking water guidelines.

[b] Based on hardness of 120 mg/L; drinking water guidelines provided are the maximum acceptable total values based on CCME 1999 + 2000 updates.

[c] n = 15 for As, B; n = 14 for Alkalinity, Ca, K, Mg, Na, SO42-, Cl-, NH3, NO3/NO2, pH, Hardness, Conductivity, Total P, and Dissolved P; n = 13 for HCO3-, Hg, Sr, Colour, TKN, TOC, Bicarbonate, Carbonate; n = 12 for Bi, Ce, Ti, Tl, TDS; n = 11 for SiO2, F; n=10 for orthophosphate; and, n = 9 for TOC, Hydroxide.

[d] n = 2 for Hg, SiO2, Sr, Colour, TOC, F.

[e] n = 8 for Hg, SiO2, Sr, DOC; and , n = 7 for Hardness, F.

[f] n = 28 for As, B; n = 27 for Alkalinity, Ca, K, Mg, Na, SO42-, Cl-, NH3, NO3/NO2, pH, Conductivity, Total P, Dissolved P; n=26 for HCO3-, TKN, Bicarbonate, Carbonate; n=25 for Bi, Ce, Ti, Tl, Hardness, TDS n=24 for Colour, TOC; n = 23 for Hg, Sr, Orthophosphate; n= 22 for Hydroxide; n = 21 for SIO2; n= 20 for F; and n = 17 for DOC.

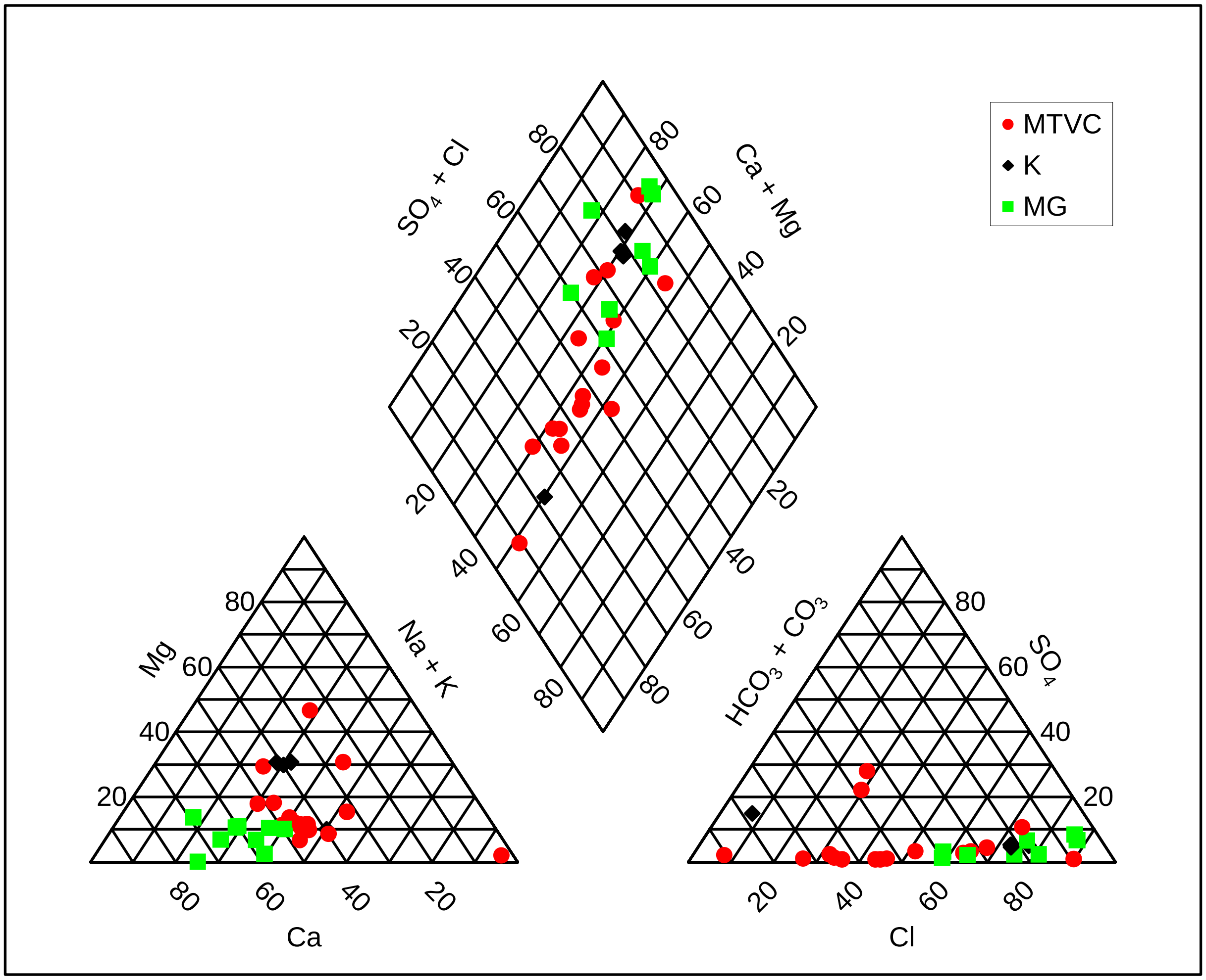
[g] Units: µg/L = micrograms per litre; mg/L = milligrams per litre; ms/cm = micro Seimens per centimetre; $mgCO_3/L$ = milligrams of carbonate per litre.

[h] Aesthetic objective.

[i] Guideline is for total metals.

[j] Shaded values undergoing QA/QC review.

Figure 9.2-2 Piper Plot Showing Major Ion Trends in Baseline Groundwater



Note: MTVC = metavolcanic; K = kimberlite; MG = granite; SO_4 = sulphate; Cl = chloride; Ca = calcium; Mg = magnesium; Na = sodium; K = potassium; HCO_3 = bicarbonate; CO_3 = carbonate.

Trace metal concentrations in the groundwater are typically elevated with respect to Snap Lake

With the exception of cadmium, cobalt, mercury, and zinc, trace metal concentrations in the groundwater samples are elevated with respect to those of Snap Lake. In general, trace metal concentrations in the groundwater samples are from 10 to 20 times those observed in Snap Lake.

Iron, manganese, chloride, and total dissolved solids exceed guidelines

The parameters iron, manganese, chloride, and TDS exceed the drinking water guidelines (CCME 1999 with 2000 updates) of 300 micrograms per litre (µg/L), 50 µg/L, 250 mg/L, and 500 mg/L, respectively, for some of the samples. For a discussion of water quality and potential effects on aquatic life, refer to Section 9.4 of the EA.

Kimberlite groundwater samples were slightly alkaline with moderate total dissolved solids; samples contained traces of boron, chromium, and nickel

Kimberlite groundwater samples were slightly alkaline in nature (pH 7.8 to 8.1) and contained moderate TDS concentrations ranging from 120 to 660 mg/L. Relative to the granitic and metavolcanic groundwater, kimberlite groundwater contained the highest average concentration of magnesium. This is consistent with the more mafic (igneous silicate minerals, magmas, and rocks that contain heavier elements) character of the kimberlite, in particular the presence of serpentine, a magnesium-silicate. Kimberlite groundwater also contained the highest average concentrations of the trace metals boron, chromium, and nickel. These metals are common constituents of mafic rocks such as kimberlite.

Metavolcanic groundwater samples were slightly alkaline with moderate total dissolved solids; samples contained trace metals

The metavolcanic groundwater samples had moderate TDS values and were slightly alkaline to alkaline, with pH values ranging from 7.7 to 8.7. Although the TDS concentrations ranged from a low of 70 mg/L to a high of 1,420 mg/L, the typical range was from 250 to 350 mg/L, with a median value of 270 mg/L. Metavolcanic groundwater did not contain average trace metal concentrations that were higher than those for kimberlite or granite groundwater, despite the fact that certain trace metals are "enriched" in the metavolcanics relative to the kimberlite and granite. This suggests that the effectiveness of leaching of metavolcanic rock by groundwater may be limited, and/or that geochemical controls may provide an upper boundary for trace metal levels in groundwater.

Three samples exceeded the drinking water guideline for total dissolved solids; one sample exceeded the drinking water guideline for chloride

In the metavolcanic unit, only one of fourteen sample locations exceeded the drinking water guideline values for chloride and TDS. This location (Groundwater Seep 7208) was sampled shortly after the ramp was completed in the permafrost (Appendix IX-1). It is likely that the re-circulated brine (saline) water used for drilling in the permafrost contributed to the high chloride and TDS values in the sample. Of the four water samples originating from the kimberlite unit, one sample exceeded the guideline value for chloride, and two samples exceeded the guideline value for TDS.

Granite groundwater samples were near neutral to alkaline with moderate to high total dissolved solids; trace metals included aluminum, barium, iron, manganese, molybdenum, rubidium, and strontium

Granite groundwater samples were near-neutral to alkaline in nature (pH 7.5 to 11.8) and contained the highest TDS concentrations of the three groundwater types, with values ranging from 360 to 1,630 mg/L. Two samples (pH 11.0 and 11.8) that were highly alkaline may have been impacted by grout (*e.g.*, cement). Relative to the two other groundwater types, granite groundwater contained the highest average concentrations of calcium, potassium, and sodium. The presence of these ions is consistent with the more felsic (*i.e.*, light coloured igneous rocks or minerals typically containing feldspars and silicates) character of the granite, particularly because of the presence of potassium (K)-feldspar and albite (a white feldspar). Chloride concentrations were also highest in granite groundwater.

The highest average concentrations of trace metals such as, aluminum, barium, iron, manganese, molybdenum, rubidium, and strontium were found in granite groundwater. These metals are common constituents of felsic rocks such as granite.

Several samples from the granite unit exceeded drinking water guidelines

Within the granite unit, four of nine water samples exceeded the drinking water guideline for chloride and six of nine exceeded the guidelines for TDS. In one sample (underground [UG]-84-1229), iron (3.5 mg/L) and manganese (0.252 mg/L) values were above the guidelines (Appendix IX.1).

9.2.1.4 Hydrostratigraphy and Groundwater Flow

There are shallow and deep groundwater flow regimes on site

There are two main groundwater flow regimes at the project site: a shallow groundwater flow regime within the active layer, and a deep groundwater flow regime located beneath the permafrost and within the talik of large water bodies. Because of the presence of thick permafrost that has low permeability, there is little to no hydraulic connection between the two regimes. Each of these groundwater regimes is discussed below.

9.2.1.4.1 Shallow Groundwater Flow Regime

Shallow groundwater regime was investigated on the northwest peninsula

The shallow groundwater regime was characterized through subsurface investigations undertaken on the northwest peninsula. The shallow groundwater regime beneath landmasses throughout the LSA is expected to be similar to that observed on the northwest peninsula.

Hydraulic conductivity of the shallow groundwater was determined

Five boreholes (geologic drill holes) were drilled on the northwest peninsula in the area of the north pile and the area of Dam 2 (reference Section 10.2 for detailed information on subsurface investigations). Permeability tests were conducted on two of the boreholes to determine hydraulic conductivity. Average hydraulic conductivity and the water level in the two boreholes are presented in Table 9.2-2.

Hydraulic conductivity ranged between approximately 1×10^{-5} m/s and less than 3×10^{-8} m/s

The hydraulic conductivity of the frost shattered and/or weathered rock underlying the till in the location of the boreholes was found to be approximately 1×10^{-5} metres per second (m/s). This is underlain at approximately 8 m depth by competent bedrock with a measured hydraulic conductivity of less than 3×10^{-8} m/s. The water level was found to be at depths of less than 1 m below ground surface.

