# **APPENDIX IX.1**

# MINE SITE WATER QUALITY

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- Appendix B Suspended Sediment Load Calculation
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- Appendix D North Pile and Site Water Balance
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# 1.0 INTRODUCTION

This report documents the prediction of mine site water quality from the Snap Lake Diamond Project in the Northwest Territories (NWT). Background information on the project and exploration history is provided in Section 1 of the environmental assessment (EA). Alternatives and opportunities related to mine development and operations are described in Section 2 of the EA, with the project description and overview provided in Section 3 of the EA. The purpose of this report is to present the details on the methods used to predict water quality from the mine and site discharging to Snap Lake, and to provide the results of these predictions.

The nature of the mining operations, geology of the kimberlite and host rock, and waste management/material handling strategies will govern the discharge water quality from the site. The site water quality estimates were developed through assessment of site monitoring data and geochemical data as developed for the project (Appendix III.2 of the EA). A chemical mass balance approach was then used to determine the significance of potential sources of chemical loading and to define estimates of expected water quality. Some limited geochemical speciation modelling was also completed to identify and incorporate potential geochemical controlling factors that may affect water quality.

This report includes detail on the site components that contribute to water quality discharge from the site, including: an overview of relevant features of the project as they relate to mine site water quality; detailed descriptions of specific components of the system and the calculation methods that were applied to these components; results for each main site component (mine, north pile, treatment, site runoff); an overview of relative contributions of the various site discharge components to the overall discharge from site; and a summary of potential management options that might affect mine site water quality. Potential impacts of the site discharge on the terrestrial and aquatic environment are not included in this document, but are described and assessed in the EA.

# 2.0 SUMMARY OF SITE COMPONENTS

The nature of the site layout, mining operations, geology of the kimberlite and host rock, and waste management/material handling strategies will govern the mine site discharge water quality. This chapter provides a brief overview of project features and a summary of the key site components that most affect mine site water quality.

# 2.1 Project Overview Aspects Relevant to Mine Site Water Quality Prediction

In 1997, a diamond-bearing kimberlite dyke was discovered at Snap Lake, NWT (Figure 3.1-1 of the EA). The kimberlite dyke averages 2.5-metres (m) thick, dips between 11 and 15 degrees to the northeast under Snap Lake, and has been delineated approximately 2,500-m east/west and 2,000-m north/south (Figure 3.1-2 of the EA). In early 1999, bulk samples of kimberlite were mined from two pits on the northwest peninsula. These samples were trucked to a processing plant at Lupin Mine where assay and environmental samples were collected.

A pre-feasibility study was completed in April 2000, which included a pre-feasibility level plan for the establishment and operation of an underground mine and associated support facilities for an ore resource of approximately 12.6 million tonnes (Mt). Continued exploration and a resource study update in August 2000 resulted in an increase in the indicated resource to approximately 22.8 Mt, including waste rock dilution to approximately 20%. During 2001, an optimization study was carried out to provide more detail on the underground mine and surface facility designs, mine operation plans, construction schedules, and costs. In addition, supplementary site bulk sampling and data collection programs were carried out. The water quality estimates for the Snap Lake site presented in this report are based on information contained in the August 2000 resource update, and the information generated through the optimization study as of October 2001.

The kimberlite dyke will be mined by underground mining methods at an average rate of approximately 3,000 tonnes per day (tpd). Underground development will be started while the process plant and surface facilities are being constructed. A small portion of the underground mining will be done beneath the northwest peninsula. The ore body extends under Snap Lake and north of Snap Lake, with the lake water influencing seepage to the mine.

The active mine area will contain the following planned facilities: site roads, yards, storage, and lay-down (storage) areas, site structures, the airstrip, the water management pond (WMP), the north pile, the explosives manufacture and storage area, and the winter access road spur to the site. The active mine area is expected to be in the order of 250 hectares (ha) (Figure 3.1-3 of the EA). All of these site facilities have a potential to affect site water quality.

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Elsewhere on the property, extensive prospecting has not revealed any other economic kimberlite deposits. However, De Beers is re-evaluating the work previously done on the property, and the potential for additional economic kimberlite discoveries has not been ruled out. Changes in the overall mine plan would affect water quality estimates.

# 2.2 Key Site Components

The Snap Lake site consists of several inter-related components. A schematic diagram outlining the main components contributing to flow and/or mass loading on site is presented in Figure IX.1-1. The Snap Lake site has been separated into five major components that are further subdivided into several sub-components. The five major components are:

- 1. Snap Lake Snap Lake consists of two main waterbodies (the "North Arm" and "Main Basin" of Snap Lake) connected by a narrow channel. A portion of the Main Basin provides recharge to the mine workings. As a consequence, water from Snap Lake is "recycled" during mine operations on a continuous basis, and the Snap Lake water quality is a dynamic function over time.
- Mine Inflow to the mine will include seepage from the lake and natural (connate) groundwater, the proportions of which will significantly affect groundwater quality. Additional influencing factors in the mine include sediment production/dissolution, paste backfill consolidation water, and explosives or cement use.
- 3. North pile Water flow from the north pile is dominated by surface runoff, with a smaller seepage component. Water quality is influenced by reactions within the pile, water from consolidation of processed kimberlite (PK), and application of water for suppression of dust. Temperature affects all flow and water quality aspects of the north pile.
- 4. Site (and Non-Point Source Discharges) Site components include flow and chemical loading from site runoff (developed and undeveloped land), process material discharges, potable water intake and sewage discharge. Most of the site runoff reports to the WMP with a small proportion reporting directly to Snap Lake via surface runoff or seepage pathways.
- 5. Treatment/WMP Flows and chemical loading from the mine, WMP and the north pile will report to the treatment plant with treated water being discharged to Snap Lake as discussed in Section 9 of the EA. The WMP will collect runoff from the site and will provide backup and upset storage capacity during operations.

# Figure IX.1-1 Snap Lake Diamond Project Overall Water Flow and Chemistry Distribution

A detailed description of each of these components is provided in Sections 4 through 8 of this document. A summary of assumptions related to each of these components, and the methodology to calculate sediment load from these components are provided in Appendix A and B, respectively, and discussed in more detail in Sections 3 through 8 of this document. A sophisticated mass and flow balance model (GoldSim Contaminant Transport model [GoldSim]) is described in Section 3.2 of this document. Appendix C was used to integrate the flow and mass loading from all of the site components to develop overall estimates of water quality and mass load from the site and site components.

# 2.3 Water Balance

The overall water balance for the Snap Lake site was based on several information sources. Flow from the mine workings was provided through the hydrogeological work completed by HCI (2001). A hydrological evaluation was completed as part of the baseline studies in the EA. Flows from the north pile and site were developed as part of the Optimization Study for the North Pile Management (Golder 2001a).

The major components contributing to flow on site are indicated in Figure IX.1-1. Table IX.1-1 provides a summary of these major flow components and their sources. More detail for each main component is presented in sections 4 through 8 of this document.

Flow ID	Description	Value	Source
	SNAP LAKE		
Q1	Natural Seepage/Runoff (excluding disturbed areas)	0.216 m <sup>3</sup> /s minus the seepage/runoff from the Snap Lake site	EA, Hydrology
Q2	Snap Lake Outflow (includes disturbed areas)	0.216 m <sup>3</sup> /s	EA, Hydrology
Q3	Snap Lake Recharge to Mine Workings	Variable	HCI (2001)
	MINE		
Q3	Flow reporting to mine workings Q3a – flow from clean workings Q3b – flow from working areas Q3c – flow due to mine flooding	Variable	HCI (2001)
Q4	Backfill Consolidation Water	15% of paste backfill volume	Golder (2001b)
Q5	Flow pumped from mine workings (includes volume pumped at startup)	Variable; See Section 5 of this document	HCI (2001), De Beers (2001a)
	NORTH PILE		
Q6	Consolidation water contribution from paste deposition in north pile	14% of paste water volume	Golder (2001b)
Q7	Dust suppression water from treatment to north pile	1,650 m <sup>3</sup> /month from June through October during operations	Golder (2001a)
Q8	Net Runoff and Seepage from the north pile reporting to the temporary pond Q8a – Runoff Q8b – Seepage	Variable	GoldSim Calculations based on Golder (2001a) and EA Hydrology Data
Q9	Non-point discharge as seepage from north pile and temporary ponds to Snap Lake	Variable	EA Hydrogeology
Q10	Net discharge from north pile and Temporary Ponds to the Treatment Plant	Variable	GoldSim Calculations based on Golder (2001a)
	SITE		
Q11	Potable Water Source	200 m <sup>3</sup> /d during operations	Golder (2001a)
Q12	Treated Sewage Discharge (see EA	200 m <sup>3</sup> /d during operations	Golder (2001a)

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Flow ID	Description	Value	Source
	SNAP LAKE		
Q13	Freshwater intake for processing	16 m <sup>3</sup> /hr	De Beers (2001c)
Q14	Non-point source seepage/runoff to Snap Lake	7,770 m <sup>3</sup> /yr	Golder (2001a)
Q15	Seepage/runoff from site to WMP	31,080 m <sup>3</sup> /yr	Golder (2001a)
	OTHER NON-POINT SOURCE DISCHARGES		
Q16	Net discharge Airstrip	833 m <sup>3</sup> /yr	Golder (2001a)
Q17	Net discharge Explosives Plant	4,070 m <sup>3</sup> /d	Golder (2001a)
	TREATMENT AND WATER MANAGEMENT POND (WMP)		
Q18	Net discharge from WMP to treatment	Variable	GoldSim calculations
Q19	Water recycled from treatment for processing	42 m <sup>3</sup> /hr	De Beers (2001c)
Q20	Net discharge from Treatment to Snap Lake	Variable	GoldSim calculations

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#### Table IX.1-1 Summary of Major Site Flow Components (Continued)

Notes: See unit and acronym list for definitions.

#### 2.4 Mass Load Components

General discussion of the baseline and background geochemical factors is presented in the geochemistry baseline report (Appendix III.2 of the EA). A summary of the geochemical mass load components is provided in Table IX.1-2. A summary of the advanced exploration program (AEP) monitoring data used in the model development is included in Appendix E, while a summary of the laboratory data and kinetic test data used in the model development is provided in Appendix F.

The modelled water quality results are tracked in terms of both dissolved load and solid phase (*i.e.*, particulate) load. For surface water discharge locations, a total load (summation of solid and dissolved phase load) is provided, thus allowing for comparison to applicable guidelines or development of site specific criteria. For seepage locations, a dissolved load is used as, for the purpose of the GoldSim modelling, particulate matter is not considered to migrate along groundwater flow paths. In the model, the sum of ammonia (NH<sub>3</sub>) and ammonium (NH<sub>4</sub>) is tracked as the ammonium ion.

While Snap Lake is accounted for in the GoldSim model, this is only for the purposes of defining the water quality of recharge infiltrating to the mine workings. Any detailed modelling of concentration variability in the lake and changes in water quality in the lake was largely performed as part of the modelling for the EA, and is presented in Section 9

Table IX.1-2	Summary of Major Site Chemical Loading Components
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Chem ID	Description	Value	Source
	SNAP LAKE		
C1	Natural Seepage/Runoff	Table IX.1-3	Environmental Assessment (EA)
C2	Snap Lake Outflow	EA/Calculated	EA/GoldSim
	MINE		
C3	C3 – Mass to Mine from Lake and Rock Mass	Initial in Table IX.1-4,	EA
	C3a – Concentration/Mass from Working Areas	then calculated	
	C3b – Concentration/Mass from Connate Water and Recharge Water		
C4	Cemented Paste Backfill Consolidation	See Section 5 of this document	EA Appendix III.2 – Geochemistry Report
C5	Mass Load due to Explosive Use	Variable	AMEC (2001), Golder (2001c)
C6	Mass due to Grout and Cement Use	100 t/yr	Golder (2001d)
C7	Mass Reporting to Treatment or water management pond (WMP)	Variable	GoldSim Calculations
	NORTH PILE		
C8	Consolidation water contribution from processed kimberlite (PK) paste deposition in north pile	Table IX.1-22	AEP Monitoring
C9	Concentrations in dust suppression water from treatment to north pile	Variable	GoldSim Calculations
C10	Pile Runoff	Variable	Appendix III.2 of EA/GoldSim Calculations
C11	Pile Seepage to temp pond and Non-point discharge to Snap Lake	Variable	GoldSim Calculations based on Geochemistry Report (Appendix III.2 of EA)
C12	Net loading from north pile and Temporary Ponds to the Treatment Plant	Variable	GoldSim Calculations based on Geochemistry Report (Appendix III.2 of EA)
	SITE		
C1	Potable Water Source	200 m <sup>3</sup> /d	Appendix D
C13	Treated Sewage Discharge (non point source, load not tracked in model)	200 m <sup>3</sup> /d	Appendix D
C1	Freshwater intake for processing	Snap Lake Baseline	EA
C14	Seepage/runoff from roads, laydown areas and operating areas	Table IX.1-30	AEP Monitoring
	OTHER NON-POINT SOURCE DISCHARGES		
C14	Seepage/Runoff form airstrip and explosives plant	Table IX.1-30	AEP Monitoring
	TREATMENT AND WMP		
C15	Net loading WMP to treatment	Variable	GoldSim calculations
C16	Net loading to Snap Lake discharge	Variable	GoldSim/PHREEQC calculations

Notes: See unit and acronym list for definitions.

of the EA. The approach to modelling of the sediment load in the model is discussed in Section 3.1.5 of this document and in Appendix B. The various source terms are calculated and applied as discussed in Sections 4 though 8 of this document.