Table 9.2-2 Summary of Packer Testing Intervals, Water Levels, and Hydraulic Conductivity Results

Test Number	Borehole Number	Test Interval Depth (m BGS [a] along dip)	Test Interval Depth (m BGS vertical)[a]	Water Level (m BGS vertical)	Test Type	Hydraulic [b] Conductivity (m/s)
1	BH-00-12	5.2 – 15.9	3.7 – 11.2	0.68	constant head	1.0×10^{-5}
2	BH-00-12	7.9 – 15.9	5.6 – 11.2	0.64	falling head constant head	3.4×10^{-5} 1.3×10^{-5}
3	BH-00-12	11.0 – 15.9	7.8 – 11.2	0.57	falling head	7.3×10^{-9}
4	BH-00-14	1.2 – 6.7	0.8 – 4.7	0.43	constant head	9.6×10^{-6}
5	BH-00-14	6.1 – 9.8	4.3 – 6.9	0.47	falling head	1.3×10^{-6}
6	BH-00-14	9.1 – 12.8	6.4 – 9.1	0.47	falling head	1.1×10^{-6}
7	BH-00-14	12.2 – 15.9	8.6 – 11.2	0.24	falling head	1.6×10^{-8}
8	BH-00-14	15.2 – 20.4	10.7 – 14.4	0.26	falling head	2.8×10^{-8}

[a] m = metres; BGS= below ground surface; m/s = metres per second.

[b] Parameter that describes the conductive properties of the rock mass with respect to groundwater flow.

At least a portion of the approximately 8 m thick active layer is thawed over the period of the middle of May to the middle of December

From the late spring to early autumn, when temperatures are above 0 degrees Celsius (°C), the active layer becomes thawed. The active layer beneath the northwest peninsula was found to be approximately 8 m thick. From thermistor data and model predictions of the thermal regime (Section 10.2 and Appendix III.1), a portion of this layer is thawed from the middle of May to the middle of December. Based on measurement in low-lying areas near Dam 2, the water table in the active layer is less than 1 m below ground surface. The water table is expected to be deeper in areas of higher topography.

Average groundwater gradients within the active layer are expected to be in the range of 0.03 m/m

Within the active layer, the watertable is expected to be a subdued replica of the topography, and is expected to parallel the topographic surface. Groundwater gradients would, therefore, be similar to topographic gradients. Groundwater in the active layer would flow to local depressions and ponds that drain to Snap Lake or would flow directly to Snap Lake. Groundwater gradients in the active layer are expected to be approximately 0.03 m/m (metres of head change over metres of distance, a dimensionless unit).

The shallow groundwater is isolated from the deep groundwater

Permafrost reduces the hydraulic conductivity of the rock by one to two orders of magnitude (Anderson and Morgenstern 1973; Burt and Williams 1976). Consequently, the permafrost in the rock at Snap Lake would be virtually impermeable to groundwater flow. The shallow groundwater flow regime, therefore, has little to no hydraulic connection with the groundwater regime located below the deep permafrost.

9.2.1.4.2 Deep Groundwater Flow Regime

The hydraulic conductivity of the bedrock was largely determined from tests conducted during exploration; eight hydrostratigraphic units were identified

The deep groundwater flow regime was characterized through groundwater investigations undertaken in the advanced exploration program (AEP) within the talik of Snap Lake. Hydraulic conductivity tests were conducted in boreholes drilled in the underground workings of the AEP. Sixty-nine shut-in recovery tests were conducted; the vertical hydraulic conductivity of the rock was determined from these tests. The test procedures and borehole locations are included in Appendix IX.2. Test results are presented in Appendix IX.3. Based on the test results and the borehole logs, eight hydrostratigraphic units were identified:

- lakebed sediments;
- exfoliated and/or weathered granite;
- exfoliated and/or weathered metavolcanics;
- hangingwall granite (*i.e.*, granite above the kimberlite);
- hangingwall metavolcanics (*i.e.*, metavolcanics above the kimberlite);
- footwall granite (*i.e.*, granite below the kimberlite);
- footwall metavolcanics (*i.e.*, metavolcanics below the kimberlite); and,
- kimberlite.

The estimated hydraulic conductivity and storativity values are summarized below

Table 9.2-3 presents the average hydraulic conductivity and the storativity values determined or estimated for each of these units. As noted above, the average vertical conductivity was calculated from measurements in the boreholes. The horizontal hydraulic conductivity for all units except the exfoliated granite were estimated, because the one vertical borehole used for determining the horizontal hydraulic conductivity likely intersected exfoliated granite over most of its length. The hydraulic conductivity of the lakebed sediments was calculated from one rising-head test conducted in the sediments and from soil descriptions of the material.

The average hydraulic conductivity for fractured rock zones was approximately 5 x 10^{-5} m/s

The average vertical hydraulic conductivities presented include values measured in fractured rock zones associated with the Snap and Crackle Faults and those associated with the north-south trending fractured-rock zones. Hydraulic conductivity values determined for these fractured rock zones were approximately 5 x 10^{-5} m/s. The hydraulic heads measured in boreholes drilled from underground were virtually identical to the elevation of the water level in Snap Lake.

Table 9.2-3 Hydrogeologic Parameters of Hydrostratigraphic Units

Unit	Material	Hydraulic Conductivity (m/s)			Storage	
					Specific Yield [a]	Specific Storage
		K_x	K_y	K_z	S_y (m/m)	S_s (m^{-1}) [b]
1	Granite – exfoliated	2×10^{-5}	2×10^{-5}	2×10^{-7}	0.01	1×10^{-5}
2	Granite – hanging wall	2×10^{-6}	2×10^{-6}	1×10^{-7}	0.005	1×10^{-6}
3	Granite – footwall	5×10^{-7}	5×10^{-7}	1×10^{-7}	0.005	1×10^{-6}
4	Metavolcanics – exfoliated	2×10^{-6}	2×10^{-6}	4×10^{-6}	0.01	1×10^{-5}
5	Metavolcanics – hanging wall	2×10^{-7}	2×10^{-7}	6×10^{-8}	0.005	1×10^{-6}
6	Metavolcanics – footwall	5×10^{-8}	5×10^{-8}	1×10^{-8}	0.005	1×10^{-6}
7	Kimberlite dyke	6×10^{-9}	6×10^{-9}	1×10^{-9}	0.005	1×10^{-6}
8	Lakebed sediments	1×10^{-8}	1×10^{-8}	1×10^{-8}	- [c]	-

[a] Parameter describing groundwater storage properties of the rock mass (unitless); m/m = metres over metres.

[b] m^{-1} = per metre; m/s = metres per second; K = hydraulic conductivity.

[c] Not estimated.

In continuous permafrost areas groundwater generally flows from higher elevation lakes to lower elevation lakes

In areas of continuous permafrost, recharge to the deep groundwater flow regime is predominantly limited to areas of talik beneath large, surface water bodies. Water level elevations in surface water bodies represent the hydraulic head within the deep groundwater flow system. Consequently, groundwater will generally flow from higher elevation lakes to lakes located at lower elevations.

Groundwater generally flows from Snap Lake to surrounding lakes at approximately 0.002 m/m

Snap Lake is a headwater lake; the water level in the lake is the highest of the lakes within the RSA. The water elevations of lakes near Snap Lake and the inferred deep groundwater flow directions are presented in Figure 9.2-3. Groundwater is expected to flow radially away from Snap Lake with the inferred hydraulic gradient ranging from approximately 0.001 m/m to 0.004 m/m, with an average gradient of approximately 0.002 m/m.

Groundwater flow from Snap Lake to surrounding lakes is approximately 10,500 m^3/d

From the hydrogeologic model developed for Snap Lake (presented in Section 9.2.2.2), the baseline total groundwater outflow from Snap Lake was calculated to be approximately 10,500 cubic metres per day (m^3/d) (Appendix IX.3). The total groundwater flow to the north lake, which is located approximately 2.5 km to the north of Snap Lake, is estimated to be approximately 25% of the total outflow (*i.e.*, 2,700 m^3/d). The total baseline groundwater flow to the northeast lake is estimated to be 8% of the total outflow (*i.e.*, 800 m^3/d).

Figure 9.2-3 Lake Elevations and Inferred Baseline Groundwater Flow Directions

9.2.2 Impact Assessment

9.2.2.1 Introduction

The project could impact groundwater

A number of issues have been identified with respect to the potential impacts of the Snap Lake Diamond Project on groundwater. These include issues raised during traditional knowledge work such as concerns "about effects on groundwater from dynamite and heavy vehicles used in mining operations" (Weledeh Yellowknives Dene 1997) and the implied concern in the observation "There are some fast-moving streams underground in the mine, and a lot of rocks are wet." (Liza Enzoc 19 06 01) (Lutsel K'e Dene First Nation 2001).

Two categories of issues were identified

These issues were consolidated into two categories:

- changes in the groundwater quantity and levels; and,
- changes in groundwater quality.

Mining and surface facilities could impact groundwater

The Snap Lake Diamond Project activities that could result in environmental changes related to groundwater were consolidated into two groups of activities:

- underground mining; and,
- construction and operation of surface facilities.

Each of these activities is evaluated for the construction, operations, closure, and post-closure phases of the mine.

Four key questions were developed

The issues and activities for the Snap Lake Diamond Project formed the basis of the following four key questions:

Key Question HG-1: Will the underground mine for the Snap Lake Diamond Project change groundwater quantity and groundwater levels?

Key Question HG-2: Will the underground mine for the Snap Lake Diamond Project change groundwater quality?

Key Question HG-3: Will the surface facilities for the Snap Lake Diamond Project change groundwater quantity and groundwater levels?

Key Question HG-4: Will the surface facilities for the Snap Lake Diamond Project change groundwater quality?

Groundwater changes may cause direct and indirect impacts

Changes in groundwater quality, quantity, and levels can potentially lead to a direct impact on the groundwater resource and to indirect impacts on surface waters that are connected to the groundwater system.

Use of groundwater as a water supply is very unlikely for the reasons listed

Direct impacts could occur if groundwater is being, or could potentially be, used as a water supply. The groundwater is not currently used as a water supply and its use as a future water supply is very unlikely for the following reasons:

- there are no permanent dwellings or facilities other than the Snap Lake Diamond Project in the LSA;
- groundwater is presently not used as a water supply source in the project area;
- deep groundwater is located beneath thick permafrost that is likely at least 100 m deep; this thick permafrost will result in freezing of the water in the well unless it is kept unfrozen through heating;
- deep groundwater below the permafrost is of poor quality with TDS above drinking water guidelines;
- the shallow groundwater regime is located within the active layer and the layer is only partially unfrozen for approximately six months of the year; and,
- better quality water is readily available from many surface water sources in the area.

Impacts on groundwater use are not assessed

For these reasons, groundwater use is very unlikely. Therefore, there is no linkage between the project activities and groundwater use. Direct impacts on the groundwater supply are not assessed in this section.

Changes in groundwater may cause indirect impacts

However, changes in groundwater could potentially change the quality, quantity, or levels of surface waters in the LSA that are influenced by either the shallow or deep groundwater regimes. Therefore, activities associated with the Snap Lake Diamond Project may be indirectly linked to the water quality, water levels, and aquatic organisms in Snap Lake and nearby lakes through changes in groundwater.

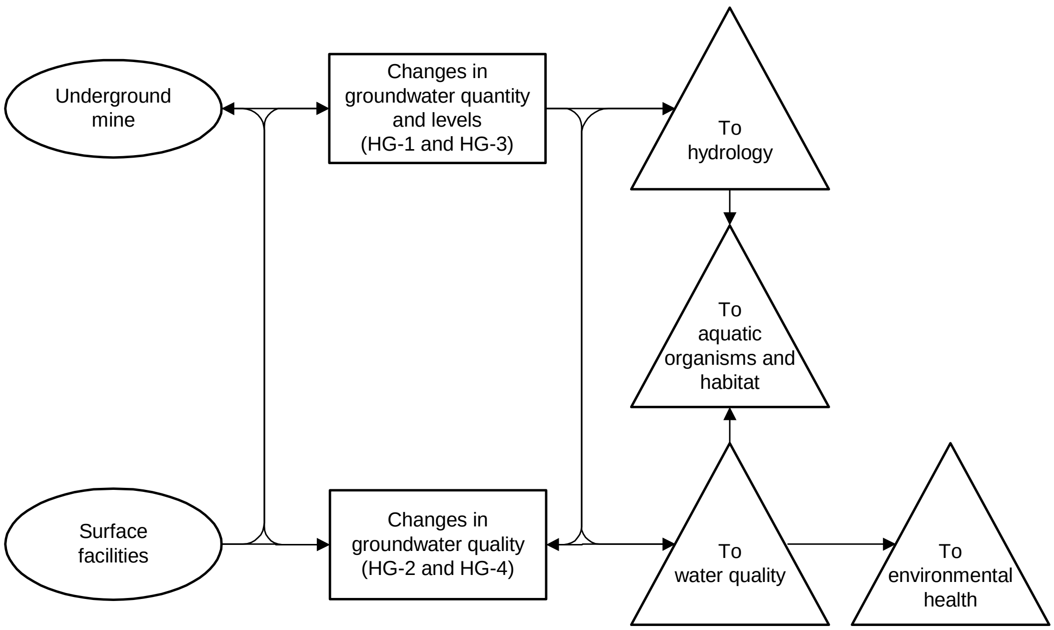
Groundwater is primarily a pathway; the environmental consequences occur in surface waters

Groundwater is primarily a pathway; the environmental consequences of groundwater changes occur in the surface waters (*e.g.*, impacts to aquatic habitat, fish health, *etc*.). This section (Section 9.2) will predict and assess the changes that occur, but the environmental consequences of these changes will be described in Sections 9.3, 9.4, and 9.5.

A linkage diagram was developed

A linkage diagram was developed (Figure 9.2-4) to illustrate the project activities considered in the analysis of the key questions, the potential environmental changes in groundwater quality, quantity, and levels, and the associated potential impacts to surface water, aquatic resources, and terrestrial resources. This section will predict the changes shown in the rectangles, but the impacts will be assessed in the sections shown by the triangles. The method used to address each key question individually is discussed in Section 9.2.2.3.

Figure 9.2-4 Linkage Diagram for Groundwater



9.2.2.2 Analytical Methods

Specific analytical methods were used to address groundwater issues

Specific analytical methods were used to predict groundwater quantity and quality during and after mining. A water quantity model was used to address Key Questions HG-1 and HG-3. A water quality model was used to address Key Questions HG-2 and HG-4. The models are discussed in brief below.

9.2.2.2.1 Groundwater Flow Model

Quantity of Groundwater Inflow

The conceptual model clarifies the deep groundwater regime

A conceptual model (Figure 9.2-5) was used to illustrate the expected flow conditions in the deep groundwater regime during mine development. A conceptual model is a representation of the groundwater regime that organizes

Figure 9.2-5 Conceptual Hydrogeologic Model of Proposed Snap Lake Mine Area

and simplifies the site hydrogeology so that it can be modelled. The conceptual model must retain enough complexity so that the numerical model adequately reproduces or simulates, to the degree required to meet the project objectives, the real groundwater flow behaviour. During the development of the conceptual model, the main hydrostratigraphic units are defined and characterized and the dominant groundwater flow patterns are identified.

Groundwater flow will be induced to flow to the mine openings; the source of this groundwater will change over time

Groundwater inflow to the mine workings will initially originate from groundwater stored within the fractures and joints in the rock. However, over time the water will predominantly originate from Snap Lake and to a lesser degree from lateral groundwater flow. The lateral movement of groundwater to the mine will be somewhat impeded by the presence of thick permafrost, which is relatively impermeable, beneath the land. The water originating from Snap Lake will flow through the lakebed sediments and the hangingwall rocks and into the mine. The hangingwall rocks consist of exfoliated rock, resulting from relaxation due to glacial uploading, and rock within a zone of subsidence which will develop over the mine workings, both of which result in an increase in the hydraulic conductivity of the hangingwall rocks.

Since mine panels will be backfilled promptly, little lake inflow is expected

The kimberlite ore is to be extracted in a series of panels that will be backfilled once each panel is mined out. Generally these panels are backfilled when inflow is still predominantly from stored groundwater. Therefore very little of the inflow to these panels is expected to originate from the lake.

Groundwater will flow to the mine until post-closure when groundwater will equilibrate to baseline

During construction, development, and closure, groundwater flow will be directed towards the mine workings. Following closure, the mine will be flooded and hydraulic heads will equilibrate back to pre-project groundwater levels and flow conditions.

Potential changes in the groundwater were evaluated using a numerical model that uses the finite-element numerical code MINEDW

After the dominant groundwater flow patterns were identified in the conceptual model, it was then used as a basis for the construction of numerical models. The potential changes in deep groundwater levels and quantities due to the underground mine were assessed using a numerical groundwater flow model. The model was developed based on the inferred conditions illustrated by the conceptual model (Figure 9.2-5). The groundwater flow model utilizes the numerical code *MINEDW* developed by Hydrologic Consultants Inc. (HCI) to solve three-dimensional groundwater flow problems with an unconfined (phreatic) surface using the finite-element method (numerical model to solve differential equations). *MINEDW* has several attributes that were specifically developed to address inflow conditions unique to mining operations (Azrag *et al*. 1998). This model was not used to assess changes in the shallow groundwater regime located in the active layer above the permafrost.

The mine plan, including panels, ramps, and haulage roads, was simulated in the numerical model to address Key-Questions HG-1 and HG-3

The model was used to address Key Questions HG-1 and HG-3. The changes caused by the mine development were evaluated by simulating the mine plan in the groundwater flow model. Each mine panel or block was simulated by activating drain nodes representing the mine workings. Following the mining of each panel or block, backfill will be placed in mined out areas. This was simulated in the model by replacing the hydraulic conductivity of the kimberlite layer by a hydraulic conductivity that represents both the backfill (which has a hydraulic conductivity on the order of 3 x 10^{-8} m/s) and voids between the backfill and the rock. As shown in Table 9.2-4, the "bulk" (for a large rock volume) hydraulic conductivity value used in the model for backfill was 1 x 10^{-5} m/s. In addition, a highly permeable fracture zone that may form above the backfill was simulated in the model by a thin (1 m thick) layer that was twice the hydraulic conductivity used to represent the backfill. To simulate the potential effect of subsidence (hanging wall movements) above mine workings, the hydraulic conductivity above the panel or block up to the mid-point of the hanging wall rock was increased by a factor of 10.

The flow model encompassed approximately 89 km^2 in the vicinity of Snap Lake and consists of 134,652 elements

The flow model encompassed a radius of approximately 89 square kilometres (km^2) around the project site. The grid for the model was composed of 134,652 elements and 71,792 nodes as shown in Figure 9.2-6. The finest discretization (the smallest discrete divisions within the grid) was within the proposed mine footprint, where the size of the elements is about 600 square metres (m^2). Figure 9.2-7 presents the vertical layering in the model and Table 9.2-4 provides the hydraulic parameters that were input into the model. The exfoliated zone, a higher permeable layer resulting from the relaxation due to glacial unloading, was assumed to be 100 m thick below the lakes and the land between the lakes. The permafrost was assumed to be impermeable and to extend down to a depth of 50 m below the land between the lakes. The leakance factor identified in Table 9.2-4 is a value assigned to each drain node to account for local resistance to groundwater flow (*i.e.*, the shape of the mine openings, local permeability changes, *etc*.). Further detail on the leakance factor is presented in Appendix IX.3.

Further details on the model are provided in Appendix IX.3

Further details on the model construction, boundary conditions, calibration, and predictions are presented in Appendix IX.3. The mine plan simulated in this model and presented in this appendix assumed that mining would be undertaken with slightly less dilution of the ore with host rock. Consequently, the mine life was simulated as being 2 years shorter (20 years rather than 22 years) than the present best estimated mine life presented in the Project Description (Section 3).

Figure 9.2-6 Map View of Finite-element Mesh of Hydrologic Study Area

Figure 9.2-7 Cross Section of Groundwater Model Showing Discretization and Layering

Table 9.2-4 Hydraulic Properties of Hydrogeologic Units and Leakance Factors in the Groundwater Model

Hydraulic Properties								
Unit	Material	Hydraulic Conductivity (m/d) [a] K_x	K_y	K_z	Specific Yield S_y (m/m)	Specific Storage S_s (m^{-1})	Uncertainty Factor	Notes
1	Granite – exfoliated	2×10^{-5}	2×10^{-5}	2×10^{-7}	0.01	1×10^{-5}		1,2
2	Granite - hanging wall	2×10^{-6}	2×10^{-6}	1×10^{-7}	0.005	1×10^{-6}	10, 0.1	3
3	Granite – footwall	5×10^{-7}	5×10^{-7}	1×10^{-7}	0.005	1×10^{-6}	10, 0.1	
4	Metavolcanics – exfoliated	2×10^{-6}	2×10^{-6}	4×10^{-6}	0.01	1×10^{-5}		2
5	Metavolcanics – hanging wall	2×10^{-7}	2×10^{-7}	6×10^{-8}	0.005	1×10^{-6}		3
6	Metavolcanics – footwall	5×10^{-8}	5×10^{-8}	1×10^{-8}	0.005	1×10^{-6}		
7	Kimberlite dyke	6×10^{-9}	6×10^{-9}	1×10^{-9}	0.005	1×10^{-6}		
8	Backfill material	1×10^{-5}	1×10^{-5}	1×10^{-5}	n/a [b]	n/a	10, 0.1	4
9	Layer above backfill	2×10^{-5}	2×10^{-5}	2×10^{-5}	0.005	1×10^{-4}	10, 0.1	5
10	Lakebed sediments	1×10^{-8}	1×10^{-8}	1×10^{-8}	n/a	n/a	10, 0.1	6

Leakance Factors			
Material / Location	Leakance Factor (m^2/d) [c]	Uncertainty Factor	Notes
Mine areas	0.3	10, 0.1	7
Drifts in footwall rock	0.1	10, 0.1	7
Lakebed sediments	0.1 to 1819.9 (average=13.9)	see above	6, 8

[a] m/d = metre per day; m/m = metres over metres; m^{-1} = per metre.
[b] n/a= not applicable.
[c] m^2/d = square metre per day.

Notes:

1. Based on shut-in recovery tests in testhole UG-45 and UG-176.
2. Zone of exfoliation (due to glacial rebound) is most likely very gradational, but in the model it is assumed to occur abruptly at a depth of 50 m.
3. Will increase K_z of rock above mine blocks and below neutral axis by a factor of 10 after block is extracted.
4. The specific yield of the backfill is very low because the paste backfill will be emplaced as a slurry very near saturation.
5. Arbitrarily assumed to be equivalent to exfoliated granite (*i.e.*, highest value of rock hydraulic conductivity), but isotropic (same values along all axes).
6. The lakebed sediments are not explicitly represented in the model. They are simulated in the model by the leakance factor applied to the constant head (assumes unimpeded inflow or outflow) nodes at the bottom of the lake.
7. Estimated and assigned globally to all applicable drain (some resistance inflow) nodes.
8. Explicitly calculated (dependent on discretization, among other factors) and assigned per node.
9. The depth of permafrost beneath land is assumed to be 50 m. It is assumed that permafrost is essentially impermeable and the top of the groundwater model is simply 50 m deeper in those areas.
10. The uncertainty factor is one order of magnitude more (factor of 10) or less (factor of 0.1) than the value used.