# 3.0 SUMMARY OF METHODS AND PROCEDURES

The approach used to develop the estimates of water quality discharge from the Snap Lake site involved compiling and assessing available data for the various components contributing to or affecting water quality and mass loading on site. Data and information assessed include:

- site monitoring data;
- laboratory test data;
- flow data;
- the mine plan; and,
- the materials and waste management plan.

Water flow through each of the units on site was calculated based on hydrologic data or hydrogeologic modelling as discussed in Sections 4 through 9 of this document. Physical conditions expected on site were specified based on conceptual engineering designs supplied by De Beers, Golder, and AMEC. Water quality estimates of various sources were based on on-site monitoring data, laboratory results, and mass loading considerations. Overall water quality estimates for discharges to Snap Lake were developed using these source terms and adjusted for geochemical controls as discussed below. A summary of assumptions used in model development is provided in Appendix A. A schematic diagram showing flow and mass loading components is provided in Figure IX.1-1.

# 3.1 Summary of Geochemical Input Methods

Sources of geochemical input were assessed to develop rates of solute mass release or expected concentrations for given areas or materials. The following three principal approaches were used:

- use of on-site monitoring data;
- material usage; and,
- use of laboratory data.

Two additional model components of importance were:

- geochemical controls; and,
- sediment load.

Where possible, on-site monitoring data developed from the AEP were used. Since underground mining methods will not significantly change the site layout or rock properties from those observed in the AEP (with the exception of the north pile), the AEP data were considered relevant with respect to full-scale operations. Where there were no existing field monitoring data (*e.g.* north pile PK and cemented paste PK backfill), chemical loading estimates were based on laboratory test work. A summary of the various methods of chemical and mass load applied is provided below. Detailed methodology for assignment of chemistry and loading for each of the main site components is presented in Sections 4 through 8 of this document.

# 3.1.1 Development of Loading Rates from Monitoring Data

Monitoring data collected between 1999 and August of 2001 were available for natural runoff, site runoff, process water discharge and for the groundwater reporting to (and discharging from) the mine workings (Appendix E). The available monitoring data were applied as follows:

- The natural runoff, site runoff and north pile paste consolidation waters were assigned the concentrations observed from the monitoring data. Natural runoff was represented by the Snap Lake baseline date; site runoff was represented by monitoring results from the 1999 Bulk Sample Mine Rock Pad (BSMRP), and north pile paste consolidation water was represented by monitoring data from the process water discharge (SNP 1735-09) as discussed in Sections 6 and 7 of this document.
- Overall concentrations in the groundwater inflow to the mine were assigned the average measured connate groundwater inflow concentrations (from the granite as measured during the AEP) adjusted for the expected Snap Lake recharge water infiltrating the mine (as discussed in Section 5 of this document).
- Mine water discharge concentrations for most parameters were assigned values based on the groundwater inflow concentrations plus an incremental mass load attributed to interaction of the infiltrating water with the working areas of the mine. This incremental loading was based on the differences between the average inflow chemistry and the average discharge chemistry observed in monitoring during the AEP. Additional mass load to the mine was attributed to material use (explosives or cement) and consolidation of backfill as discussed in Section 5 of this document.

# 3.1.2 Mass Load as a Function of Material Usage

For some parameters affected by explosives use (*i.e.*,  $NH_4$ , nitrate  $[NO_{3]}$ , sodium [Na]) or cement/grout use (*i.e.*, calcium [Ca], chloride [Cl], and alkalinity), the material usage schedule was used to develop mass load rates. The mass released was added to the calculated mine water flow rate to develop estimates of concentration over time for these parameters.

The method of assigning mass as a function of material usage was only used for the major elements and compounds of a given material, and not used to estimate trace element contributions. Trace element concentrations in explosives and cement depend on the source material and may change over time. It was therefore considered that use of AEP monitoring data would better account for possible trace metal contributions from explosives and cement. During the AEP, cement and explosives were used in the mine in greater proportions (relative to groundwater inflow) than is expected during mining operations. As a result, the concentrations of the trace elements in the AEP mine water were likely biased high and environmentally conservative. This conservatism was not warranted where the major components of the explosives and cement were concerned, as more accurate information regarding their make-up and use in the mine was available.

# 3.1.3 Development of Loading Rates Based on Laboratory Data

Paste PK is placed in two locations: underground as cemented backfill and on the north pile as uncemented paste. The cemented paste backfill contribution to the mine water was calculated based on short-term leach test data from laboratory testing since there are no on-site monitoring data of cemented paste PK. The short-term consolidation and expulsion of porewater from PK paste on the north pile was represented by current process plant data. However, the long-term mass loading rates from the north pile materials were estimated using long-term laboratory data (Appendix F) as there are currently no on-site monitoring data available that adequately represent long-term release from the PK.

Long-term mass loading from the north pile was based on mass loading rates derived from the kinetic test data as discussed in Section 6.4 of this document and in the Geochemistry Report (Appendix III.2 of the EA). These leach rates were adjusted for the low temperatures expected at Snap Lake following the methodology used at Diavik (1998). The mass load was then added to the expected volume of water discharging either to surface or groundwater to develop estimates of seepage and discharge concentrations over time.

# 3.1.4 Geochemical Controls

Where applicable, geochemical controls were applied to the observed concentrations using the well-known geochemical model pH Redox Equilibrium C (PHREEQC), Version 2 (Parkhurst and Appelo 1999). The geochemical controls were used to estimate solubility limits for several parameters based on the peak weekly concentrations as determined from preliminary model runs. These solubility limits were then employed in the final model run.

For treatment discharge and mine sump water, geochemical solubility controls consisted of the relatively rapidly-equilibrating minerals calcite  $[CaCO_3]$ , gypsum  $[CaSO_4 2H_2O]$ , and dolomite  $[CaMg(CO_3)_2]$ . For waters from the north pile and seepage from the WMP, the peak average annual concentrations were also used to identify geochemically-credible phases. These phases were then allowed to precipitate at their solubility limits (as defined by PHREEQC) for the final model run (Section 6.4.4 of this document). Geochemical modelling completed using PHREEQC is described in Appendix G.

# 3.1.5 Sediment Load

During operations, the majority of the chemical load to the water treatment plant reports as particulate (*i.e.*, suspended) material rather than in dissolved form. The sediment load in the model is tracked from each model component as both total suspended solids (TSStotal) and as the proportion of total suspended solids (TSS) associated with the three main rock types: kimberlite (TSSk), granite (TSSgt) or metavolcanic (TSSmtvc).

The solid-phase compositions of each rock type were derived as part of the baseline geochemistry program (Appendix III.2 of the EA) and involved collection and analyses of representative samples of kimberlite, granite, and metavolcanic rock. It should be noted that analysis of the rock samples was completed using an Aqua Regia acid digest followed by an ICP-MS scan. Incomplete digestion of some samples could result in an underestimation of some parameters present in the more refractory mineral phases. Thus, the chemical concentrations of each parameter, in each of the three rock types were conservatively assumed to be the average measured concentration + 1 standard deviation (Appendix B). The composition of the TSStotal was then derived by allocating the contributions from TSSk, TSSgt, and TSSmtvs in their appropriate proportions.

# 3.2 Mass Loading Calculations

In order to track mass movement and develop estimates of mass load and concentrations at various points in the system, the GoldSim model (Appendix C) was selected as the main platform for the mass balance calculations. Supplemental calculations were completed using the geochemical speciation code PHREEQC and simple spreadsheets to develop the overall estimates of water quality discharging from site.

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 is set up as linked elements (or cells), each cell describing 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. A diagram outlining the relevant linkages associated with the Snap Lake site is provided as Figure IX.1-1.

The Snap Lake GoldSim model, as constructed, calculates water quality at various points on site and at the site discharge locations. The model is currently set to run for forty years with a starting date of January 1, 2000 and an ending data 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 through the use of "feedback" links (Golder 2000b) by which the concentration at the previous model time step is used to calculate (through an iterative process) the concentration at the current time step.

GoldSim was originally developed by Golder Associates as a comprehensive modelling program for assessing the performance of high-level radioactive waste repositories. GoldSim, and its predecessor RIP, have been used extensively in this regard over the past eight years in the United States (primarily at their Yucca Mountain and WIPP repository projects), Japan, Spain, and several other countries. More recently, GoldSim has been used for addressing a wider range of non-nuclear environmental issues including site decommissioning and environmental risk assessment. For example, GoldSim was recently used in evaluations of mine waste management plans at Boliden's Los Frailes Mine in Spain, and is currently being used to assess different strategies for the management of uranium tailings at Wismuth in Germany.

The GoldSim program, as utilized for the Snap Lake Project, is fully documented in the 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. GoldSim code development, testing, and maintenance are compliant with American Society of Mechanical Engineers (ASME) Nuclear Quality Assurance (NQA)-1-1994, Quality Assurance Requirements for Nuclear Facility Applications (ASME 1994). Code documentation is in general accordance with NUREG-0856, Final Technical Position on Documentation of Computer Codes for High-Level Waste Management (US-NRC 1983). Documentation and configuration management are also in general accordance with American National Standards Institute (ANSI)/Institute of Electrical and Electronic Engineers (IEEE) 730, IEEE Standard for Software Quality Assurance Plans (IEEE 1984).

# 3.3 Modelled Time Interval

Water quality estimates are provided starting in January 2000 for a forty-year period. For the purposes of modelling, it is assumed that the mine was flooded at the end of August 2001 and remains flooded until 2003. A pre-development phase is assumed to last from 2003 to 2005, followed by an operational phase from 2005 through 2027. Closure is assumed to occur at the end of December 2027. Other than at early time, it is not expected that minor adjustments to the project schedule will result in significant changes to the predicted peak operational loadings.

# 3.4 Model Limitations

Detailed assumptions that govern the model are outlined in Appendix A and presented throughout the text. A few key limitations of the GoldSim model are discussed in this section:

- Changes to project or site conditions The project description and site conditions as identified in the EA are the basis for the model. The data and approach used to estimate future water quality are currently believed to provide a reasonable approximation of the Snap Lake system as stated and understood in Section 3 of the EA. Changes in project or site conditions will necessarily result in changes to water quality predictions. This is particularly true for early stages of mine development; the model is limited in its ability to accurately forecast early-time values due to the dynamic nature of developments in a project of this type, and potential short-term changes to site conditions during AEP and site construction.
- Groundwater inflow data Uncertainty related to groundwater inflows results in uncertainty in water quality predictions. Potential changes in groundwater inflow (*e.g.*, proportions of lakewater vs. connate water recharge) are discussed in Section 5.4.3 of this document.
- North pile mass load The mass load estimates of the north pile are limited by the availability of site data, and as such are based on laboratory data. Scaling of laboratory data to field conditions is an important limitation inherent to all attempts to use laboratory data for prediction of field behaviour. This issue can be addressed and mitigated through on-site monitoring programs during operations and periodic reassessment of predictions.
- System complexity For the Snap Lake site, care was taken to incorporate all known processes as understood during model development. However, it should be noted that, in natural systems and complex man-made systems, observed conditions will

almost certainly vary with respect to estimated conditions, even for the most thorough system simulation.

Ultimately, even the best of models cannot compare with operational monitoring data. Once the Snap Lake site is operational, monitoring of water quality and occasional reassessment of potential impact predictions and/or remedial measures will therefore be required.

#### 4.0 SNAP LAKE

#### 4.1 Background

Snap Lake is the ultimate receiver for both treated water discharge and non-point source discharge from the site. During site development, operation, and post closure, the waters in Snap Lake consist of a natural runoff component and site discharge components. These components mix in Snap Lake and discharge to the Lockhart River system. During operations, a significant portion of the water from Snap Lake will recharge the mine workings from whence it will be pumped out, treated and discharged back to Snap Lake (Figure IX.1-2).

# Figure IX.1-2 Simplified Schematic of Snap Lake System and Mine Water Cycling



#### 4.2 Flow Summary– Snap Lake

Snap Lake consists of two main waterbodies (the "North Arm" and "Main Basin" of Snap Lake) connected by a narrow channel. The total volume of water in Snap Lake is about 87 million cubic metres (Mm<sup>3</sup>). For the purposes of modelling, the "Effective Lake Volume" of Snap Lake refers to that portion of the lake that mixes with the treated discharge and site discharge prior to recharging the fractured rock and mine workings. The volume of the Effective Lake Volume is estimated to be about 8.7 Mm<sup>3</sup> based on the preliminary hydrodynamic mixing model results (see Section 9 of the EA for discussion of mixing in the lake). The Effective Lake Volume water recharges the lakebed sediments and fracture zones and ultimately affects the recharge water quality in the mine. Estimates of recharge to the fracture network were provided by HCI (2001) (Section 5 of this document).