The predicted inflows to the underground mine reach a maximum inflow rate of approximately 26,000 m³/d in year 2018, with 95 percent confidence that the flows will be less than a maximum of 43,000 m³/d

Based on the model predictions and some minor adjustments to account for the shorter mine life, the maximum expected inflows to the underground mine are predicted to gradually increase from 6,300 m^3/d to a maximum expected value of approximately 26,000 m^3/d in year 2018, with 95% confidence level that the flows will be less than 43,000 m^3/d. The predictions are presented in Figure 9.2-8 together with the calculated uncertainty in these inflow values. One standard deviation (1σ) indicates inflows are within the 68 percent confidence interval, while two standard deviations (2σ) indicate inflows within 95 percent confidence interval. Average annual flows for select years are presented in Table 3.6-1.

Figure 9.2-8 Predicted Total Groundwater Inflow to Underground Mine and Uncertainty Analysis

Connate versus Lakewater Composition of Inflows

The flow model was used to assess the proportion of mine water made up of lakewater versus connate water

The flow model was also used to assess the proportion of groundwater inflow to the mine that is composed of lakewater versus deep connate water that is entrapped in sediments and rock. An upper bound case and lower bound case for the percentage of lakewater were estimated.

In the lower bound case, the lakewater proportion would range from 50% to 70% (or 50% to 30% connate water) over much of the mine life

To arrive at the lower bound case of a higher proportion of connate water, it was assumed that all water flowing into mine workings open for longer than one year would be composed of lakewater. Inflow to workings open for less than one year (generally all of the panels excavated in the ore that are backfilled within one year) were assumed to be composed of connate water. Based on these assumptions and the model results, the lakewater component of the mine inflow water would increase from near zero in 2003 to about 50% lakewater and 50% connate water in 2007 (Figure 9.2-9). From 2007 to 2013, the inflow would be composed of 50% to 60% lakewater, and from 2013 to 2023, the lake water component would generally range from 60% to 70%. From 2023 to the end of mining, the lakewater component would gradually increase to a value of 95% lakewater.

The lower bound estimates likely underestimate the lakewater component

These are considered lower bound estimates because they likely underestimate the lakewater component in the mine inflow, and because they ignore the groundwater inflow to the mine panels that will continue to occur even when a panel is backfilled after approximately 6 months. Over time, the groundwater flowing to these backfilled panels will be predominantly composed of lakewater. In addition, it likely underestimates the lakewater component because it does not account for lakewater taking less time to reach mine workings that were opened in the vicinity of previously opened mine workings. These previously opened mine workings would have removed most of the connate water in the vicinity and induced lakewater to flow downwards thus reducing the travel time to the new openings.

In the upper bound case, lakewater proportion is about 90% over much of the mine life

To arrive at the upper boundary, it was assumed that the amount of lakewater that flows into the underground is the difference between the model-predicted groundwater outflow from the lake during mining and the model predicted steady state outflow (baseline outflow) from the lake. The connate water component in this case is then the difference between the model-predicted inflow to the mine and the amount of lakewater calculated above. In addition, this lakewater is assumed to take approximately one and one-half years to reach the mine workings. Based on these assumptions and the results of the numerical model, Figure 9.2-9 shows that the lakewater component increases from near zero in 2003 to about 90% of the total mine inflow within the first five years of operations.

Figure 9.2-9 Lakewater as a Percentage of Total Mine Inflow

9.2.2.2.2 Water Quality Models

GoldSim

The potential changes in groundwater quality was assessed using a water quality model that uses the GoldSim software

The potential changes in groundwater quality due to the underground mine and the surface facilities (Key Questions HG-2 and HG-4) were assessed by a computer model developed using GoldSim software. GoldSim and its associated Contaminant Transport Module were selected as the main platform for the following:

- to calculate mass balance;
- to track mass movement;
- to develop estimates of mass load; and,
- to estimate concentrations at various points in the system.

Supplemental calculations were also done

Supplemental calculations were completed using the geochemical speciation code PHREEQC (pH Redox Equilibrium C) and spreadsheets to develop the overall estimates of water quality (Parkhurst and Appelo 1999).

GoldSim is a flexible program used to predict water quality over time

GoldSim is a highly graphical, flexible, object-oriented computer program that is designed to provide the user with an understanding of the factors which control the performance of an engineered or natural system (as defined by a user specified mathematical model) and to predict the future behaviour (performance) of the defined system. With respect to the Snap Lake site, the GoldSim model was set up as linked elements or cells in which each cell describes an input condition, or process affecting water quality or flow. These cells are subdivided into containers within the model. Each container contains a group of elements linked together by appropriate mathematical relationships describing the pertinent processes.

The GoldSim model calculated water quality at various points on site and at discharge locations

The Snap Lake GoldSim model, as constructed, calculated water quality at various points on site and at the site discharge locations. The model was set to run for forty years with a starting date of January 1, 2000 and an end date of January 1, 2040 (*i.e.,* 13 years after mine closure). The inter-relationships and cycling of water between the various site components were incorporated in the GoldSim model by "feedback" links where the concentration at the previous model time step was used to calculate (through an iterative process) the concentration at the current time step.

GoldSim methods and results are documented in various reports

The water quality calculations for the Snap Lake Diamond Project are documented in Appendix IX.1. The GoldSim program itself is documented in a Main Users Guide (Golder 2000a) and the Contaminant Transport

Module Users Guide (Golder 2000b). Version 7.21.200 was used for the predictive calculations completed in this report. Each release of GoldSim (including its contaminant transport module) is verified using an extensive test suite (over 600 individual tests) prior to release. As referenced in Appendix IX.1, GoldSim code development, testing, and maintenance are compliant with the American Society of Mechanical Engineers (ASME) NQA-1-1994, Quality Assurance Requirements for Nuclear Facility Applications.

Code documentation meets several standards

Code documentation is in general accordance with NUREG-0856 (Formal series of publications by the Nuclear Regulatory Commission [NRC]), Final Technical Position on Documentation of Computer Codes for High-Level Waste Management. Documentation and configuration management are also in general accordance with ANSI/IEEE 730 (American National Standards Institute/Institute of Electrical and Electronic Engineers), IEEE Standard for Software Quality Assurance Plans.

Detailed information is presented in Appendix IX.1

Detailed information on the raw data entered into GoldSim, and the assumptions and water quality predictions of GoldSim are found in Appendix IX.1.

Saline Water Upwelling

A model, FEFLOW, was used to predict connate inflow of saline water

The connate groundwater inflow to the mine may include upwelling of deep, saline groundwater. To address potential water quality issues related to connate groundwater, a two-dimensional model was developed using the software FEFLOW. FEFLOW is a finite element thermohaline (effects of temperature and salinity) flow and transport model code.

Results from Diavik, Lupin, and Snap Lake were entered into the model

A cross section of the underground mine was modelled. The section extended from the ground surface to a depth of 1,000 m. Based on data from the Diavik Diamond Mine and the Lupin Mine, a TDS with depth profile was assigned to the model. The hydraulic conductivity and other hydrogeologic parameters used in the flow model (Table 9.2-4) were assigned to the elements in the FEFLOW model to a depth of 400 m. Below that depth, the hydraulic conductivity was reduced according to reductions in hydraulic conductivity values observed at the Diavik Diamond Mine. Representative mine workings, which were assumed to be open for 26 years, were simulated in the model. The results of the modelling were used to estimate expected relative changes in TDS and corresponding changes in chloride concentrations.

The model predicted that chloride concentrations in connate groundwater would increase

The model predicted that, after five years of mining, the chloride concentrations in connate groundwater would increase from the baseline average of approximately 300 mg/L to 480 mg/L. This would represent an approximately 60% increase from baseline concentrations. The connate water concentration is predicted to remain at approximately 480 mg/L for the life of the mine.

Predictions were used in GoldSim

These predicted chloride concentrations were then used in the GoldSim Model to predict mine water quality.

9.2.2.2.3 Seepage Water Model

The model SEEP/W was used to estimate north pile and water management pond seepage

A model, SEEP/W, was used to estimate the volume and quality of water seeping from the north pile and the water management pond (WMP). SEEP/W is a finite element software product developed by Geo-Slope (1998) that can be used to model the movement and porewater pressure distribution within porous materials such as soil and rock. Model applications include analyses of unconfined flow, precipitation infiltration, pond infiltration, excess porewater pressure, and transient seepage.

This model can analyze saturated and unsaturated flow

SEEP/W is formulated to analyze both saturated and unsaturated flow. Flow in unsaturated soil follows Darcy's Law in a similar manner to flow in saturated soil. The flow is proportional to the hydraulic gradient and the hydraulic conductivity. The system of equations set up by the problem definition is solved in SEEP/W by Gaussian numerical integration which is used to formulate the element characteristic matrices. The integration involves sampling the element characteristics at selected points and summing the sampled values. As a result, it is possible to use a different material property at each sampled point with the result that the material properties, such as the hydraulic conductivity, can vary throughout the element. SEEP/W is also formulated to handle transient boundary conditions and to modify boundary conditions in response to computed results.

9.2.2.3 Assessment Method

Key questions were addressed with a consistent approach

Each key question was addressed by quantifying the changes in groundwater using the following methodology:

- identifying the linkage of various project activities with the issues and determining whether the linkage is valid;
- describing the mitigation measures that will be implemented to minimize groundwater changes;

- conducting hydrogeological analyses to quantify the changes in groundwater quality, quantity, or levels;
- summarizing the residual changes and identifying the pathways to potential environmental consequences addressed in other aquatic resources sections; and,
- describing monitoring programs that will be implemented to monitor the changes so that additional mitigation can be undertaken if warranted.

9.2.2.4 Key Question HG-1: Will the Underground Mine for the Snap Lake Diamond Project Change Groundwater Quantity and Groundwater Levels?

9.2.2.4.1 Linkage Analysis

Groundwater will flow downwards into the mine changing flow to nearby lakes

The baseline hydrogeology indicated that water from Snap Lake generally flows in a radial pattern towards nearby lakes. The development of the mine beneath Snap Lake will result in groundwater being induced to flow downwards into the mine. This will reduce the hydraulic heads within the bedrock in the vicinity of the mine. The depressurization of the bedrock beneath Snap Lake during mine development, may reduce, eliminate, or reverse (*i.e.*, induce water in a nearby lake to flow as groundwater towards Snap Lake) the groundwater component originating from Snap Lake. This may affect the water levels of lakes in the vicinity of Snap Lake.

The mine will not affect shallow groundwater

The underground mine could potentially affect the deep groundwater that is beneath the permafrost and in the talik of Snap Lake and nearby lakes. It will not affect the shallow groundwater in the active layer on the northwest peninsula.

Pre-project conditions will return after closure

At closure, the mine will be allowed to re-flood. During post-closure, the pressures and groundwater flow conditions are expected to return to pre-project conditions.

The linkage between the mine and groundwater quantity and levels is valid

Because of the above, the linkage between the underground mine and changes in the groundwater quantity and levels is valid for all phases (construction, operations, closure, and post-closure).

9.2.2.4.2 Mitigation

Mitigation consists of avoiding or grouting high groundwater inflow zones

Mitigation strategies consist of reducing the inflows to the underground mine by grouting or providing a rock setback to high groundwater zones in the rock (fractured rock zones). During the AEP, grouting of such zones ahead of mining was found to be an effective method of reducing inflows.

9.2.2.4.3 Analysis of Changes

Groundwater changes were assessed relative to drawdown of the water table

The potential changes in the groundwater quantity and levels due to the Snap Lake Diamond Project are discussed in terms of the depression of the watertable (drawdown) and the groundwater quantity. The measurement point for the drawdown is the predicted drawdown at a distance of 1.5 km from the edge of the mine footprint. This distance represents the average lateral width of the mine. The change from baseline water level is defined as the percentage of the drawdown of a typical water column of a well installed in the deep groundwater regime. A well installed into the deep groundwater flow regime would have to be at least 100 m deep to penetrate through the permafrost. The water level in the well prior to mining would be near to the ground surface, thus the water column would be 100 m long.

These changes to groundwater quantity and the depressurization were evaluated with the groundwater flow model. The impact analysis of potential effects of groundwater changes to surface water levels in Snap Lake and other waterbodies is presented separately in Hydrology (Section 9.3) of this EA.

Change Groundwater Levels

A 5% change in baseline water level is predicted for lakes to the north

The greatest change in groundwater levels will be evident in the final year of mine operation when the mine workings have been open for over 22 years. Figure 9.2-10 presents the model-predicted drawdown in the last year of mining. The drawdown cone will be centred in the northern portion of Snap Lake and will extend beneath the north lake, NL5, NL6, and the northeast lake. The decrease in the water level will be less than 5 m and will represent less than a 5% change from the baseline groundwater level (assumed to be a water column 100 m long) at distances of greater than 1.5 km from the mine.

There will be little to no change in the quantity of deep groundwater

The water level in the deep groundwater regime will not drop below the bottom of the permafrost, which defines the top of the deep groundwater regime. Consequently, there will be little to no change in the quantity of water in the deep groundwater regime.

Recovery to near baseline flow conditions is predicted to occur within one month

At closure, the mine will be allowed to flood. Figure 9.2-11 indicates that groundwater levels will return to baseline levels within one month. At that time, groundwater flow conditions that existed prior to development will be re-established.

Figure 9.2-10 Predicted Maximum Water Level Drawdown in the Deep Groundwater Flow System

Figure 9.2-11 Predicted Recovery of Groundwater Levels During Post-Closure

Change in Groundwater Flow to Lakes

Approximately 2,700 m^3/d of deep groundwater flowed to the nearest lake before mining

It has been inferred that, prior to development, water in the deep groundwater flow system (*i.e.*, below the permafrost) moved radially from Snap Lake to nearby lakes (Figure 9.2-5). The groundwater loss from Snap Lake was estimated to be approximately 10,500 m^3/d. Approximately 2,700 m^3/d of this flow would be going to the nearest, largest lake in the LSA, the north lake, and 800 m^3/d would flow to the next largest lake, the northeast lake. This deep groundwater will not flow to small lakes such as NL1 through NL6 (Figure 9.2-3) as these are likely underlain by thick permafrost that effectively isolates them from the deep groundwater regime.

During mining, the net deep groundwater flow from Snap Lake to the nearby lake most effected by the project (north lake) is reduced by approximately 60%

The groundwater flow model was used to assess the potential changes in the groundwater flow to the lakes affected by mine development (*i.e.*, lakes within the drawdown cone). Figure 9.2-12 presents the model predicted hydraulic head in the last year of mining when the mine has been open for 22 years and the maximum change in hydraulic heads resulting from mining occurs. A portion of the groundwater flow from Snap Lake (1,900 m^3/d) will still be directed towards the north lake (Figure 9.2-12). However, at the east end of the north lake, the water level drawdown will be sufficient to divert approximately 800 m^3/d of groundwater flow from the north lake to the underground mine. The impact of this reduction in groundwater flow to the north lake will be evaluated in the Hydrology section of this EA (Section 9.3). The groundwater flow to the northeast lake is virtually unaffected by the mining, with groundwater flow from Snap Lake to this lake being maintained at approximately 800 m^3/d.

9.2.2.4.4 Residual Groundwater Changes

There will be a 5% change in deep groundwater levels

In the last year of mining when flows will be at their peak, there will only be a minor change (5%) in deep groundwater levels from the baseline. There will be little or no change in the deep groundwater quantity. This change will be limited to the LSA. Changes will occur continuously during the construction, operation, and closure of the project, although the magnitude of the change in groundwater level will be less than 5% for most of the project duration. The change will be continuous, but it will be reversed within one month of mine closure.

Environmental consequences will be assessed in Section 9.3

The environmental consequences of this change in groundwater quantity and levels will be assessed in Hydrology (Section 9.3) and included as part of the residual impact classification in Section 9.3.

Figure 9.2-12 Effect of Mining on Groundwater Levels, Deep Groundwater Flow System

Changes are expected to be less than predicted

There is a high probability that the actual changes will be less than predicted because of the degree of conservatism used in the analysis. There is a high degree of confidence that these effects to the groundwater quantity and levels will not be greater than predicted. The model assumes that the lower 50 m of the highly permeable exfoliated rock is unfrozen beneath the landmasses between the lakes. This is considered conservative, because it is likely that all of the exfoliated rock would be frozen (in permafrost) resulting in a much lower hydraulic conductivity. This lower hydraulic conductivity would result in less groundwater outflow from Snap Lake to the northern lakes prior to mining and a lower quantity of groundwater flow reversal during mining.

9.2.2.5 Key Question HG-2: Will the Underground Mine for the Snap Lake Diamond Project Change Groundwater Quality?

9.2.2.5.1 Linkage Analysis

During construction, operation, and closure, groundwater will flow into the mine coming into contact with materials on the mine floor

During construction, operations, and closure, deep groundwater flow (*i.e.*, groundwater beneath the permafrost or within the talik beneath Snap Lake) will be induced to flow towards the mine. Groundwater inflow to the underground mine will be collected in trenches and sumps located underground and then pumped to a treatment plant on surface. As the groundwater flows across the floor of the mine, it will come in contact with such materials as explosive residue, crushed kimberlite, granite and/or metavolcanics, grout material, and backfill that may alter the water chemistry. The water from the mine will be pumped to the surface and treated before being discharged to Snap Lake. Through this route, groundwater will discharge to surface water; mine water will not alter groundwater quality in the surrounding environment.

At post-closure, water that is in contact with the mine will flow to the north

Mine panels will be backfilled immediately after mining. The backfill will be placed as a slurry very near saturation. During closure, pumping will cease, and the underground mine will be allowed to flood. At post-closure, when baseline flow conditions are re-established, groundwater will come into contact with the paste backfill and any other materials remaining in the mine. This groundwater will migrate in a northward direction from Snap Lake and effect groundwater quality enroute. Eventually, this groundwater will discharge to lakes to the north, which may affect the quality of the water in those lakes. The potential impacts to the water quality of lakes to the north will be evaluated in Section 9.4 of the EA. The quality of deep groundwater flowing outward from Snap Lake in other directions will be unaffected and will not be discussed further.

Shallow groundwater will not be affected by the mine

Shallow groundwater within the active layer on the northwest peninsula will not be affected by the underground mine through all phases of the project (construction, operations, closure, and post-closure).

The linkage between the underground mine and groundwater quality is considered valid for the post-closure phase

Based on the above, the linkage between the underground mine and groundwater quality is considered valid for the post-closure phase only. The potential changes are restricted to the deep groundwater beneath the permafrost and within the talik beneath Snap Lake. Potential changes to the deep groundwater during the post-closure phase will be assessed. Since there are no valid linkages for the other phases, they will not be assessed further.

9.2.2.5.2 Mitigation

Mitigation will include management practices to limit the addition of chemicals to groundwater

Mitigation measures consist of explosive management practices that reduce the quantity of explosive waste and the use of alternative grouts or cements to limit chemical leaching.

Post-closure mitigation will also occur

During post-closure, mitigation measures include allowing the mine to flood naturally by groundwater flow from the lake to the underground workings. Should water within the WMP be used to flood the mine at closure, this water will be treated before pumping it to the mine.

9.2.2.5.3 Analysis of Changes

Groundwater constituents are compared to baseline

The water quality model, GoldSim, and geochemical speciation model, PHREEQC, were used to assess the quality of the deep groundwater during post-closure. The potential changes to groundwater due to the underground mine are discussed in terms of predicted chemical constituents and parameters. These constituents are then compared to the baseline chemistry. Potential effects to the water quality of lakes to the north are evaluated separately in Section 9.4 of the EA.

Change in Groundwater Quality

After the mine is flooded, groundwater that has been in contact with the mine will flow away from the mine

At closure, the mine will be flooded. Assuming it is allowed to flood naturally, it is estimated that the pressures and water levels will return to near baseline conditions in less than one month. Groundwater flow conditions in the deep groundwater flow regime would then revert to near baseline conditions. Groundwater will then move down from Snap Lake and radially outwards to large lakes located at lower elevations. As the water from Snap Lake flows down in the groundwater, a portion of the water will contact the underground mine.

About 600 m^3/d of groundwater will flow from the mine to the north and northeast lakes

The total groundwater flow from all of Snap Lake is estimated to be approximately 10,500 m^3/d. It is estimated that approximately 5% of this groundwater, or about 600 m^3/d, will pass through the underground workings. As shown in Figure 9.2-13, this groundwater is then expected

Figure 9.2-13 Post-Closure Pathway of Groundwater in Contact with Mine Workings

to flow northwards, with approximately 400 m^3/d flowing to the eastern end of the north lake. Approximately 200 m^3/d will flow to the northeast lake. Groundwater is not expected to flow up into the smaller lakes NL5 and NL6, located between the north and northeast lakes (Figure 9.2-13) because these lakes are not expected to have taliks. The small lakes to the north, NL1 to NL6, are hydraulically isolated from the deep groundwater flow system.

At post-closure, the groundwater flow to the mine occurs in areas not backfilled

The estimated hydraulic conductivity of the cemented paste backfill (5×10^{-8} m/s) in the underground workings is nearly two orders of magnitude less than that estimated for the horizontal conductivity of the hangingwall rock (2×10^{-6} m/s). Consequently, once the mine has flooded during post-closure, groundwater flow through the mine workings will predominantly occur as advective flux (transport by flowing groundwater) in the open workings that have not been backfilled.

It will take about 80 years for water from the mine to reach the north lake

Based on the model results, the underground workings take about one month to fill. When this has occurred and water levels have returned to near baseline levels, water will begin to flow in the groundwater system towards the lakes to the north. The estimated travel time from the underground workings to the northern lakes is in the order of 80 years. This estimate is based on the following assumptions:

- the horizontal hydraulic conductivity of the hangingwall rock is approximately 2×10^{-6} m/s;
- the hydraulic gradient towards the northern lake is approximately 0.002;
- distance from the northern edge of the mine to the northern lake is 2 km; and,
- fracture porosity (fracture openings in rock) is approximately 0.005.

Due to diffusion from the paste backfill, water flowing through the mine is estimated to have the same signature as the paste backfill

The approximate average lateral width of the mine working is 1.5 km. Given this and the above parameters, groundwater is estimated to be in contact with the backfill for over 60 years. Because of the long contact time, diffusion gradients within the backfill and the water in the mine openings will likely result in equilibrium conditions between the backfill water and that of the water in the open workings. Consequently, it is estimated that the groundwater flowing through the fracture system to the lakes to the north will have a chemical signature (specific chemical make-up) similar to that of the cemented paste backfill. However, because the porosity of the mine workings is greater than that of the host rock (in the mine opening themselves the effective porosity would be near 1), the estimates for the contact time with the backfill and the travel time to the lakes to the north are considered conservatively low.