The total flow discharge from Snap Lake as estimated prior to mining is about 18,600  $m^3/d$  (see Section 9.3 of the EA). Of this volume, approximately 96% (17,800  $m^3/d$ ) is expected to mix with potential recharge to the mine workings.

The estimated natural discharge measured during the baseline hydrology work includes runoff and seepage flows from the proposed and existing mine site area. For the water quality model, a distinction must be made between natural runoff (*i.e.*, runoff not originating from the site), site runoff unaffected by site activities, and site runoff affected by the mining operation. For the purposes of estimating runoff and seepage from the site, the water balance is used as the basis for assigning flows for the two site components. The natural discharge (precipitation, runoff, and seepage) that does not originate from the site is estimated as the value from the hydrology data (17,800 m<sup>3</sup>/d) less that calculated as being derived from the site.

In addition to the precipitation, runoff, and seepage components, there will be an increase in the water reporting to Snap Lake due to discharge from the mine during operations. Since Snap Lake provides the majority of recharge to the fracture system supplying the mine workings, any increase in flow to Snap Lake is related to water released from aquifer storage by the mine dewatering (as discussed in Section 9 of this document).

# 4.3 Mass Load – Snap Lake

Natural inflow/runoff concentrations are combined to include all hydrologic processes affecting water quality in Snap Lake under baseline conditions. Initial concentrations in Snap Lake, and concentrations reporting from natural runoff are set to the median concentration measured in Snap Lake in the baseline studies (Table IX.1-3 of this document, see also the EA). The median (as opposed to the average) concentration was selected to reduce the potential bias that could result from including a sampling location with elevated concentrations (*e.g.*, near an inflow to Snap Lake).

For the purposes of the site water quality modelling, concentrations in Snap Lake are calculated assuming that all discharge from the site will be completely mixed in the Effective Lake Volume (8.7 Mm<sup>3</sup>), which is defined as that area of Snap Lake that contributes recharge to the mine workings. It is further assumed, for the purposes of the site water quality model, that no attenuation of discharge parameters occurs in the Effective Lake Volume. Detailed evaluation of changes in Snap Lake water quality for the purposes of impact assessment is provided in Section 9 of the EA.

# Table IX.1-3 Baseline Water Quality in Snap Lake

		Snap Lake			
Parameter		1998-2001			
	Units	min	max	median	
Conventional Parameters					
рН	рН	6.3	6.9	6.7	
Alkalinity	mg/L	4	10	6	
Total Dissolved Solids	mg/L	<10	70	15	
Total Suspended Solids	mg/L	<3	7	<3	
Conductivity	uS/cm	14	31	19	
Nutrients		0.000	0.000	0.004	
Ammonia	mg/L	0.002	0.086	0.024	
Nitrate + Nitrite	mg/L	<0.006	0.041	<0.008	
Nitrate-N	mg/L	< 0.006	0.038	0.02	
Nitrite-N	mg/L	< 0.002	< 0.002	<0.002	
Total Phosphorus	mg/L	< 0.001	0.026	0.009	
Dissolved Phosphorus	mg/L	< 0.001	0.012	0.003	
Orthophosphate	mg/L	<0.001	0.005	0.002	
Total Kjeldahl Nitrogen	mg/L	< 0.05	0.7	0.2	
	Ing/L	<1	0.0	3.0	
	00 //	5.0	40		
Bicarbonate	mgCO <sub>3</sub> /L	5.2	12	(	
Carbonate	mg/L	<5	<5	<5	
Calcium	mg/L	0.93	2.43	1.34	
Chloride	mg/L	0.2	<1	<0.2	
Fluoride	mg/L	0.04	0.06	<0.05	
Hydroxide	mg/L	<5	<5	<5	
Magnesium	mg/L	0.48	1.01	0.61	
Potassium	mg/L	0.32	0.78	0.44	
Silica	mg/L	0.4	0.6	0.4	
Sodium	mg/L	0.44	1	0.57	
Sulphate	mg/L	1.31	36	3	
Dissolved Metals					
Aluminium	ug/L	1.9	<30	10.3	
Antimony	ug/L	< 0.03	1.9	0.4	
Arsenic	ug/L	< 0.03	<0.2	<0.2	
Barium	ug/L	1.8	4.5	2.4	
Beryllium	ug/L	0.1	<0.2	<0.1	
Bismuth	ug/L	< 0.03	0.1	<0.1	
Boron	ug/L	<1	3	1	
Cadmium	ug/L	< 0.05	0.1	<0.1	
Cesium	ug/L	<0.1	0.1	<0.1	
Chromium	ug/L	< 0.06	0.8	0.3	
Cobalt	ug/L	<0.1	0.2	<0.1	
Copper	ug/L	0.4	4.4	0.7	
Iron	mg/L	< 0.005	0.041	< 0.02	
Lead	ug/L	< 0.05	1.4	<0.2	
Lithium	ug/L	0.5	1.5	0.9	
Manganese	ug/L	<0.1	10	0.5	
Mercury	ug/L	< 0.01	<0.02	<0.01	
Molybdenum	ug/L	< 0.06	<1	<0.1	
Nickel	ug/L	0.09	3.72	0.3	
Rubidium	ug/L	<1	2	<1	
Selenium	ug/L	<0.1	<10	<1	
Silver	ug/L	<0.1	0.1	<0.1	
Strontium	ug/L	5.6	12.1	/.4	
	ug/L	< 0.03	0.1	<0.1	
litanium	ug/L	<0.1	<0.3	<0.2	
Uranium	ug/L	< 0.05	0.1	<0.1	
Vanadium	ug/L	< 0.05	0.1	<0.1	
Zinc	ug/L	<0.5	24.2	<10	

< = less than detection limit

Mass load from the site to Snap Lake will occur from the following sources, each of which is discussed in its respective section of this document:

- north pile seepage (Section 6);
- north pile runoff at closure (Section 6);
- non-point source runoff (Section 7); and,
- treatment discharge (Section 8),

Mass load from natural runoff and from each of these site locations is added to the basin volume representing the Effective Lake Volume (*i.e.*, the portion of Snap Lake that affects recharge to the mine). All loadings are assumed to be fully mixed for development of water quality estimates in the Effective Lake Volume.

The newly calculated basin water quality is then propagated through the lakebed sediments and rock mass and mixed with the connate water of the fracture system to develop estimates of mine recharge water quality in future time steps. In this fashion, the continuous cycling of mine water and lake water is accounted for in the model.

# 4.4 Results and Conclusions

Mass loading calculations for Snap Lake are only used within the site water quality model to estimate the water quality reporting from Snap Lake to the mine workings. Detailed modelling of Snap Lake itself, discussion of distribution of flow and mass within the lake, and potential aquatic implications are reported in detail in Section 9 of the EA.

# 5.0 THE MINE

#### 5.1 Background

The mine at Snap Lake will be developed as an underground mine from which about 22 Mt of ore and dilution rock will be extracted. The mine will be developed as a series of drifts and panels and the ore extracted via two haulage ramps. Shortly after startup, worked-out panels will be backfilled with cemented paste PK such that at any given time there will be two working panels.

During operations, the groundwater inflow components to the mine will include connate water and recharge from Snap Lake (Figure IX.1-3). Recharge water from Snap Lake will pass through lakebed sediments and fractured bedrock prior to reporting to the mine workings. As discussed in Section 4 of this document, other than removal of suspended solids, the water quality calculations do not account for any attenuation processes in the sediments or fractured rock. Water from the mine is collected in the sump and pumped to the surface for treatment. When the treatment system cannot operate or has insufficient capacity, the mine water will be pumped to the WMP for interim storage prior to treatment and discharge. At closure, the mine will be flooded and the only discharge from the mine will be via regional groundwater flow. Table IX.1-4 provides an overview of the various inputs and their expected values for the mine component.

#### Figure IX.1-3 Schematic of Mine Water System



ID	Description	Value	Source
	FLOWS		
Q3	Total Inflow to Mine Workings	(Q3a + Q3b + Q4 + Q3e) Figure IX.1-4	HCI (2001)
Q3a	Snap Lake Recharge to Mine Workings	Figure IX.1-4	HCI (2001)
Q3b	Connate Water Recharge to Mine Workings	Figure IX.1-4	HCI (2001)
Q3c	Recharge to inactive areas (tracked for mass load purposes)	Figure IX.1-5	HCI (2001), Golder (2001e)
Q3d	Recharge to working areas (tracked for mass load purposes)	Figure IX.1-5	HCI (2001), Golder (2001e)
Q3e	Mine flooding volume	70,000 m <sup>3</sup>	De Beers (2001a)
Q4	Backfill consolidation-water	15% of paste backfill volume	Golder (2001b)
Q5	Total water pumped from mine workings	Equal to Q3 with the exception of start-up pumping	De Beers (2001a)
	CHEMISTRY		
C3	Mass to mine from recharge and working areas	(C3a x Q3a) + (C3b x Q3b) + (C3c x Q3d)	Calculated
СЗа	Concentration of lake recharge	Initial in Table IX.1-3, then calculated	EA
C3b	Concentration of connate water	Initial in Table IX.1-6 then calculated	EA
C3c	Incremental concentration addition to "Working Area" recharge	Table IX.1-6	EA
C4	Mass load from cemented paste backfill consolidation-water	C4a x Q4	Calculated
C4a	Concentration of cemented paste backfill consolidation-water	See Table IX.1-6 of this document	EA Appendix III.2 – Geochemistry Report
C5	Mass Load due to Explosive Use	See Figure IX.1-6 of this document	AMEC (2001), Golder (2001c)
C6	Mass due to Grout and Cement Use	100 t/yr	Golder (2001d)
C7	Mass Reporting to Treatment or WMP	(C3 + C4 + C5 + C6 + mass flood water) x Q5	GoldSim Calculations
C7a	Concentration reporting to treatment or WMP	C7/Q5	GoldSim Calculations

#### Table IX.1-4 Summary of Expected Case – Mine

Notes: See unit and acronym list for definitions.

#### 5.2 Mine Water Inflow and Discharge

At present, the ramp and drifts developed as part of the AEP are flooded with about 70,000 cubic metres  $(m^3)$  of water. Initially this water will be pumped to the WMP, treated, and discharged. Following this initial discharge and during mining operations, water inflow to the mine will originate from three sources:

- recharge water from Snap Lake;
- recharge of connate water; and,

• consolidation water from the cemented paste backfill.

The mine water discharge calculated during operations is the sum of the above three sources. The early time groundwater inflow estimates are based on pumping rates observed by De Beers during the AEP (De Beers 2001a) and estimates from project hydrogeologists as summarized in Table IX.1-5. When required, drilling water will be taken from underground groundwater inflows and will ultimately report to the discharge.

The mine was flooded in September 2001 and does not currently discharge to Snap Lake. For the purposes of modelling, it is assumed that the mine will remain flooded until January 2003. The duration of flooding is, however, currently not fixed, but will depend largely on the progress of the permitting process. Depending on project timing, there may be some implications with respect to short-term concentrations that will need to be monitored and assessed on an on-going basis, in particular if the early activities deviate significantly from the scenario included in the GoldSim model.

It is estimated that, when permitted, the 70,000  $\text{m}^3$  of water in the mine will be pumped out at a rate of approximately 3,000  $\text{m}^3/\text{d}$ , following which flows to the mine will resume at the rates predicted by HCI (2001). For the purpose of the GoldSim modelling, groundwater inflows were estimated assuming that pre-development would begin in February 2003 and that operations would commence in January 2005 (Table IX.1-5).

# 5.2.1 Recharge of Connate Water versus Snap Lake Water

The volumes of Snap Lake water and connate water that enter the mine were estimated based on hydrogeological information provided by HCI (2001). The ultimate proportion of lakewater recharging the mine that is used in the GoldSim model is approximately 65% overall. This value is quite conservative, as it is near the low end of the expected range of possible lakewater recharge fluxes (about 62% to 90% based on the HCI 2001 data) as discussed in Section 9.2 of the EA. The value is conservative from a water quality perspective because it increases the proportion of connate water, which generally has higher concentrations.

Initially, water reporting to the mine workings will consist entirely of connate water. However, as the lake water displaces connate water in the fractures, the proportion of Snap Lake water entering the mine workings will increase. The total mine inflow from groundwater recharge and the relative proportions of inflow from the connate water and from Snap Lake that are used in the GoldSim model are provided on Figure IX.1-4.

GoldSim Year	Year Represented	Inflow (m³/d)	Mine Water Outflow (m <sup>3</sup> /d)	Notes
0 to 0.5	2000 - 2000.5	0 to 265	0 to 265	Linear interpolation
0.5 to 1.6	2000.5 to 2001.6	265 to 900	265 to 900	Variable depending on advanced exploration program (AEP) discharge records
1.61 to 1.7	2001.61 to 2001.7	3000	0	Flood mine
1.71 to 3	2001.71 to 2003	0	0	No activity
3.0 to 3.1	Jan. 2003	0 to 865	Inflow + 3,000	Input based on linear interpolation from zero to initial HCI value, Output based on pumping- out mine and inflow
3.1 to 5	2003.1 to 2005	Recharge as per HCI Report	Recharge as per HCI Report	Pre-Development (HCI)
5 to 27	2005 to 2027	Recharge as per HCI Report plus paste consolidation water	Recharge as per HCI Report plus paste consolidation water	Operations
> 27	> 2027	0	0	Closed

IX.1-24

Table IX.1-5	<b>Mine Inflow</b>	Summary
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Notes: See unit and acronym list for definitions.