Groundwater quality estimates are based on leach testing and process plant discharges

Table 9.2-5 presents the expected concentrations in the water seeping from the mine and migrating to the northern lakes, and the measured concentrations in the baseline waters of the granitic rock (*i.e.*, the connate water). The expected concentrations presented in Table 9.2-5 are based on leach testing of cemented processed kimberlite (PK) paste. The chemistry derived from these leach tests of the backfill paste includes the affects of cement, grout, and crushed rock on the groundwater chemistry. Where appropriate, and to account for the affects of explosive residue on the groundwater chemistry, values from the site monitoring data were used to supplement the laboratory test work (discussed further in Appendix IX.1). The maximum estimated concentrations are based on the maximum values observed in the process plant discharge or in the lab testing of the cemented paste material. As such, some of these values are likely over-estimates of concentrations as the process plant discharges are at a lower pH (about 9) than that measured in the cemented PK paste samples (at 11.4 to 12.2).

Table 9.2-5 Summary of Estimated Concentrations of Deep Groundwater from the Underground Mine at Post-closure

Parameter	Units	Connate Water (Granite)[a] (n=9)[b]		Long Term Seepage Water[c]
		Median	Average	Expected
Conventional Parameters				
pH	pH	9.2	9.2	11.8
Alkalinity	mg/L	80.0	106	760
Total Dissolved Solids	mg/L	920	902	897
Total Hardness	mg/L	286	425	-
Dissolved Organic Carbon	mg/L	4.0	4.0	3.1
Conductivity	µS/cm	1,130	1,526	4,070
Nutrients				
Ammonia	mg/L	4.1	7.6	6.6
Nitrate + Nitrite	mg/L	2.4	6.6	42.7
Total Phosphorus	mg/L	0.08	0.10	0.01
Dissolved Phosphorus	mg/L	0.04	0.06	0.02
Orthophosphate	mg/L	0.003	0.012	-
Total Kjeldahl Nitrogen	mg/L	3.2	5.6	26.6
Total Organic Carbon	mg/L	4.0	4.2	3.3
Major Ions				
Calcium	mg/L	110	152	389
Chloride	mg/L	248	330	8.6
Fluoride	mg/L	0.6	0.6	0.6
Hydroxide	mg/L	<5	12.4	-

Table 9.2-5 Summary of Estimated Concentrations of Deep Groundwater from Underground Mine at Post-closure (continued)

Parameter	Units	Connate Water (Granite)[a] (n=9)[b]		Long Term Seepage Water[c]
		Median	Average	Expected
Magnesium	mg/L	7.8	11.5	<0.03
Potassium	mg/L	9.3	10.0	19.0
Silica	mg/L	12.5	11.3	-
Sodium	mg/L	76.7	76.9	19.2
Sulphate	mg/L	10.0	29.2	5.3
Metals (Expected total values)				
Aluminum	µg/L	7.2	10.4	468
Antimony	µg/L	0.21	0.31	1.7
Arsenic	µg/L	1.1	1.7	0.7
Barium	µg/L	55.4	69.7	440
Beryllium	µg/L	<0.2	0.1	<3
Bismuth	µg/L	<0.03	0.05	<3
Boron	µg/L	64.0	58.7	-
Cadmium	µg/L	<0.05	0.025	<0.3
Cesium	µg/L	0.50	0.37	-
Chromium	µg/L	0.06	0.62	313
Cobalt	µg/L	0.15	0.12	<0.5
Copper	µg/L	2.8	4.3	5.1
Iron	µg/L	21.0	402	<10
Lead	µg/L	0.20	0.28	0.4
Lithium	µg/L	45.2	43.9	-
Manganese	µg/L	7.1	36.0	<0.3
Mercury	µg/L	0.10	0.12	<0.1
Molybdenum	µg/L	5.6	5.6	81.1
Nickel	µg/L	0.8	1.2	<3
Rubidium	µg/L	23.0	22.1	-
Selenium	µg/L	<0.4	0.2	0.43
Silver	µg/L	<0.1	0.05	<0.05
Strontium	µg/L	1760	2292	4950
Thallium	µg/L	<0.03	0.04	<0.5
Titanium	µg/L	1.3	1.2	<10
Uranium	µg/L	0.13	0.18	<0.05
Vanadium	µg/L	1.8	2.2	<5
Zinc	µg/L	3.4	2.7	<5

< = less than detection limit (see glossary for definition).

[a] Values based on baseline groundwater data (Table 9.2-1). Where values were below detection 1/2 of the median detection limit value was used to calculate the average (see Appendix IX.1 for more detail).

[b] n = 8 for Hg, SiO2, Sr, DOC; and n = 7 for Hardness, F.

[c] Values based on August 01 leach extraction "PK Paste Leach A1". Process water discharge data from the AEP were used where PK Paste Leach A1 data were unavailable as discussed in Appendix IX.1.

mg/L = milligrams per litre; µS/cm = micro Seimens per centimetre; µ/L = micrograms per litre.

Mine water will be alkaline

The pH of the seepage from the mine workings is expected to be alkaline (11.9) due to the cement component of the PK paste.

Seepage water quality is compared to the baseline granite groundwater

The seepage water is expected to be similar in concentrations to the granitic connate water (baseline water quality) for copper, lead, and mercury, and lower in concentration for chloride, iron, magnesium, sodium, arsenic, and sulphate. Nitrate, total Kjeldahl nitrogen, calcium, cobalt, cadmium, potassium, nickel, antimony, barium, and strontium are expected to be less than ten times that of the connate water. Substantial increases in aluminum (468 µg/L), chromium (313 µg/L), and molybdenum (81 µg/L) relative to the connate water values of 10.4 µg/L, 0.62 µg/L and 5.6 µg/L, respectively, are expected due to the composition of the PK and the alkaline pH values.

Changes on Water Quality of Nearby Lakes

The water quality of the north and northeast lakes will be affected by groundwater flowing from the mine workings

Once the groundwater levels have recovered during post-closure, the groundwater that has come in contact with the mine workings will flow and discharge into the north and northeast lakes, located approximately 2.5 km north of Snap Lake and approximately 2 km north of the mine workings. The groundwater flow from Snap Lake that has come in contact with the mine workings is estimated to be approximately 400 m^3/d to the east end of the north lake and 200 m^3/d to the west end of the northeast lake. The chemistry of this groundwater is estimated to be that presented in Table 9.2-5. The groundwater concentrations are estimated to remain relatively constant for about 300 years (*i.e.*, 300 years after the groundwater from the mine reaches the north lake), although this estimate has a high level of uncertainty. Concentrations are expected to decrease gradually after this time. The overall duration is uncertain, but it could extend well beyond 380 years from mine closure. The impact of this groundwater on the water quality of the north and northeast lakes is evaluated in Section 9.4 (Water Quality).

9.2.2.5.4 Residual Groundwater Changes

Residual changes are expected to occur for a long time after post-closure

The residual changes due to the underground mine in the deep groundwater are limited to a small portion (<5%) of the LSA. Groundwater in contact with the mine is expected to have a pH of 11.9 due to the cement in the backfill and substantial increases in aluminum (468 µg/L), chromium 313 µg/L), and molybdenum (81 µg/L) relative to the baseline groundwater. They are expected to occur during post-closure only and they are predicted to reach the north lake in 80 years. They are expected to be reversible in the long-term; however, long-term is uncertain and could be much longer than the 100 years used in other sections of the EA.

Groundwater quality is expected to be better than predicted because concentrations may decline over distance

The confidence level that the groundwater flow from Snap Lake that has come in contact with the mine workings will not be greater than predicted is high. The model assumes that the lower 50 m of the highly permeable exfoliated rock is unfrozen beneath the land between the lakes. This is considered conservative, because it is likely that all of the exfoliated rock would be frozen (in permafrost) resulting in a much lower hydraulic conductivity. This lower hydraulic conductivity would result in less groundwater outflow from Snap Lake to the northern lakes during post-closure.

There is a high level of confidence that groundwater quality will not be greater than predicted

The confidence level that groundwater quality changes resulting from the underground mine will not be greater than predicted is high. Predicted water quality concentrations are based on initial short-term leach testing results for cemented PK paste. In the long term, leach rates are expected to decline over time. Further, the predicted groundwater quality does not take into account any geochemical reactions along the flow path that serve to attenuate and reduce concentrations in the groundwater.

Additional studies are proposed or underway

Further refinement of the predicted chemistry of mine affected groundwater during post-closure is expected to reduce the magnitude of predicted impacts to the north and northeast lakes. Additional studies are proposed or underway as described in Section 9.2.3.

9.2.2.6 Key Question HG-3: Will the Surface Facilities for the Snap Lake Diamond Project Change Groundwater Quantity and Groundwater Levels?

9.2.2.6.1 Linkage Analyses

Linkage between the surface facilities and the shallow groundwater quantity and levels is invalid

Runoff from core surface facilities, including the north pile, the process plant, and the buildings complex, will be collected in trenches and directed to the WMP. The water will then be directed to a treatment plant prior to discharge to Snap Lake. These trenches are expected to be approximately 1 m deep. The active layer has been found to be up to 8 m deep. Consequently, most of the groundwater is expected to flow beneath these trenches and then flow through the active layer to depressions or ponds in the northwest peninsula and then to Snap Lake. Groundwater may also flow beneath these trenches and through the active layer directly to Snap Lake. Therefore these surface facilities are expected to have negligible affect on the groundwater quantity and levels in the shallow active layer on the northern peninsula.

Linkage between surface facilities and deep groundwater quantity and levels is invalid

The surface facilities are also expected to have negligible affect on the groundwater quantity and levels in the deep groundwater flow regime because of the presence of approximately 100 m of low permeable permafrost. Because of these reasons, the link between surface facilities and groundwater quantity and water levels is considered invalid.

9.2.2.7 Key Question HG-4: Will the Surface Facilities for the Snap Lake Diamond Project Change Groundwater Quality?

9.2.2.7.1 Linkage Analysis

Seepage from surface facilities will flow into Snap Lake

During the period of thaw, seepage originating from surface facilities, including the north pile and the WMP located on the northwest peninsula, is expected to flow as groundwater through the active layer to Snap Lake.

The chemistry of the seepage water may be altered

The chemistry of these groundwater seepages may be altered due to contact with such materials as PK paste, grout, explosive residues, and waste rock. The chemistry of this groundwater will likely be different from the baseline groundwater. This groundwater, as it seeps into Snap Lake, may alter the chemistry of the lake.

Seepage originating at other locations will flow as surface water

Surface water from other facilities on the site such as the airstrip are expected to flow into surface depressions and low-lying areas and then flow as surface water to Snap Lake. The affect of these surface flows on the chemistry of Snap Lake is assessed in Section 9.4 (Water Quality).

The deep groundwater will not be affected

None of the surface facilities are expected to affect the chemistry of the deep groundwater located beneath the permafrost and within the talik of Snap Lake.

The linkage to shallow groundwater quality is valid

Based on the above, the linkage between surface facilities on the northwest peninsula and water quality of the shallow groundwater is valid for all phases (construction, operations, closure, and post-closure).

9.2.2.7.2 Mitigation

Mitigation will include deeper trenches

Mitigation will include the installation of deeper trenches, particularly along the north side of the north peninsula between the north pile and the north arm of Snap Lake.

9.2.2.7.3 Analysis of Changes

The changes in groundwater quality are predicted using the water quality model

The water quality model was used to assess the affects of the surface facilities on the shallow groundwater quality. The potential changes in the groundwater due to the surface facilities is discussed in terms of predicted changes in chemical constituents. The potential effects of the groundwater on the water quality of Snap Lake is evaluated separately in Section 9.4 of the EA.

Seepage from the North Pile

Assumptions that were made are listed

The quantity of groundwater flowing from the north pile to the north arm of Snap Lake was estimated to be 1% of the precipitation falling on the entire footprint of the north pile and 10% of the precipitation falling on the area between the north pile and Snap Lake. Given the above, the quantity of groundwater flowing through the north pile is calculated to be approximately 2,900 cubic metres per year (m^3/yr) or a daily average of approximately 8 m^3/d. This value of groundwater flow assumes that the north pile will freeze. Higher infiltration rates than this are expected if the north pile does not freeze, but this lower infiltration rate is more conservative as it results in higher estimated concentrations of chemical constituents in the seepage. Therefore, the following analysis is based on an infiltration rate of 1% for a frozen north pile. The amount of precipitation infiltrating to the groundwater from the area between the north pile and Snap Lake (*i.e.*, precipitation that has not come in contact with the north pile) is calculated to be approximately 8,600 m^3/yr.

Average annual concentrations in north pile seepage are presented in Table 9.2-6

The determination of the water quality of the north pile seepage was based on relative contributions from the rock types of the north pile, the PK paste consolidation water flux (water volume passing a location), the precipitation rate, runoff factors (discharge in a given area), and other factors as input into the GoldSim model (Appendix IX.1). A detailed discussion of the geochemical source terms used in the model is provided in Appendix III.2. Model results showing the estimated major ion and metal concentrations over time are provided in Appendix IX.1. A summary table showing average annual concentrations for selected years is provided in Table 9.2-6. Figures 9.2-14 and 9.2-15 are provided to illustrate general trends over time for selected major ion and metal concentrations.

The pH of the north pile seepage is expected to be neutral or near neutral

The pH of the seepage from the north pile is expected to be near neutral based on observed pH values from geochemical test work and monitoring programs completed as part of the water quality assessment (Appendix IX.1). Seepage from the north pile will migrate through fracture pathways in the granitic bedrock where it will mix with infiltrating water. The seepage will then discharge to the base of Snap Lake.

Table 9.2-6 Summary of Estimated Concentrations for North Pile Seepage Water

Parameter	Units	North Pile Seepage[a]							Groundwater
		Average Annual				Summary			Baseline Granite[b]
		Year 5	Year 15	Year 25	Year 35	Peak Average Annual[c]	Median Average Annual (year 1 through 40)	Average Post Closure (model year 34 - 39)	Median
Conventional Parameters									
pH[d]	pH	6.5 - 7.1	6.5 - 7.1	6.5 - 7.1	6.5 - 7.1	7.1	-	6.5 - 7.1	9.2
Alkalinity	mg/L	3.8	104	104	104	104	104	104	80.0
Total Dissolved Solids	mg/L	27.0	361	312	157	400	312	156	920
Total Suspended Solids	mg/L	-	-	-	-	-	-	-	-
Nutrients									
Ammonia	mg/L	0.4	4.3	3.1	0.1	5.3	3.2	0.1	4.1
Nitrate-N	mg/L	1.5	15.3	11.3	0.5	18.7	11.4	0.4	-
Total Phosphorus	mg/L	0.006	0.35	0.33	0.26	0.35	0.33	0.26	0.1
Dissolved Phosphorus	mg/L	0.001	0.033	0.033	0.026	0.033	0.032	0.026	0.035
Total Kjeldahl Nitrogen	mg/L	1.0	11.0	8.9	2.4	13.1	8.9	2.4	3.2
Major Ions									
Calcium	mg/L	2.9	56.8	51.3	29.3	60.8	51.3	29.1	110
Chloride	mg/L	3.3	32.6	24.1	0.7	40.1	24.2	0.6	248
Magnesium	mg/L	2.5	39.7	34.1	13.3	44.1	34.2	13.2	7.8
Potassium	mg/L	0.9	18.7	16.9	9.2	19.9	16.9	9.1	9.3
Silica	mg/L	4.1	9.4	9.4	9.4	9.4	9.4	9.4	12.5
Sodium	mg/L	1.6	18.0	14.1	3.2	21.4	14.1	3.1	76.7
Sulphate	mg/L	7.8	109	88.7	29.4	124	88.8	29.1	10.0
Dissolved Metals									
Aluminum	µg/L	1.6	150	194	244	245	138	244	7.2
Arsenic[e]	µg/L	0.1	7.5	7.6	7.6	7.6	7.5	7.6	1.1
Barium	µg/L	4.0	132	126	79.4	136	126	79.1	55.4
Beryllium[e]	µg/L	0.03	2.8	3.1	3.3	3.3	2.6	3.3	<0.2
Cadmium[e]	µg/L	0.02	1.7	1.8	1.4	1.8	1.6	1.4	<0.05
Chromium	µg/L	0.1	1.8	1.8	1.8	1.8	1.8	1.8	0.1
Cobalt	µg/L	0.1	3.9	3.4	2.7	3.9	3.4	2.7	0.2
Copper	µg/L	0.1	9.6	10.4	9.6	10.4	9.2	9.6	2.8
Iron	µg/L	0.5	1.2	1.2	1.2	1.2	1.2	1.2	21.0

Table 9.2-6 Summary of Estimated Concentrations for North Pile Seepage Water (continued)

		North Pile Seepage[a]							Groundwater
		Average Annual				Summary			Baseline Granite[b]
Parameter	Units	Year 5	Year 15	Year 25	Year 35	Peak Average Annual[c]	Median Average Annual (year 1 through 40)	Average Post Closure (model year 34 - 39)	Median
Lead[e]	µg/L	0.1	15.4	16.8	15.8	16.8	14.7	15.8	0.2
Manganese	µg/L	1.1	65.6	65.3	79.8	79.9	64.7	79.8	7.1
Mercury[e]	µg/L	0.01	0.8	0.9	0.9	0.9	0.8	0.9	0.1
Molybdenum	µg/L	5.2	126	160	182	182	125	182	5.6
Nickel	µg/L	2.5	108	99.2	61.7	110	99.2	61.5	0.8
Selenium[e]	µg/L	0.14	13.9	14.8	12.1	14.8	13.4	12.1	<0.4
Silver[e]	µg/L	0.004	0.28	0.29	0.26	0.29	0.27	0.26	<0.1
Strontium	µg/L	43.3	982	935	596	1037	935	595	1760
Thallium	µg/L	0.05	0.8	0.7	0.4	0.9	0.7	0.4	<0.03
Uranium[e]	µg/L	0.3	27.8	32.2	31.5	32.3	26.2	31.5	0.1
Vanadium	µg/L	0.6	65.7	78.9	85.7	85.8	61.4	85.7	1.8
Zinc	µg/L	0.2	13.7	15.4	17.1	17.1	13.2	17.1	3.4

"<" denotes values below the detection limit (see glossary).

[a] Estimates at seepage discharge from north pile to North Arm of Snap Lake, values based on average annual values of weekly data as calculated using GoldSim.

[b] Baseline Granite values based on median groundwater inflow water from the granitic unit.

[c] The peak average annual value is the maximum average annual value from years from 1 through 40.

[d] pH values estimated based on geochemical speciation modelling.

[e] GoldSim input data based on one half of typical lower detection limits where values were below detection, elevated detection limits not included in average detection limit values the resulting calculated values may be biased upwards by the associated input data detection limits.

Figure 9.2-14 Selected Major Ion Concentration Trends for North Pile Seepage Estimates

Figure 9.2-15 Selected Metal Concentration Trends for North Pile Seepage Estimates

Concentrations in north pile seepage show two distinct trends

The calculated concentrations for the north pile seepage show two distinct trends over time. The concentrations of nickel, cobalt, and to some degree cadmium, are more strongly associated with kimberlite and are highest during production when more kimberlite is exposed at surface. During closure, a granite cap will cover the kimberlite and the concentration of these metals will decrease. The remaining metal concentrations tend to be associated with all rock types and tend to increase as the north pile area increases.

Major ion concentrations typically peak during operations and decrease at closure and are either near, or slightly elevated above, baseline granitic water

The TDS and major ion concentrations will peak during operations between year 5 and 10 and will then decrease as the north pile is progressively reclaimed and is covered with granite. The peak TDS concentrations of 300 to 400 mg/L indicate moderate mineralization of the seepage; the TDS concentration will decrease at closure to about 150 mg/L (Figure 9.2-14). The TDS will be lower than the baseline water quality from the granitic unit (920 mg/L). Chloride concentrations in the north pile seepage will be less then one tenth of those observed in the baseline; sodium values will be one fifth of the baseline concentrations. The other major ions will be near, or elevated by one to ten times, the observed concentrations in the baseline granitic groundwater.

Estimated north pile seepage concentrations for most metals are typically elevated with respect to baseline groundwater

Metal concentrations in north pile seepage results are predicted to range from 1 to 20 times those of the baseline granite water quality, with the exceptions of aluminum, molybdenum, nickel, and uranium. These metals will be higher than those observed in the baseline water quality; however, this likely overestimates concentrations that will be observed under field conditions. Several of the leachate values observed in the kinetic testing for aluminum, arsenic, cadmium, mercury, molybdenum, nickel, uranium, lead, and arsenic were below laboratory detection limits. The overestimation of these parameters results from the use of values at some proportion of the detection limit (either one half or one tenth depending on the parameter). A more detailed discussion of the use of concentrations reported at detection limits is provided in Appendix III.2 and IX.1.

Groundwater Seepage from the Water Management Pond

About 12,000 m^3/yr of seepage is expected from Dam 1 of the water management pond

Water will seep from the WMP through Dam 1 and into the active layer south of the dam. It will then either discharge to the surface and then flow to Snap Lake or flow as groundwater to Snap Lake. The quantity of this groundwater flow is estimated to be approximately 12,000 m^3/yr based on SEEP/W modelling. The seepage will be released during periods when the ground is thawed as indicated in Appendix IX.1. The water quality of the seepage below the dam will be predominantly influenced by the dissolved-phase water quality of the WMP and is estimated based on relative contributions from the mine and site reporting to the WMP (Appendix IX.1).

Seepage pH is expected to be near neutral to slightly alkaline

The pH of the seepage below Dam 1 is expected to be near neutral based on the pH measured in the mine discharge and from the site runoff during the AEP (Appendix III.2). A summary table showing average annual expected concentrations in the WMP seepage for selected years is provided in Table 9.2-7. Figures 9.2-16 and 9.2-17 are provided to illustrate general trends over time for selected major ion and metal concentrations of the seepage expected to migrate below Dam 1. More detail is provided in Appendix IX.1.

As modelled the water management pond seepage is influenced by early mine discharge chemistry followed by site runoff chemistry during operations and closure

Initial concentrations in the WMP seepage will be primarily influenced by mine water currently stored in the pond and from the de-watering of the underground workings at construction. The seepage will reflect the baseline groundwater and mine water discharge concentrations, which have relatively high concentrations of major ions and nutrients. As currently modelled, the site runoff becomes the major influence on the WMP water quality after 2005. Consequently, the concentrations of TDS and major ions decrease over time whereas the concentrations of some metals (*e.g.*, iron, copper, manganese, zinc) increase to a steady-state level reflective of the observed site runoff.

Water management pond seepage concentrations may change; however, the overall loading to the lake is accounted for in the water quality estimates as either discharge from treatment or as seepage

During operations, the WMP will be used as temporary storage for water from either the mine or the north pile. In such instances, the quality of the WMP seepage will also reflect the contribution of the mine water or north pile runoff. Regardless of the ultimate water quality in the WMP, the current overall discharge water quality estimates (Appendix IX.1) take into account the entire dissolved component of the predicted load from the north pile, mine, and site runoff. As presently envisioned, treatment consists of sediment removal. Therefore, the dissolved load to Snap Lake is accounted for in the impact assessment stage regardless of whether the water arrives as seepage from the WMP or as discharge from the water treatment plant.

At closure seepage from the water management pond will be greatly reduced or eliminated altogether

It is currently anticipated that, after 2005, water from the mine and from the north pile will be routed directly to the treatment plant and will not pass through the WMP. At closure, there will be no water reporting from the mine, and water from the north pile will be routed directly to the north arm of Snap Lake. Therefore, the only water impacting seepage quality from the WMP area will be site runoff. At closure, the WMP will be decommissioned, thereby greatly reducing or eliminating seepage from the WMP area.