#### Figure IX.1-4 Groundwater Inflows and Mine Water Discharge Used in GoldSim

#### 5.2.2 Backfill Consolidation Water

Water released due to consolidation of the paste backfill represents a very small contribution to the overall discharge (<1%) as indicated in Figure IX.1-5. The volume is estimated based on a release of water corresponding to a 15% reduction of the total paste volume deposited in the mine. However, depending on the degree of consolidation of the mine waste, the volume of water released could be as low as about 7% of the total paste volume (Golder 2001b). The contribution from backfill consolidation water has therefore likely been overestimated. For the purposes of the model, the total amount of paste deposited in the mine was estimated based on the production schedule as presented in the waste management report (Golder 2001a). In addition, it was assumed that the release of consolidation water will be instantaneous.





# 5.2.3 Working Area versus Old Workings

To facilitate mass loading estimates, groundwater inflows are subdivided into two components:

- a component that will be exposed to fresh, fine grained solids in active workings (working area); and,
- a component that will pass through the old, inactive workings of the mine and be relatively unaffected by mining activities (old workings).

The inactive workings include the following (Golder 2001e):

- haulage drifts (flow increases to 5,000 m<sup>3</sup>/d at year 2016 through closure);
- north ramp not used for main haulage (flow increases to 1,500 m<sup>3</sup>/d at year 2016 through closure); and,

• ore drifts (kimberlite development) – some drifts will remain open for ventilation purposes (approximately 50% of flow to the kimberlite development from year 2008 through closure).

Initially, all flows in the mine are assigned to Working Areas, however, after Year 3 of operations (2008) it is expected that portions of the Haulage Drifts and North Ramp will only be used infrequently. Flow to these inactive portions increases from zero at year 2008 to a peak of  $6,500 \text{ m}^3/\text{d}$  at year 2016. From year 2016 though the end of operations, this flow is assumed constant at  $6,500 \text{ m}^3/\text{d}$ . In addition, some of the kimberlite ore drifts will remain open for ventilation purposes. These inactive areas are expected to represent approximately 50% of flows to the kimberlite development after year 3 of operations.

Flows to the Working Areas include (Golder 2001e):

- haulage drifts (*i.e.*, the fraction of haulage drifts in use). A total flow of 2,000 m<sup>3</sup>/d is assumed to be present in the active haulage drifts at year 16 through end of operations;
- south ramp used for main haulage throughout operations;
- conveyor drift throughout operations;
- ore drifts (kimberlite development) it is estimated that 50% of the flow after year 3 (2008) of operations will be affected by mining; and,
- other inflows all remaining inflows not accounted for in the "Old Workings" are classified as originating from "Working Areas".

In the water quality model, the fraction of water from the working areas is calculated as the total mine inflow due to recharge from connate water and lake water less the contribution from the old workings. The distribution of these flows is provided in Figure IX.1-5.

# 5.2.4 Flow at Closure

As Snap Lake is at the highest elevation of the surrounding waters, it will act as recharge to the mine. At closure, the only discharge from the mine will be through the regional groundwater flow system to surrounding lakes as discussed in Section 9 of the EA.

# 5.3 Mass Load – Mine

Solid phase and dissolved phase mass load will result from a number of activities within the mine (*e.g.*, drilling, blasting, grouting, backfill placement, haulage of rock and ore). The mass load reporting to the mine is further complicated by the interaction of connate water with recharge from Snap Lake. The combined mine recharge occurs in both operating and worked-out areas of the mine.

To make optimal use of the current monitoring data from the AEP, it is necessary to break out the individual contributions into a few integrated components as follows:

- mass load due to recharge;
- mass load due to operations (fresh, fine grained solids);
- mass load due to water released from cemented paste backfill consolidation;
- mass load from explosives use in the mine; and,
- mass load due to grout and cement use in the mine.

Each of these components is accounted for in the water quality estimates as discussed in the following sections.

# 5.3.1 Mass Load Due to Recharge

Recharge water to the mine from connate water is assigned chemistry values based on the average water quality measured from the granitic unit during the AEP monitoring program (Table IX.1-6, Appendix E). Groundwater data from granite were selected since the majority of the underground host rock during operations is granite. Further, concentrations of trace metals from groundwater inflows originating from both granite and metavolcanic are similar, however, the major ion concentrations are higher in groundwater originating from the granitic unit, thereby adding a measure of conservatism. A discussion of baseline groundwater quality is presented in Appendix III.2 of the EA. Water recharging from Snap Lake will mix with the connate water fraction reporting to the mine workings, the relative proportions of which are discussed in Section 5.2 of this document. The resulting groundwater recharge concentrations are based on the relative contributions from these two sources.

The initial recharge water from Snap Lake is assigned the median water quality observed from the Snap Lake baseline water quality data (Table IX.1-3). Thereafter, the recharge water from Snap Lake reflects the calculated concentrations in the Effective Lake Volume of Snap Lake as determined from the previous time step in the GoldSim modelling.

#### Table IX.1-6 Average Inflow Chemistry and Incremental Mass Load

		<sup>a</sup> AEP Average	<sup>®</sup> AEP Average		
		Inflow	Discharge	<sup>c</sup> Incrimental	
Parameter Goldsim	unit	(n = 9)	(n = 10 to 30)	Load Applied	dLimit
Ag	ug/l	0.05	0.055	0.005	0.2
AI	ug/l	10.4	50.3	39.9	328
As	ug/l	1.68	2.1	0.42	5
Ва	ug/l	69.7	388	318.3	4300
Ca	mg/l	152.1	229	76.9	741
Cd	ug/l	0.025	0.025	0	0.05
CI	mg/l	330	418	88	830
Со	ug/l	0.12	0.28	0.16	1.3
Cr	ug/l	0.62	4.6	3.98	4.6
Cu	ug/l	4.34	2.7	0	10.8
Fe	ug/l	402	80.6	0	699
Hg	ug/l	0.12	0.03	0	0.08
К	mg/l	9.97	17.6	7.63	188
Mg	mg/l	11.5	20.8	9.3	56.7
Mn	ug/l	36	8.3	0	37.5
Мо	ug/l	5.59	8.1	2.51	32.8
Na	mg/l	76.9	74	0	no limit
NH4	mg/l	7.63	9.8	2.17	no limit
Ni	ug/l	1.19	8.5	7.31	66
NO <sub>3</sub>	mg/l	6.58	6.8	0.22	no limit
Pb	ug/l	0.28	0.55	0.27	3.2
Se	ug/l	0.2	0.44	0.24	5.2
Silica	mg/l	11.34	11.2	0	22.8
SO <sub>4</sub>	mg/l	29.2	28.7	0	59.6
Sr	ug/l	2290	2664	374	13200
TI	ug/l	0.044	0.1	0.056	0.4
U	ug/l	0.18	0.24	0.06	1.1
Zn	ug/l	2.73	13.5	10.77	64.4
TSS	mg/l	30.7	2120	2089.3	no limit
Alkalinity as CaCO <sub>3</sub>	mg/l	106	230	124	410 <sup>e</sup>
Total-P	mg/l	0.096	2.4	2.304	15
PO <sub>4</sub>	mg/l	0.012	0.009	0	10
TKN	mg/l	5.6	9.5	3.9	24.3
Ве	ug/l	0.1	0.1	0	0.3
V	ug/l	2.18	1.7	0	5.8

Notes: See unit and acronym list for definitions

a Average inflow concentrations based on monitoring data from the Granite ports typically based on 9 samples

though number of samples for each parameter vary as indicated in Appendix E.

Average calculated using one half of typical lower detection limits, elevated detection limits not included in average (Appendix E).

b Average discharge concentrations based on montoring data from the sump decant and UEOP samples to Aug 30, 2001.

Number of samples is typically close to 30 with a range from 10 to 79 depending on the parameter (see Appendix E). Average calculated using one half of typical lower detection limits, elevated detection limits not included in average (Appendix E).

c Incrimental increase in concentration applied to all mine water estiamted to flow through working areas of the mine.

d maximum discharge concentration limit based on maximum observed concentration in the mine water discharge from the UEOP up to Aug 30, 2001.

e maximum alkalinity based on geochemical speciation modelling on sump water.

The method by which groundwater quality is assigned in the GoldSim model ignores changes in recharge water quality due to transient geochemical processes caused by wall rock exposure (e.g., sulfide oxidation). In other words, the composition of the connate component remains constant. (The Snap Lake recharge component does change its composition during mine operations due to site discharge into the lake.) There are several reasons why connate water composition is assumed to remain constant over time:
- the duration of wall rock exposure is short (less than 1 year);
- the exposed rock, granite, is relatively unreactive, as evidenced by the kinetic testing results, and monitoring of granite groundwater quality over time. In particular, the potential for acid generation is very low to non-existent due to its very low sulphur contents; and,
- the kinetic testing results are very similar to those of granite groundwater samples, providing further support for the assumption that granite groundwater quality will remain approximately constant over time.

The TSS load applied to the recharge water is set at 31 milligrams per litre (mg/L). This is the average value observed in the AEP monitoring program for samples collected from seeps and ports in the mine. It is considered reasonable to assume that this value represents TSS that might be expected from the Old Workings since similar values were observed in samples collected along the floor of the mine in relatively inactive areas (Appendix III.2 of the EA).

# 5.3.2 Dissolution of Fresh Fine-grained Solids Due to Operations

Fresh surface area will be exposed as fine-grained particulate matter is generated during drilling, blasting, and hauling. Dissolution of certain trace metals and major ions will be enhanced in the working areas of the mine due to the presence of these fines.

The estimated contribution resulting from dissolution of solid phase particulate matter is based on the observed difference between the groundwater inflow concentrations (Section 5.3.1 of this document) and discharge concentrations observed during the AEP. This contribution is only applied for parameters where the concentrations in the discharge are greater than those observed in the groundwater inflow (*i.e.*, no negative contributions, or reductions in concentrations, are incorporated in the GoldSim model). Table IX.1-6 summarizes the average concentrations from the mine inflow and discharge used to derive the incremental mass load applied to all water flowing though the working areas of the mine. The monitoring data used to develop these estimates are provided in Appendix E.

The rate of groundwater inflow during the AEP was small relative to the rate expected at operations (<5% of that that expected during peak operating periods). Therefore, "dilution" of flow in the active workings was also considered minor relative to that expected during operations. In addition, a large proportion of the AEP workings could be considered active areas for the duration of the AEP program since essentially all haulage and blasting occurred along one drift and ramp. As a result of these two factors, it is expected that the observed monitoring values in the AEP mine water overestimate the concentrations from the mine workings under "normal" operating conditions.

An upper limit to the concentration was assigned to the mine water outflow based on observed peak values during the AEP. Since there were also proportionally more explosives and grout used in the AEP (relative to the groundwater inflow rates) than is expected during operations, the incremental load assigned using this method also accounts for the trace metals that may be associated with the grout/cement and explosives. Nitrate, NH<sub>3</sub>, Ca, Na, and alkalinity were excluded from this approach as, in the modelling simulations, their contribution was strictly based on usage of grout/cement and explosives. It should be noted that chloride was inadvertently assessed allowing for incremental mass addition on the floor of the mine, resulting in a conservative estimate of chloride concentrations that, in effect, double-counts chloride added as a function of grout use. In variability analyses runs (Section 5.4.3 of this document) the chloride is excluded from incremental addition on the floor of the mine.

The TSS loading applied per litre of water flowing through working areas of the mine is 2,120 mg/L. This value represents the average TSS concentration measured from the AEP discharge. This average was derived from measured data excluding values greater than 10,000 mg/L. Due to greater mine inflow volumes and additional sumps during operation, it is expected that the large peaks in TSS loading observed in the AEP will not occur once the mine is operational.

# 5.3.3 Mass Load Due to Explosives Use

The GoldSim modelling assumes that explosives use in the mine will contribute to loading of nitrates,  $NH_3$ , and to some extent Na. As modelled, the rate of mass addition due to the use of explosives is independent of the rate of groundwater inflow but rather is a function of the rate of explosives used in the mine. In developing estimates of mass load due to explosive use, the following factors were considered:

- the type of explosives used;
- the schedule of explosives use (AMEC 2001); and,
- explosives handling considerations (*i.e.*, spillage/unreacted explosives).

Trace metal and other contributions from explosives were not explicitly incorporated in this approach. However, as explained in the previous section, by assigning an incremental load to flow in the active workings based on the difference between sump water quality and mine inflow, any trace metal releases from explosives use are implicitly accounted for.

Geochemical reactions and attenuation mechanisms for the nitrogen species were not included in the model, however they have the potential to reduce observed concentrations along the flow system. It is considered doubtful that biologically-mediated reactions, which play an important role in the natural nitrogen cycle, occur to any significant degree in the underground workings. Consequently, these were ignored as well.

At present, it is estimated that the primary type of explosive used during operations will be an emulsion type explosive (emulsion), with ammonium nitrate/fuel oil (ANFO) being used for footwall development. A minor amount of packaged explosive and detonator cord will also be used. The bulk compositions of the emulsion and ANFO are provided in Table IX.1-7. For the purposes of the mass loading estimates, all types of packaged explosives and other explosive products (excluding emulsion) were conservatively assigned the chemical composition of ANFO since ANFO has a higher proportion of  $NH_4$ and  $NO_3$  relative to emulsion.

Components	Ammonium Nitrate/Fuel Oil	Emulsion (non- aluminized)
NH <sub>4</sub> NO <sub>3</sub>	94 %	63 %
NaNO <sub>3</sub>	0 %	18 %
H <sub>2</sub> O	0 %	9 %
fuel Oil	6 %	6 %
microballoons (glass)	0 %	4 %
aluminum	0 %	0 %

#### Table IX.1-7Explosive Composition (based on data from manufacturers)

Notes: See unit and acronym list for definitions.

The amount of waste explosive that will dissolve and enter the flow system can range from less than 2% to greater than 10% depending on the handling procedures for a given mine. Under the assumption that reasonable handling practices will be employed at the Snap Lake project site, an explosives waste rate of 5% was used to calculate mass load in the GoldSim model (Golder 2001c). It was further assumed that all wasted explosives would dissolve entirely. Figure IX.1-6 shows the anticipated emulsion and ANFO use incorporated in the model (AMEC 2001). A discussion on model results and their sensitivity to changes in explosives use/wastage is provided in Section 5.4.3 of this document.



IX.1-33

# Figure IX.1-6 Explosive Use in the Mine

#### 5.3.4 Mass Load Due to Grout and Cement Use

Grout and cement used in the mine will contribute to loading of Ca, chloride, and alkalinity, and will serve to raise the pH of the mine water. In the GoldSim model, the rate of mass addition of Ca, chloride, and alkalinity is incorporated as a function of the rate of grouting and the amount of cement used in the backfill. The factors considered in estimating loading due to grout and cement use include the composition of these materials (Table IX.1-8), the estimate cement usage, and the estimated rate of grouting.

#### Table IX.1-8 Mine Grout Composition

Component	Grout Mass – solids (kg/t)
Portland Cement	978
CaCl <sub>2</sub>	11
Bentonite	11

Source: De Beers, July 2001.

Notes: See unit and acronym list for definitions.

Cement composition can vary significantly depending on the type of cement, which in turn is related to its required properties. An "average" cement is composed of up to three parts calcium oxide (CaO) to one part silica dioxide (SiO<sub>2</sub>), along with several other components including aluminum oxide (Al<sub>2</sub>O<sub>3</sub>) and iron oxide (Fe<sub>2</sub>O<sub>3</sub>). As applied in the GoldSim, it was assumed that the only the CaO component of the cement would be soluble and that the remainder would not be released. The main contributions from grout and cement to mine loading therefore consist of Ca and alkalinity. Calcium was assigned 40% of the mass load from cement whereas hydroxide alkalinity was converted to alkalinity as CaCO<sub>3</sub> and assigned the remainder of the cement load. Chloride was added based on its relative use in grout (about 12 kilograms per tonne (kg/t) of cement).

It is anticipated that perhaps 3 to 4 underground locations per year need grouting for water control. This would require the use of 60 to 80 tonnes (t) of cement per year. This estimate is slightly lower than the grout use observed during the AEP (Table IX.1-9). However, during the AEP diamond drill holes used for exploration were grouted and excessive wastage (at times) resulted in high grout usage as well. Further, it is expected that in the future grouting will take place in advance of excavation, in which case grouting will be more efficient (*i.e.*, less usage and reduced losses). Therefore, the usage rate selected for the GoldSim modelling (100 t/yr) likely represents an overestimate (Golder 2001d).

Month	Cement (kg)
November 2000	450
January 2001	17,795
February 2001	39,025
March 2001	27,653
April 2001	-
May 2001	-
June 2001	32,521
July 2001	22,581
August 2001	54,938

# Table IX.1-9 Cement Use During the Advanced Exploration Program

Notes: See unit and acronym list for definitions. Source: De Beers 2001b

In the GoldSim model, Ca and chloride release from grout was conservatively considered to take place in two manners:

• a direct waste rate from grouting operations of 50% (as is normal for grouting operations); and,

• an indirect waste rate assuming that 25% of the placed grout would leach all Ca and chloride.

The cement is further assumed to have 2% calcium chloride (CaCl<sub>2</sub>) accelerator since this is the maximum routine dose. With respect to the timing of grouting event, the GoldSim model assumes that grouting applications occur two times per year (January and July) for a period of one month (Table IX.1-10). Although cement is also used in concrete pillars, the release of cement from grout by far exceeds the potential release from the concrete pillars, and no separate component for the cement pillars was included in the GoldSim model.

# Table IX.1-10 Grout Use Estimated During Operations

Month	Grout (kg)
January	50,000
July	50,000

Notes: See unit and acronym lists for definitions.

All wasted grout and cement were assumed to dissolve completely and release their Ca, chloride, and alkalinity. As mentioned previously, other constituents were not considered to originate from use of grout and cement. However, during the AEP grout and cement were used in the mine in greater proportions (relative to groundwater inflow) than is expected during mining operations. Since the mine water chemistry is calculated based on the AEP monitoring data (with the exception of Ca, Na, nitrogen species, chloride, and alkalinity), the concentrations of the trace elements associated with these cement and grout are therefore conservatively accounted for in the incremental mass addition to mine water from the active workings.

The GoldSim modelling approach to incorporation of grout and cement has resulted in predicted concentrations of Ca, magnesium, and bicarbonate that exceed solubility limits imposed by geochemically-credible phases discussed earlier (CaCO<sub>3</sub>, CaSO<sub>4</sub>,  $2H_20$ , CaMg[CO<sub>3</sub>]<sub>2</sub>). In the model, these elevated concentrations were allowed to migrate to the pre-treatment cell where their concentrations were constrained by applying geochemical controls as discussed in Section 8.2 of this document.

# 5.3.5 Cemented Paste Consolidation

The water released as a result of consolidation of the backfill material represents only a very small fraction of the overall potential load from the mine (Section 5.4 of this document). The backfill material will consist of cemented PK paste, thus the water

released from the backfill was assigned the chemistry as observed in leachate testing of cemented paste backfill (Table IX.1-11).

		SNP 1735-09		Concentration
		Decant -	Cemented Paste	Applied to Cemented
Parameter	Unit	Average	- Leach A1	PK Consolidation
		$(n = 4)^{d}$		Water
πH	На	8.1 <sup>a</sup>	11.8	11.8
Aa		0.05	<0.05	0,025
Al	ug/l	10.8	468	468
As	ug/l	1.9	0.70	0.7
Ва	ug/l	83.7	440	440
Са	mg/l	69.1	389	389
Cd	ug/l	0.18	<0.3	0.15
Cl	mg/l	93.1	8.6	8.6
Со	ug/l	0.73	<0.5	0.25
Cr	ug/l	0.57	313	313
Cu	ug/l	0.86	5.1	5.1
Fe	ug/l	10.0	<10	5
Hg	ug/l	0.05	<1	0.05 <sup>b</sup>
K	mg/l	20.5	19.0	19.0
Mg	mg/l	65.0	<0.03	0.015
Mn	ug/l	12.3	<0.3	0.15
Мо	ug/l	130	81.1	81.1
Na	mg/l	44.1	19.2	19.2
NH <sub>4</sub>	mg/l	12.3	6.6	6.6
Ni	ug/l	42.4	<3	1.5
NO <sub>3</sub>	mg/l	42.7	-	42.7c
Pb	ug/l	0.15	0.40	0.40
Se	ug/l	0.43	<5	0.43b
Silica	mg/l	177	-	177c
SO <sub>4</sub>	mg/l	205	5.3	5.3
Sr	ug/l	1045	4950	4950
TI	ug/l	1.4	<0.5	0.25
U	ug/l	0.7	<0.05	0.025
Zn	ug/l	3.8	<5	2.5
TSS	ug/l	0.0	-	0.0
TSSk	mg/l	0.0	N/A	0.0
TSSgt	mg/l	0.0	N/A	0.0
TSSmtvc	mg/l	0.0	N/A	0.0
EXP_Fuel_Oil	mg/l	0.0	N/A	0.0
Alkalinity - CaCO <sub>3</sub>	mg/l	68	760	760
Total-P	mg/l	0.1	0.013	0.013
PO <sub>4</sub>	mg/l	0.02	-	0.02 <sup>c</sup>
TKN	mg/l	26.6	-	26.6 <sup>°</sup>
Be	ug/l	0.1	<3	0.1 <sup>D</sup>

## Table IX 1-11 Leach Test Results from Cemented Paste Backfill as Included in

Notes: See unit and acronym list for definitions.

Shaded values set at one half detection limit.

ug/l

N/A = not applicable

V

median pH value used.

b elevated detection limit due to sample matrix, decant values used.

с no analyses available for cemented paste leach, decant value used.

1.2

<sup>d</sup> Averages calculated using one half of detection limit where applicable. For some parameters the number included in the average is 2 or 3 (see appendix E).

<5

1.2<sup>b</sup>

Table IX.1-11 also includes average concentrations from the decant at sample location SNP 1735-09, the process plant outflow. For certain constituents, values from this location are used rather than from the leach testing due to elevated detection limits in the leachate sample. This is the case for mercury (Hg), selenium (Se), beryllium (Be) and vanadium (V). In the absence of analytical results from the leachate sample, values from SNP 1735-09 were also included in the GoldSim modelling for NO<sub>3</sub>, phosphate (PO<sub>4</sub>), silica, and total Kjeldahl nitrogen (TKN).

In the GoldSim model, cemented paste backfill is only assumed to contribute dissolved constituents to the mine water. A particulate load was not considered. The rationale for this is that consolidation is a gradual process that allows particulate matter to settle during porewater expulsion. Furthermore, the cement in the paste is an effective attenuant for solids by trapping the particulate matter. Anecdotal evidence based on personal experience also indicates that waters expelled from paste during consolidation tend to be clear. Lastly, the contribution of paste consolidation water to the overall mine water is so small that ignoring the TSS from the cemented paste has no impact on suspended solids in the mine water. In particular, the amount of TSS contributed by the active workings overwhelms any potential inputs from other sources.

# 5.4 Results and Discussion – Mine Water

Table IX.1-12 and Figures IX.1-7 through IX.1-12 provide a summary of the mine water discharge concentrations and loading for selected dissolved parameters and TSS. Additional detail on concentration and mass load over time from the mine water is available upon request. A discussion of the relative contribution of mass loading from the mine with respect to the site as a whole is provided in Section 9 of this document.

# 5.4.1 Concentrations – Mine Water

The pH of the mine water during operations will largely be governed by the pH of the mine recharge and by the amount and timing of grouting in the mine. Based on monitoring data from the AEP, the pH of the mine water will likely range from a low over 7 during relatively inactive periods to a potential high of about 9 during periods of active grouting.

The suspended solids content in the mine waters is expected to have a significant range depending on the location and time of measurement. Factors such as the ratio of active working areas vs. inactive areas will affect the TSS concentrations. In addition, the removal of sediments in the mine through the use of sumps will limit peaks in TSS concentrations. Based on the data used in the model, the initial expected TSS in the mine

Table IX.1-12	Summary of Mine Water Concentrations
---------------	--------------------------------------