Table 9.2-7 Summary of Estimated Concentrations for Water Management Pond Seepage Water

Parameter	Units	WMP Seepage[a]							Groundwater
		Average Annual				Summary			Baseline Granite[b]
		Year 5	Year 15	Year 25	Year 35	Peak Average Annual[c]	Median Average Annual (year 1 through 40)	Average Post Closure (model year 34 - 39)	Median
Conventional Parameters									
pH[d]	pH	6.5 - 9.3	6.5 - 7.1	6.5 - 7.1	6.5 - 7.1	6.5 - 9.3	6.5 - 9.3	6.5 - 7.1	9.2
Alkalinity	mg/L	53.1	1.4	1.2	1.1	174	1	1.2	80.0
Total Dissolved Solids	mg/L	257	147	147	193	647	177	193	920
Nutrients									
Ammonia	mg/L	1.7	0.9	0.9	0.9	7.1	0.9	0.9	4.1
Nitrate + Nitrite	mg/L	-	-	-	-	-	-	-	2.4
Nitrate-N	mg/L	4.5	4	4	4.1	8	4	4.1	-
Total Phosphorus	mg/L	0.16	0.003	0.002	0.002	1.1	0.0	0.002	0.1
Dissolved Phosphorus	mg/L	0.004	0.003	0.003	0.003	0.007	0.003	0.003	0.035
Total Kjeldahl Nitrogen	mg/L	1.0	0.42	0.42	0.42	4.6	0.4	0.42	3.2
Major Ions									
Calcium	mg/L	55.6	25.6	25.4	25.4	213	25	25.4	110
Chloride	mg/L	88.7	48.7	48.4	48.4	225	48	48.4	248
Magnesium	mg/L	18.1	17.7	17.7	17.7	18.9	17.7	17.7	7.8
Potassium	mg/L	3.0	1.8	1.8	1.8	9.0	1.8	1.8	9.3
Silica	mg/L	1.6	1.8	1.8	1.8	1.8	1.8	1.8	12.5
Sodium	mg/L	9.8	2.5	2.5	2.5	38.0	2.5	2.5	76.7
Sulphate	mg/L	43.7	44.4	44.3	44.3	44.4	44.3	44.3	10.0
Dissolved Metals									
Aluminum	µg/L	48.8	42.2	42.1	42.1	61.8	42.2	42.1	7.2
Arsenic[e]	µg/L	0.03	0.03	0.03	0.03	0.03	0.03	0.03	1.1
Barium	µg/L	59.8	32.4	32.2	32.2	195	32	32.2	55.4
Beryllium[e]	µg/L	0.05	0.05	0.05	0.05	0.07	0.05	0.05	<0.2
Cadmium[e]	µg/L	0.08	0.09	0.09	0.09	0.09	0.09	0.09	<0.05
Chromium	µg/L	1.1	0.7	0.7	0.7	2.5	0.7	0.7	0.1
Cobalt	µg/L	4.2	4.7	4.7	4.7	4.8	4.7	4.7	0.2
Copper	µg/L	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.8
Iron	µg/L	2.9	2.9	2.9	2.9	2.9	2.9	2.9	21.0

Table 9.2-7 Summary of Estimated Concentrations for Water Management Pond Seepage Water (continued)

Parameter	Units	WMP Seepage[a]							Groundwater
		Average Annual				Summary			Baseline Granite[b]
		Year 5	Year 15	Year 25	Year 35	Peak Average Annual[c]	Median Average Annual (year 1 through 40)	Average Post Closure (model year 34 - 39)	Median
Lead[e]	µg/L	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.2
Manganese	µg/L	189	211	211	211	211	211	211	7.1
Mercury[e]	µg/L	0.013	0.003	0.003	0.003	0.04	0.00	0.003	0.1
Molybdenum	µg/L	2.4	1.7	1.6	1.6	4.5	1.7	1.6	5.6
Nickel	µg/L	7.8	7.5	7.5	7.5	8.3	7.5	7.5	0.8
Selenium[e]	µg/L	2.2	1.9	1.9	1.9	2.6	1.9	1.9	<0.4
Silver[e]	µg/L	0.04	0.03	0.03	0.03	0.05	0.03	0.03	<0.1
Strontium	µg/L	336	89.5	88.2	88.1	1306	88	88.2	1760
Thallium	µg/L	0.04	0.03	0.03	0.03	0.06	0.03	0.03	<0.03
Uranium[e]	µg/L	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.1
Vanadium	µg/L	0.3	0.2	0.2	0.2	1.1	0.2	0.2	1.8
Zinc	µg/L	15.8	16.8	16.8	16.8	16.8	16.8	16.8	3.4

"<" denotes values below the detection limit (see glossary).

[a] Estimates seepage discharge from WMP to Snap Lake, values based on average annual values of weekly data as calculated using GoldSim.

[b] Baseline granite values based on median groundwater inflow water from the granitic unit.

[c] The peak average annual value is the maximum average annual value from years from 1 through 40.

[d] pH values estimated based on geochemical speciation modelling.

[e] GoldSim input data based on one half of typical lower detection limits where values were below detection, elevated detection limits not included in average detection limit values the resulting calculated values may be biased upwards by the associated input data detection limits.

Figure 9.2-16 Selected Major Ion Concentration Trends for Water Management Pond Seepage Estimates

Figure 9.2-17 Selected Metal Concentration Trends for Water Management Pond Seepage Estimates

Major ion concentrations are typically from one fifth to one tenth baseline; magnesium and sulphate concentrations are two to five times baseline

The TDS concentrations in the seepage are expected to be two to five times lower than median baseline water quality from the granitic unit. Chloride concentrations in the WMP seepage are estimated to be one fifth of those observed in the baseline granite groundwater (*i.e.*, connate water). The remaining major ion concentrations will be one fifth to one tenth those observed in the baseline groundwater, with the exception of magnesium and sulphate, which will be two to five times that of the baseline granite groundwater.

Estimated water management pond seepage concentrations for most metals are near to or greater than baseline groundwater

Iron, strontium, and vanadium concentrations in the WMP seepage will be lower than the median baseline groundwater concentrations. Concentrations of manganese, chromium, and copper are predicted to be greater than 10 times baseline groundwater quality due to the influence of the metavolcanic rock and kimberlite on the mine drainage and the alkaline conditions of the mine water discharge during the AEP. Other metal concentrations in the seepage will range from one to 10 times those of the median baseline granite groundwater.

Water Quality of Snap Lake

Impacts of seepage to Snap Lake are assessed in Section 9.4

The quality and quantity of the groundwater seeping from the north pile to the north arm of Snap Lake and from the WMP through Dam 1 is outlined above. The impact of the quantity and quality of groundwater on the surface water quality and quantity will be assessed in Sections 9.3 and 9.4 of this EA.

9.2.2.7.4 Residual Groundwater Changes

Changes in shallow groundwater quality will decrease as reclamation proceeds

Changes in shallow groundwater quality will be due to seepage from the north pile and the WMP. These impacts are local, originating on the northwest peninsula and seeping into Snap Lake. Changes in seepage quality from the north pile will be greatest during operations, decreasing after closure. Increases in nickel, cobalt, and cadmium, which are associated with the exposed kimberlite, are greatest during operations. They will decrease when the granite capping of the north pile is completed. The metal concentrations remaining after closure tend to be associated with all rock types. Major ions and TDS are also expected to follow this pattern. Water quality of seepage from the WMP will be greatly influenced by site runoff after 2005 except for concentrations of manganese, chromium, and copper. Closure and reclamation of the WMP will greatly reduce seepage.

There is a high probability that the actual impacts will be less than predicted

The confidence level that the changes in water quality resulting from the surface facilities will not be greater than predicted is high. The method used a combination of measured values and laboratory data to define groundwater quality changes due to surface facilities. In using the laboratory data to estimate field conditions, all of the thawed material was allowed to react and contribute mass to the water. Under field conditions, the effective reactivity of the active layer is expected to decrease with depth as infiltrating solutions become gradually more concentrated during downward progress. Further, in the model, reaction rates were not assumed to decline over the modelled period, whereas under field conditions the rates of reaction will decline. There is a high probability that the actual changes will be less than predicted because of the degree of conservatism used in the analysis.

9.2.3 Monitoring and Studies

9.2.3.1 Additional Studies

Refinement to post-closure groundwater quality and flow predictions is expected to reduce the magnitude of predicted impacts

The predicted rate of groundwater outflow from Snap Lake and the chemistry of the mine-affected groundwater used in the environmental assessment were based on conservative worst-case assumptions. Further refinement of groundwater flows and the chemistry of mine affected groundwater during post-closure is expected to reduce the magnitude of predicted impacts to the north and northeast lakes. The following additional work is proposed or currently underway to refine the impact predictions for mine affected groundwater:

- Additional column leach testing to refine predictions of mine affected groundwater concentrations at post-closure. Column leach testing would include tests to better define leaching processes and to investigate the interaction of mine affected groundwater with country rock and lake-bottom sediments. Additional leachate testing, completed after the water quality assessment predictions were complete (Appendix III.2), indicated that expected mine affected chromium concentrations used in the assessment could be overestimated by at least one-third.
- The expected values used in the assessment do not account for geochemical reactions that may further reduce chromium concentrations during the 80 years of travel time between the flooded underground workings and the north and northeast lakes. The results of the column leach testing will be used in a geochemical model to evaluate the potential for reduction and/or attenuation of metals in mine affected groundwater. This work will provide a more realistic estimate of the chemistry of mine affected groundwater when it reaches the north and northeast lakes.
- The impact predictions for water quality (Section 9.4), use the worst-case assumption that porewater chemistry and lake water chemistry immediately overlying the sediments during ice-covered conditions will

be the same as mine affected groundwater chemistry, without accounting for any mixing or diffusion. Sampling and analysis of lake water, porewater, and sediment in the north and northeast lakes can be combined with transport models to provide a better understanding of physical and chemical processes in the porewater and at the sediment-water interface. This work will provide a more realistic estimate of the porewater and lake water concentrations that benthic invertebrates could be exposed to in areas receiving mine affected groundwater.

- The estimated rate of groundwater outflow from Snap Lake to the north and northeast lakes used in the impact assessment are higher than expected values because of conservative parameters used in the hydrogeologic modelling. A detailed evaluation of the winter water balance in Snap Lake will be undertaken to refine estimates of groundwater outflow from Snap Lake. Preliminary water balance calculations indicate that groundwater losses are likely less than assumed in the environmental assessment.
- Mine affected groundwater is predicted to be very alkaline, which results in the leaching of some metals, notably chromium. The high alkalinity results from the equilibration of groundwater with cement in the paste backfill. There are options available to reduce the amount of cement required in the mine, and a review of these options is currently underway.

Investigation results will be filed as supplementals

The results of these ongoing investigations were not available for inclusion in the environmental assessment. Investigation results will be filed as supplemental information.

9.2.3.2 Monitoring

Monitoring will determine groundwater conditions and verify predictions

Groundwater monitoring will be undertaken to determine groundwater quality, quantity, and levels as the project progresses. The monitoring program will consist of wells to measure groundwater levels and water quality and flow meters to measure water inflows to the mine. Monitoring results will be compared to the predictions of the EA.

Predictive models will be updated, if necessary

The monitoring results will be reviewed together with the flow model used to predict mine inflows and the water quality model used to predict water quality. Should the monitoring indicate water quantity or quality different from those predicted, the model will be re-calibrated using the observed values. The refined model will then be used to predict future inflows and water quality, and to refine water management.