		Mine Water" Gro				Groundwater	
Parameter		Average Annual Summary (Operations)			(Operations)	Baseline Granite <sup>e</sup>	
	Units	Year 5	Year 15	Year 25	Peak Average Annual <sup>d</sup>	Median	Median
<b>Conventional Parameters</b>		_			-		
pH <sup>a</sup>	pН	7 - 9	7 - 9	7 - 9	9		9.2
Alkalinity	mg/L	243	178	162	400	186	80
Total Dissolved Solids	mg/L	807	556	448	1229	602	920
Total Suspended Solids	mg/L	2095	1208	1277	2120	1351	-
Nutrients	- • •	•			• •		
Ammonia	mg/L	11.0	7.1	4.6	23.0	7.5	4.1
Nitrate + Nitrite	mg/L	-	-	-	-	-	2.4
Nitrate-N	mg/L	9.2	5.8	3.2	20.8	6.0	-
Total Phosphorus	mg/L	2.38	2.02	2.18	2.74	2.11	0.1
Dissolved Phosphorus	mg/L	0.010	0.007	0.006	0.012	0.008	0.035
Total Kjeldahl Nitrogen	mg/L	8.4	6.3	5.8	9.5	6.7	3.2
Major Ions	-	-	1	r			
Calcium	mg/L	206.7	144.4	120.8	431.5	155.3	110.0
Chloride	mg/L	332.1	223.5	1/1.9	417.5	245.5	248.0
Magnesium	mg/L	18.0	13.7	12.6	20.8	14.6	7.8
Potassium	mg/L	15.3	11.5	10.5	17.6	12.3	9.3
Silica	mg/L	0.02	0.02	0.02	0.02	0.02	12.5
Sodium	mg/L	57.9	35.4	21.7	78.1	39.5	/6./
Sulphate Disselved Metals	mg/L	22.0	14.7	10.1	32.4	16.0	10.0
	lug/l	55.8	50.5	56.7	65.2	52.0	7.2
Aroonio <sup>c</sup>	ug/L	33.0	1.0	1.0	00.2	32.9	1.2
Arsenic		1.7	1.2	225.0	<u> </u>	1.3	1.1
Bandin C	ug/L	370.1	0.00	0.00	417.2	0.00	.0.0
	ug/L	0.09	0.08	0.09	0.10	0.09	<0.2
	ug/L	0.03	0.04	0.05	0.05	0.04	<0.05
Chromium	ug/L	4.6	4.6	4.6	4.6	4.6	0.1
Coppor	ug/L	0.3	0.3	0.3	0.4	0.3	0.2
lrop	ug/L	3.4 200 5	2.4	1.0	4.3	2.0	2.0
	ug/L	299.5	107.0	120.7	414.0	207.0	21.0
Manganaga	ug/L	0.5	0.5	12.0	0.0	0.5	0.2
Managanese	ug/L	20.9	10.2	12.0	30.8	19.9	7.1
Mahihdapum	ug/L	0.08	0.06	0.04	0.08	0.07	0.10
Niekel	ug/L	7.0	0.0	0.7	8.1	0.9	5.0
Solonium <sup>c</sup>	ug/L	0.3	1.0	0.3	9.0	0.2	0.0
	ug/L	0.4	0.3	0.3	1.5	0.3	<0.4
	ug/L	0.05	0.05	0.05	0.06	0.05	<0.1
Strontium	ug/L	2121	1412	1062	2660	1547	1/60
	ug/L	0.10	0.10	0.10	0.11	0.10	<0.03
	ug/L	0.2	0.3	0.5	0.5	0.3	0.1
vanadium Zina	ug/L	1.6	1.4	1.4	2.2	1.5	1.8
∠inc	ug/L	14.1	12.7	13.9	15.9	13.1	3.4

<sup>a</sup>Estimates of mine water reporting to treatment,

values based on average annual values of weekly data as calculated using GoldSim.

<sup>b</sup>pH values estimated based on geochemical speciation modelling, and is dependant on grout use in mine

<sup>c</sup>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.

<sup>d</sup>The peak average annual value is the maximum average annual value from years from 1 through 27

<sup>e</sup>Baseline Granite values based on median groundwater inflow water from the granitic unit as described in Section IX of the EA "<" denotes values below the detection limit (see glossary)



Figure IX.1-7 Major Ion Concentrations – Mine Water







Figure IX.1-9a Selected Trace Metal Concentrations – Mine Water

Figure IX.1-9b Selected Trace Metal Concentrations – Mine Water





# Figure IX.1-10 Total Dissolved Solids Load from Mine Sources

Figure IX.1-11 Ammonium Load from Mine Sources



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# Figure IX.1-12 Chromium Load from Mine Sources

Figure IX.1-13 Effects of Recharge Rate Variability on Chloride Concentrations (model run R2a/b)



# Figure IX.1-14 Effects of Connate Water Variability on Chloride Concentrations (model run R2c/d)



Figure IX.1-15 Effects of Explosive Waste Rate on Ammonium Concentrations (model run R2e)



IX.1	-44
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Model Run	Description	Value	Results
R1	EXPECTED CASE		
	MINE		
R2a	Increase flow to Mine	Expected plus 1 standard deviation	Figure IX.1-13
R2b	Decrease flow to Mine	Expected less 1 standard deviation	Figure IX.1-13
R2c	Increase proportion of connate water inflow	Increase average connate water proportion to about 50% (from about 35 %)	Figure IX.1-14
R2d	Increase concentrations of connate water - Upwelling of connate water results in about 60% increase in concentrations of CI and selected parameters after year 5 of operations based on advanced exploration program (AEP) data		Figure IX.1-14
R2e	Increased explosive waste rate	10 % (expected = 5%)	Figure IX.1-15

Table IX.1-13	Model Runs to Assess Variability of Key Parameters - Min	ne
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Notes: See unit and acronym list for definitions.

water is estimated at approximately 2,100 mg/L (Figure IX.1-7). As more areas become inactive, this concentration is expected to decrease slowly and stabilize at about 1,200 mg/L after year 10 of operations. It should be noted that the mine water will report to treatment prior to release. TSS will be treated to less than 5 mg/L under operating conditions, thereby limiting the TSS concentrations that will report to Snap Lake.

The mine water discharge will have the highest total dissolved solids (TDS) value (about 1,500 mg/L with an average annual value of about 1,200 mg/L) occurring near startup, after which the TDS decreases as the volume and proportion of lake water recharging the mine increase. Not surprisingly, major ion concentrations follow a similar trend. The concentrations of chloride and Na are initially higher than in baseline granite groundwater, but decrease to below those of the groundwater over time. The concentrations of Ca, Mg, K, and sulphate (SO<sub>4</sub>) remain above those of the granite, due to the addition of mass from interaction with floor workings. Calcium and alkalinity exhibit a spiky trend as illustrated in Figure IX.1-7 and Appendix H. This trend results from intermittent use of grout in the mine. Since Ca and alkalinity are important contributors to the overall TDS load, the spiky trend is also seen for TDS.

Initial concentrations (Figure IX.1-8) of NH<sub>3</sub>, NO<sub>3</sub>, and TKN are two to five times those of the baseline (connate) groundwater. Over time, the observed concentrations of these parameters decrease to near those of the baseline groundwater in response to reductions in explosives use relative to groundwater inflows and addition of lake-water recharge. Trace metal concentrations (Figure IX.1-9a, b) remain relatively constant when their

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concentrations in connate water and lake water are similar and there is no observed increase in concentration due to interaction with floor material. Such is the case for Be, cadmium (Cd), chromium (Cr), cobalt (Co), lead (Pb), Hg, silver (Ag), thallium (Tl), and uranium (U). Other parameters, such as aluminum (Al), arsenic (As), barium (Ba), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), Se, strontium (Sr), V, and zinc (Zn), are more strongly influenced by interactions with floor sediments and the connate water. These parameters typically show elevated concentrations at early time, followed by a decrease to relatively steady concentrations as the lake water recharge increases and the contribution from the inactive workings increases.

### 5.4.2 Distribution of Mass Load – Mine Water

Figures IX.1-10, IX.1-11, and IX.1-12 show the total mass load discharged from the mine for TDS, NH<sub>4</sub>, and dissolved Cr as well as the individual contributions from the various components that make up the overall load from the mine. Mass loading trends typically mimic the groundwater inflow trends. This is due to mass originating from connate water and, more importantly, addition of mass from sediments on the mine floor in the active workings. Peak loading generally occurs during the period of peak inflow between year 8 and year 22 (year 3 to year 17 of operations). Variability in the load is related to variation in the groundwater inflow rate. There is no mass load from the mine workings to Snap Lake during periods of inoperation from August 2001 through 2003 and in closure and post closure when the mine is not pumped.

Typical mass loading trends are illustrated by the TDS load distribution (Figure IX.1-10). The TDS concentrations are almost entirely governed by mass addition from the mine recharge, with the contributions from the working areas (working face) dominating over those from the inactive areas of the mine (old workings). Additional minor TDS loads, also occur in the form of Ca due to grout and cement use as can be observed in the biannual TDS spikes. The TDS contribution from explosives and PK paste backfill water is insignificant relative to the total TDS load.

For the parameters NH<sub>4</sub>, NO<sub>3</sub>, Cl, Ca, and alkalinity, variability is governed not only by groundwater inflow, but also by material use. The NH<sub>4</sub> loading shown in Figure IX.1-11 illustrates the relative influence of explosives use on the total load for constituents derived from explosives. For these parameters, explosives use contributes about one/fifth of the total mine water load, with the recharge water to the mine contributing the remainder. The paste backfill consolidation water only contributes to any significant degree when the consolidation water concentrations are relatively high and the concentrations in the groundwater inflow are low (most notably for Cr). Figure IX.1-12 illustrates that, for Cr, the PK paste consolidation water contributes about half of the total Cr load. Loading trends for the remaining trace elements typically follow those of TDS. However, for some parameters, additional mass may be introduced in the working areas

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through interaction of the inflow water with sediments on the mine floor, resulting in a slightly higher proportion of mass originating in the working area.

# 5.4.3 Variability of Key Parameters

Model runs were completed to investigate potential effects of changes in mine input parameters on loading to Snap Lake as indicated in Table IX.1-13. The resultant changes in the treated discharge to Snap Lake relative to the expected conditions are summarized in Figures IX.1-13 through IX.1-15. It should be noted that, for the variability runs, the "Expected Cl" values are those calculated after removal of the incremental addition of mass from the working areas (as discussed in Section 5.3.2 of this document). The "Assessed Cl" reflects the concentrations assessed in the EA that were developed using the conservative scenario whereby mass is incrementally added in the working areas. The assessed vs. expected case only affects the chloride values.

Figure IX.1-13 illustrates the potential changes to chloride that might result from varying the overall amount of recharge reporting to the mine. The recharge during operations was varied from 0.67 times the expected value (model run R2a) to 1.33 times the expected value (model run R2b) based on the hydrogeological uncertainty as determined by HCI (2001). Although the proportions of mass added are similar regardless of the groundwater recharge rate, cycling of water between the lake and mine results in higher chloride concentrations when mine inflow rates are higher and vice versa.

Figures IX.1-14 shows differences in chloride concentrations that would result from varying the proportion of connate water to lakewater (model run R2c), and the concentrations in the connate water (model run R2d). The results from Figure IX.1-14 illustrate that, relative to the expected concentrations, an increase in the proportion of connate water from about 30% of the recharge to between 50 and 60% will result in an increase in chloride concentration of about 45%. An increase in the chloride concentration of about 45%. An increase in the chloride concentration of about 45% about 480 mg/L in the first five years of operations would result in a similar increase in concentrations. The sensitivity analyses illustrated by Figures IX.1-13 and IX.1-14 both indicate that the chloride concentrations are largely controlled by connate water, and that grout/cement use has relatively little impact.

Figures IX.1-13 and IX.1-14 show how chloride values might differ from the expected concentration used in the EA. Despite the fact that the figures demonstrate that chloride concentrations could increase under certain scenarios, the values used in the impact assessment are considered conservative because all assumptions leading to the expected case have a built-in measure of conservatism. Further, it should be noted that the modelled changes in chloride concentrations are reflective of the behaviour that might be expected for the major ions, but that trends for trace metals may be different.

Concentrations for parameters with similar values in connate and lake water (*i.e.*, most trace metals) will not experience significant impacts from changes in recharge water proportions.

Concentrations of  $NH_3$  as a function of explosive waste rates are provided in Figure IX.1-15 (model run R2e). As is clearly illustrated, a 10% increase in the waste rate will result in an initial increase in  $NH_4$  concentrations from 15 mg/L to 23 mg/L. Over time, the concentrations increase is less drastic, from about 5 mg/L to about 7 mg/L. The current expected conditions assume a 5% explosives waste rate. Good housekeeping and management practices may reduce this number. Especially during pre-production and at early time in the mine life, when recharge inflows are low, it is important that explosives wastage be minimized to the maximum extent practicable.

# 5.4.4 Concentrations and Mass Load at Closure

At closure, there will be no direct discharge to Snap Lake from pumping of the mine workings. Instead, recharge from Snap Lake to the regional groundwater flow system will result in flow passing through the inactive workings. The model assumes that all mass loading from the mine at closure will result from leaching of cemented paste backfill material. This assumption is based on the leach testing of cemented PK paste and modelling of post-closure hydrogeologic conditions in the backfilled mine. The results from these two efforts indicate that the cemented PK paste represents a material that is sufficiently reactive to impart its geochemical signature on groundwater moving along the backfill surfaces. As a result the water quality of the cemented paste PK as presented in Table IX.1-11 is applied to any seepage interacting with the mine workings.

The pH of the seepage from the mine workings is expected to be alkaline (11.9) due to the cement component in the PK paste. The seepage water is expected to be similar in concentration to the granitic connate water for Cu, Pb, and Hg, and lower in concentration for the Cl, Fe, Mg, Na, As, and SO<sub>4</sub>. Nitrate, TKN, Ca, Co, Cd, K, Ni, Sb, Ba, and Sr are expected to be higher than connate water, but never by more than an order of magnitude. Significant increases with respect to connate water are expected for Al, Cr, and Mo. The elevated Al, Cr, and Mo concentrations are due to the composition of the PK and the alkaline pH values, which result in enhanced solubility of these three parameters.

Additional analyses completed on cemented paste suggest that the concentrations of some parameters, notably Cr, may be lower than those used in the EA (Appendix III.2 of the EA). The current values for seepage loading are thus considered conservative. There may be further potential to reduce the concentrations of these parameters as the recharge water migrates along the groundwater flowpath, however due to remaining uncertainties these mechanisms are not currently included in the EA. Additional geochemical testing and modelling is underway to refine estimates of cemented paste PK chemistry at closure and potential attenuation mechanisms.

# 5.4.5 Key Results and Discussion

Based on the model results, the following processes, trends and influences are considered most relevant with respect to the quality of mine water discharge.

- Mine water concentrations and loading are typically dominated by groundwater inflow characteristics, and to a lesser extent by interaction with sediments on the mine floor or material usage.
- The use of explosives in the mine contributes about 25% of the NO<sub>3</sub> and NH<sub>3</sub> loading to the mine water.
- Use of cement and grout in the mine contributes less than 5% of the total TDS and chloride load to the mine water.
- Consolidation of backfill and release of backfill water has a very minor influence on the overall concentrations discharging from the mine. The principal exception is Cr, which occurs in high concentrations in the backfill.
- Higher mine inflow from the lake may result in a short-term decrease in concentrations in mine water for those parameters governed by mass added as a function of material use. However, over the longer term, concentrations are higher relative to the expected conditions due to re-cycling effects between the lake and mine. The converse is true for lower predicted inflows to the mine.
- The fraction and concentration of connate water entering the mine have a greater influence on concentrations in the mine water than does the total amount of recharge if the proportions of the recharge remain the same.
- Under higher inflow conditions, additional load to the lake will result.
- Chromium concentrations are relatively high in the PK paste backfill. During operations, any effect from backfill is limited due to the small amount of consolidation water expected to be released from the backfill. Also, as pH conditions become less alkaline, the Cr is expected to convert from hexavalent chromium (Cr[VI]) to trivalent chromium (Cr[III]), much of which may precipitate as insoluble chromium hydroxides.

• There is still some uncertainty regarding the ultimate amount of Cr that will persist in the groundwater migration pathway at closure. Limited laboratory data suggest a potential to reduce Cr concentrations along the flow path due to interactions with country rock. Geochemical speciation modelling further indicates that, should there be a change in pH to less alkaline conditions, the Cr will convert to Cr(III). This could then result in precipitation of insoluble chromium hydroxides along the flowpath, reducing the dissolved Cr concentrations in groundwater and receiving surface waters. Given the uncertainty presently surrounding the extent and effectiveness of these processes, the EA at closure is based upon the concentrations measured in leachates from the cemented PK backfill, with no consideration given to potential attenuation of Cr.

# 6.0 NORTH PILE

#### 6.1 Background

The site selected for the PK containment facility (*i.e.*, north pile) is to the west of the mine. About 80% of the site surface consists of granite outcrop, with the remainder having a thin, discontinuous cover of organic and mineral soil over the granite bedrock. Of the 22 Mt of ore and dilution rock processed during the 22-year mine life, about one half will be pumped back underground as paste for use as mine backfill, with the remainder placed as paste in the north pile. The diamond processing will result in three size fractions of PK: coarse PK (fine gravel), grits (sand), and fines (silt).

Initially, a containment cell will be developed along the southern portion of the facility, approximately 500 m from Snap Lake. The embankment to create this cell will be constructed from rock that does not have potential for acid generation (non-PAG rock). Any rock that might be considered to have some potential for acid generation (PAG rock), would be used only inside the outer containment shell where it would be covered by a significant thickness (over 5 m) of processed kimberlite and would remain permanently frozen. Coarse PK, grits, and fines not pumped underground will be thickened to the consistency of paste and deposited on the north pile. At closure, the north pile will be covered by non-PAG granite rock to prevent erosion and dust. Additional detail on pile design is provided in Golder (2001a).

A schematic diagram showing the components of the north pile system is presented in Figure IX.1-16. Assumptions and details on the approach used in the development of flow and mass loading estimates are provided in Sections 6.3 and 6.4 of this document, respectively.

Surface runoff and seepage to surface within (or near the base of) the north pile will be collected through a series of sumps and temporary ponds on the surface and pumped to the water treatment plant during operations and while closure is implemented. Post closure, runoff from the north pile will report directly to the North Arm of Snap Lake once it meets acceptable discharge criteria. Some seepage from the north pile to Snap Lake will also occur through the adjoining fracture system as discussed in Section 6.3 of this document. In the GoldSim model, mass load from the pile and paste consolidation is accumulated in a representative temporary pond or in seepage water as discussed in more detail in Section 6.4 of this document.

#### Figure IX.1-16 Schematic of North Pile Components



#### 6.2 North Pile Properties

Relevant north pile properties used in the calculations of flow and mass loading in the pile were taken from the waste management report (Golder 2001a). Tables IX.1-14 through IX.1-19 provide the properties of the north pile as used in the GoldSim model.

 Table IX.1-14
 Material Proportions – as Deposited

Year (from start of operations)	Development Rock	Coarse + Grits Processed Kimberlite (PK)	PK Paste
0	0.25	0.75	0
0 to 1	0.2	0.15	0.65
1 to 10	0	0.2	0.8
10 to 22	0	0.1	0.9

Notes: proportion of distribution by volume, dilution included. See unit and acronym list for definitions.

#### Table IX.1-15 North Pile Surface Area

Year (from start of operations)	Total Area	Area Closed (Capped)
1 to 2	22 hectares	0 hectares
2 to 10	50 hectares	22 hectares
10 to 22	92 hectares	50 hectares
> 22	92 hectares	92 hectares

# Table IX.1-16 Porosity

Material	Porosity
36% Coarse/35% Grits/29% Fines Processed Kimberlite (PK)	0.48
36% Coarse/35% Grits/29% Fines PK – after consolidation	0.42
50% Coarse/50% Grits PK (Berm material)	0.32
Rock (Granite, Metavolcanic)/Rip-Rap	0.38

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Notes: See unit and acronym list for definitions.

# Table IX.1-17Specific Gravity of Rock-Types

Material	Specific Gravity
Metavolcanic	2.70
Granite	3.00
Kimberlite	2.44

# Table IX.1-18Material Distribution – Proportion by Rock Mass in Upper Active<br/>Layer

Year (from start of operations)	Metavolcanic	Granite	Processed Kimberlite (PK) (Coarse + Grits)	PK (Paste)
0	0.22	0.00	0.78	0.00
0 to 1	0.24	0.00	0.09	0.67
1 to 10	0.16	0.08	0.09	0.67
10 to 22	0.06	0.25	0.08	0.61
>22	0.06	0.49	0.05	0.40

Notes: See unit and acronym list for definitions.

#### Table IX.1-19 Runoff Factor

Material	Runoff Factor
Processed Kimberlite (PK)	0.9
Undisturbed ground	0.7
Road and developed surfaces	0.95

#### 6.2.1 Thermal Analysis and Cryo-concentration

The low temperatures during much of the year reduce the rates at which geochemical reactions occur. As a rule of thumb, rates of chemical reactions typically decrease by a

factor of about 2 for each 10 degrees Celsius (°C) decrease in temperature when the reaction occurs not far from standard temperature. Diavik (1998) conducted a series of paired kinetic tests to evaluate this issue. Their findings were that, for SO<sub>4</sub> and major ions, release rates indeed adhered to the general relationship. For leaching of trace metals, however, no systematic temperature effects could be identified. Their assertion was that release rates of trace metals were controlled by formation of secondary phases rather than dissolution of primary minerals. In addition to reduced reaction rates, the absence of flowing water during most of the year also effectively limits transport of any reaction products to the summer months.

A thermal analysis of the north pile and site materials was completed as part of the waste management study (Golder 2001a). The results of the thermal modelling indicate that material placed in the summer months is initially unfrozen, while that placed in the winter months freezes and remains frozen.

Waste materials placed in the summer months will freeze completely within the second winter following deposition. The thickness of the active layer during the summer months will depend on the deposition rate. Since the greatest rate of deposition (for the initial starter cell) is estimated to be 2.5 to 3 m per year, it is not expected that there will be more than 2 m of thawed material near the surface of the pile. This implies that, at any given time, no more than a 2 m thick layer will contribute to flow and mass loading. Further, thermal modelling completed on the inactive pile indicates that the active layer depth in the final deposited PK material will be approximately 2 m as well.

During operations it may be that isolated events of high deposition rate occur on a portion of the pile. This could conceivably result in a pocket of PK that has a thawed thickness greater than 2 m. This is compensated for in the GoldSim model by the assumption that, once deposition begins in an area of the pile, a 2 m thickness over the entire surface is immediately available for reaction. In reality it will take time to cover all of this area and an even longer amount of time to cover these zones to a thickness of greater than 2 m. The presence of increased amounts of reactive material is further compensated for by the assumption that the entire north pile has a temperature profile associated with that of inactive tailings, with temperatures in the upper 25 centimetres (cm) to 50 cm reaching values of up to 25°C in the summer months (Table IX.1-20). However, the thermal modelling indicates that the temperature of the freshly deposited PK in the summer months will be closer to 10°C (Golder 2001a).

For the purposes of the water quality model, the 2 m thickness of the active layer is applied throughout operations and at closure on the upper materials, regardless of their nature. In practice, the presence of a coarse granite placed on the surface as a cover material may result in a slightly thicker active layer depending on the granite's properties. Should an active layer of a thickness greater than 2 m be obtained at times, the deeper

portions of this active layer would only be thawed for a short period of time and would remain at a relatively low temperature (likely less than  $5^{\circ}$ C). This deeper zone is therefore not expected to contribute significantly to the loadings from the north pile, and it is currently not included in the model calculations.

	Depth (metres)				
	0 - 0.25	0.25 - 0.5	0.5 - 1	1 - 1.5	1.5 - 2
		Temperat	ure (degrees	s Celsius)	
January	-13.4	-10.9	-7.1	-2.3	0
February	-12.9	-11	-8.3	-5.1	-2.6
March	-10.4	-9.7	-8.5	-6.8	-5.1
April	-5.6	-5.8	-6	-5.6	-5
May	-0.3	-1.2	-2.5	-3.1	-3.4
June	13.9	8.5	0.4	-1.6	-2.7
July	21.2	16.2	8.8	1.8	-1.9
August	18.9	15.6	10.7	3.9	-0.3
September	5.7	5.8	6	3.8	1.5
October	-2.4	-1	1.1	0.8	0.4
November	-7.7	-4.6	0	0.6	0.5
December	-11.7	-8.9	-4.7	-0.7	0.7

#### Table IX.1-20 North Pile Temperature Estimates

Source: Golder 2001a.

During the winter months, freezing of the PK is expected to be relatively rapid, thus ice within the PK will likely be incorporated into the PK matrix or in thin, discrete lenses. There will be little potential for the formation of significant thicknesses of ice lenses within the PK deposited at this time. In the summer months, a thickness of PK of up to 1.5 m (typically less than 1 m) will be unfrozen. Based on the thermal modelling, the surface of this layer will essentially be capped by permanently-frozen PK. While there may be some potential for formation of ice lenses and cryoconcentration within the layer deposited in the summer months as it freezes, this water will essentially be trapped and isolated.

Expansion of ice may result in expulsion of up to 7% of the water in the matrix of the PK (the 7% result from the approximate differences in molar volume between water and ice). However, it is expected that the majority of this water will remain trapped within the north pile as small ice lenses or small brine lenses. Once thermal equilibrium is attained, the surrounding frozen PK will for the most part preclude release of this saline solution from the north pile. It is therefore recognized that there may be some potential for short-term discharges of saline water expelled during the freezing process, but these loads have not been accounted for in the model as they are likely to occur as isolated

events during operations. Instead, they will have to be monitored for and dealt with onsite as part of operations. Since virtually all discharge from the north pile will report to treatment, the potential for significant impacts from cryoconcentration processes on Snap Lake water quality is considered very low.

# 6.3 Flow Summary – North Pile

Water from the north pile originates from precipitation (330 millimetres per year [mm/year]), dust suppression water (9,500 m<sup>3</sup>/yr) pumped onto the pile, and consolidation of the PK paste (14% of total water content of PK paste). Evaporation (180 mm/yr) will affect the amount of water that infiltrates into the pile and discharges as direct runoff. The timing and quantity of runoff vs. seepage that report from the pile will depend to a large degree on temperature conditions, with a substantial proportion of runoff reporting during the spring freshet (Table IX.1-21). The monthly release factors applied in the GoldSim water quality model are based on those from the north pile water balance (Golder 2001a) as provided in Appendix D and in Figures IX.1-17 and IX.1-18. The precipitation rate used is based on the rate as indicated in Section 9.3 of the EA. Since this value is slightly lower than the one used for engineering design (Golder 2001a), it is conservative from a water quality perspective.

Description	Precipitation, proportional by month (%)	Runoff, proportional by month (%)	Lake Evaporation, proportional by month (%)	P.K. Bleed Water Flow, proportional by month (%)	Dust Control, proportional by month (%)	Pile Evaporation (%)	Seepage, proportional by month <sup>a</sup> (%)
Annual	100	100	100	100	100.0	100.0	100.0
Jan	6	0	0	0.0	0.0	0.5	0.0
Feb	6	0	0	0.0	0.0	0.4	0.0
Mar	6	0	0	0.0	0.0	0.8	0.0
Apr	5	0	0	0.0	0.0	1.6	0.0
May	6	60	0	67.0	16.7	1.9	10.0
Jun	7	7	15	8.3	16.7	24.1	30.0
Jul	10	10	40	8.3	16.7	31.0	25.0
Aug	12	12	30	8.3	16.7	23.2	20.0
Sept	11	11	10	8.3	16.7	12.0	15.0
Oct	13	0	5	0.0	16.7	3.2	0.0
Nov	10	0	0	0.0	0.0	0.8	0.0
Dec	8	0	0	0.0	0.0	0.4	0.0

#### Table IX.1-21 Monthly Proportion of Annual Flow Release

Except where noted proportions are based on those used in the Water Balance

<sup>a</sup>The proportion of seepage is estimated based on a review of thermal data and monthly flows

Notes: See unit and acronym list for definitions.

The majority of the water from the north pile will report as runoff. The runoff as well as the majority of the seepage at the toe of the north pile will be collected in temporary ponds and sumps, and will be directed to the treatment plant during operations. For the purpose of the water quality estimates, it has been assumed that the storage volume of the temporary pond is  $25,000 \text{ m}^3$ .

In periods of high runoff or under upset conditions, it may be necessary to temporarily divert water to the WMP. Any diverted water will be treated once capacity is available in

the treatment plant. At closure, the north pile will be capped and any post-closure surface water flow will report directly to the North Arm of Snap Lake.

Based on a runoff factor of 0.9 and a north pile surface area of 92 ha, it is expected that about 29,000  $\text{m}^3/\text{yr}$  (*i.e.*, 10% of net precipitation) will infiltrate in the pile. However, seepage analyses completed as part of the waste management study (Golder 2001a) indicate that only about 10% of the total infiltration reports to the deeper flow system connected to Snap Lake (2,900  $\text{m}^3/\text{yr}$  at full pile dimensions). This equates to 1% of the net precipitation. The remainder of the infiltrating water (26,100  $\text{m}^3/\text{yr}$ ) will report to the edges of the pile as toe seepage, be captured, and directed to the temporary sedimentation ponds. The relative proportions of "deep" seepage versus toe seepage are largely governed by the frozen conditions within the pile and foundation. Seepage will be released over the summer months as indicated in Table IX.1-21.

It is expected that the component of north pile seepage directed to Snap Lake will mix with precipitation infiltrating into the overburden and granite located between the north pile and Snap Lake before reporting to the base of the North Arm of Snap Lake. Since the amount of infiltration is estimated at  $8,600 \text{ m}^3/\text{yr}$ , this results in a dilution of the seepage by approximately a factor of 3.

Detailed flow and water balance calculations for the north pile are presented in Golder (2001a). Time histories of relevant north pile flows based on the water balance data are included in Appendix I and J.



Figure IX.1-17 North Pile Surface Discharge – Flow

Figure IX.1-18 North Pile Seepage Discharge - Flow



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# 6.4 Mass Load – North Pile

The chemical loading from the PK consolidation water and dust suppression water represents the short-term chemical load from the pile and is tracked as a concentrationbased load. Long-term dissolved loading from the PK and dilution rock deposited in the pile is estimated based on late-time kinetic test data and is calculated as a mass load per unit mass per unit time. Particulate load resulting from runoff is determined in Golder (2001a).

In the GoldSim model, chemical loading from the north pile is applied to the temporary water pond and seepage pathway to Snap Lake. This allows for development of estimates of water quality in the pond and Snap Lake, as well as estimates of water quality that will report to treatment as discussed in the next sections.

# 6.4.1 Short-term Mass Load – Particulate Load, Processed Kimberlite Consolidation Water, and Dust Suppression Water

Particulate load for the north pile is estimated in Golder (2001a) based on erosion rates as applied to the site runoff on an average annual basis, resulting in about 1,600 mg/L TSS. This value is conservatively applied to all runoff water from the north pile.

Paste consolidation water is assigned an average concentration based on dissolved concentrations in water quality measurements from the process discharge line during the AEP (Table IX.1-22). In accordance with the approach used for consolidation water from underground cemented PK backfill, it is assumed that paste consolidation water in the north pile contains dissolved constituents only. It is assumed that consolidation is essentially instantaneous (*i.e.*, within one month). Dust suppression water consists of treated water taken from the water treatment plant prior to discharge, and as such the concentrations within the dust suppression water will change over time as discussed in Section 8 of this document. Dissolved concentrations in dust suppression water were iteratively obtained from the GoldSim modelling.

Parameter	Unit	Paste Consolidation Water Expected Dissoved Concentrations based or Average from SNP 1735-09 (n = 4)
рН <sup>а</sup>	pН	7.4 - 8.7
Ag	ug/l	0.05
Al	ug/l	10.8
As	ug/l	1.9
Ва	ug/l	83.7
Са	mg/l	69.1
Cd	ug/l	0.18
CI	mg/l	93.1
Со	ug/l	0.73
Cr	ug/l	0.57
Cu	ug/l	0.86
Fe	ug/l	10.0
Hg	ug/l	0.05
K	mg/l	20.5
Mg	mg/l	65.0
Mn	ug/l	12.3
Мо	ug/l	130.0
Na	mg/l	44.1
NH4	mg/l	12.3
Ni	ug/l	42.4
NO <sub>3</sub>	ma/l	42.7
Pb	ua/l	0.15
Se	ug/l	0.43
Silica	ma/l	177
SO <sub>4</sub>	mg/l	205
Sr	ua/l	1045
TI	ug/l	1.4
U	ug/l	0.7
Zn	ua/l	3.8
Alkalnity - CaCO₃	mg/l	68.3
Total P	mg/l	0.1
PO <sub>4</sub>	mg/l	0.02
TKN	mg/l	26.6
Ве	ya/l	0.1
V	ug/l	12

#### Table IX.1-22 **Concentrations Applied to Paste Consolidation Water**

Based on average of values from process plant discharge, decant fraction,

(Class B water license monitoirng location SNP 1735-09). Averages calculated using one half of detection limit where applicable. For some parameters the number

included in the average is 2 or 3 (see Appendix E). <sup>a</sup> pH based on observed range in process water discharge from SNP 1735-09.

# 6.4.2 Long-term Dissolved Mass Load – Processed Kimberlite Solids and **Dilution Rock**

A detailed discussion on kinetic test procedures is provided in Appendix III.2 of the EA. Samples for kinetic testing were selected such that they represented the compositional and spatial range of the three rock types of interest: kimberlite, granite, and metavolcanic. The arithmetic mean of the late-time kinetic test data was used to define dissolved mass loading rates (*i.e.*, rates expressed in milligrams per kilogram per week [mg/kg/week]) for north pile seepage. All kinetic test samples were included in calculating the mean for the kimberlite and granite units, whereas the arithmetic mean of the metavolcanic unit was determined using samples representative of the metavolcanic unit as a whole. Metavolcanic samples not included were those samples that had been selected specifically for investigation of high sulphide content. This was considered reasonable and appropriate since the high-sulphide metavolcanics represent a very small portion of the metavolcanic unit as a whole. In addition, any metavolcanic rock deposited in the north pile will undergo significant dilution by low-sulphide PK and granite material.

Details on the geochemical testing procedures and results are provided in the Geochemistry Baseline Report (Appendix III.2 of the EA). The calculated loading rates are listed in Table IX.1-23.

Table IX.1-23	Mass Loading Rates Developed from Kinetic Testing (not
	corrected for temperature)

	Average loading	Pile (mg/kg/week)	
	Metavolcanic	Granite	Kimberlite
Parameter	(n = 18) <sup>a</sup>	(n = 9) <sup>b</sup>	(n = 15) <sup>c</sup>
Ag	4.40E-06	4.26E-06	6.82E-06
AI	2.49E-03	7.01E-03	3.09E-03
As	1.85E-04	1.58E-04	1.67E-04
Ва	1.01E-03	5.49E-04	3.12E-03
Са	2.04E+00	1.55E+00	3.67E+00
Cd	1.11E-05	1.78E-05	4.74E-05
CI	3.13E-02	3.25E-02	6.93E-02
Co	1.63E-04	2.38E-05	7.67E-05
Cr	4.40E-05	8.87E-05	1.67E-04
Cu	1.19E-04	1.68E-04	2.52E-04
Fe	9.45E-04	1.55E-03	4.41E-03
Hg	1.81E-05	1.81E-05	1.81E-05
к	5.36E-01	3.16E-01	1.38E+00
Mg	2.31E-01	3.47E-01	2.21E+00
Mn	3.86E-03	2.08E-03	7.44E-04
Мо	2.62E-04	5.93E-03	1.67E-03
Na	3.05E-01	2.52E-01	2.60E-01
NH4	1.24E-03	5.98E-03	2.61E-03
Ni	1.72E-03	9.62E-05	2.68E-03
NO3	3.21E-02	6.28E-03	6.90E-02
Pb	2.05E-04	2.76E-04	4.14E-04
Se	8.80E-05	1.41E-04	4.15E-04
Silica	2.00E-03	2.00E-03	2.00E-03
SO4	2.83E+00	9.63E-01	4.25E+00
Sr	6.49E-03	8.81E-03	1.77E-02
TI	1.02E-05	8.62E-06	7.08E-06
U	1.37E-04	6.22E-04	7.80E-04
Zn	3.40E-04	4.35E-04	2.56E-04
Alk_as_CaCO₃	4.44E+00	4.53E+00	1.29E+01
Total_P	1.07E-02	3.05E-03	7.57E-03
PO4	1.04E-03	1.83E-03	2.75E-03
TKN	1.48E-01	2.24E-01	1.79E-01
Be	4.40E-05	7.04E-05	6.82E-05
V	7.00E-04	2.01E-03	1.67E-03

Note: Rates based on averages of kinetic test data (Appendix 3.2 of EIS report)

<sup>a</sup> based on long term leachate analyses (latest 3 sample events, or latest 5 sampling events for parameters SO<sub>4</sub> and Alkalinity) from 6 separate samples

<sup>b</sup> based on long term leachate analyses (latest 3 sample events, or latest 5 sampling events for parameters SO<sub>4</sub> and Alkalinity) from 3 separate samples

<sup>c</sup> based on long term leachate analyses (latest 3 sample events, or latest 5 sampling events for parameters SO<sub>4</sub> and Alkalinity) from 5 separate samples

See unit and acronym list for definitions.

The dissolved loading rates were derived from the kinetic testing results and applied to the north pile as follows:

- 1. Leachate concentrations (in mg/L) from each representative column were transposed to units of mg/kg/week (Appendix III.3 of the EA).
- 2. The late-time mass loading rates for each parameter of each column were developed by taking the average of either the last 5 data points where measurements were taken every week or the last 3 data points where measurements were less frequent.
- 3. The representative late-time data of the columns in each group were averaged to develop the long-term mass release rates for the three rock types (Appendix F).
- 4. The proportion of rock (by mass) in the upper active layer in the north pile (Table IX.1-18) was calculated assuming:
  - 20% dilution (by volume) of the kimberlite with country rock (granite and/or metavolcanic).
  - It is estimated that the dilution rock consists of metavolcanic rock through year 2, changing to an equal mixture of metavolcanic and granite after year 2. From year 10 of operations onward, all dilution rock consists of granite.
  - The material properties of kimberlite, metavolcanic, and granite are as defined in Tables IX.1-14 through IX.1- 17 (Golder 2001a).
  - At closure a 0.5 m non-PAG granite cap will cover the pile. At the time of model development, a 1 m cap was assumed, and the modelling was conducted with this 1 m thick cap. The granite cap is applied progressively as active deposition in an area ends (Table IX.1-15). A discussion and results showing implications of changes in the thickness of the granite cap and active layer is provided in Section 6.5.4 of this document.
- 5. The entire 2 m thick active layer described in Section 6.2 of this document is assumed to have a mass release rate based on the kinetic testing as adjusted for temperature. This active layer is further subdivided into five zones to account for temperature differences within the 2 m layer (0-25 cm, 25-50 cm, 50-100 cm, 100-150 cm, and 150-250 cm). The mass load from each of these sub-layers is calculated separately.
- 6. The temperature for each sub-layer is assigned based on the summary of the thermal modelling results as provided in Table IX.1-20 (Golder 2001a). These temperatures are assumed to be representative for any given year, and are therefore not adjusted based on potential annual variability. For each time-step and depth zone, a temperature is assigned based on the time of year as tracked in the GoldSim model (with time zero set as January 1, 2000), using a linear interpolation between the monthly temperature data from each zone.

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- 7. Mass release rates as measured in the laboratory are adjusted based on temperature factors and applied to the total mass of active material for a given zone. The temperature adjustment of mass release rates is applied as follows:
  - Frozen materials (<0°C) are assumed to make no contribution to the mass load because the reaction rates are severely depressed due to the low temperature. In addition, in the absence of free water, transport of reactants or reaction products either to or from the reaction sites is very limited.
  - Major ions (*e.g.*, Mg, Ca, Cl, Na, K, SO<sub>4</sub>) contribute mass at a rate that is governed by the temperature of the materials. For every 10°C reduction in temperature from 25°C, the rate of reaction is halved from that observed in the laboratory data in accordance with the observations and procedure used at Diavik (1998).
  - Trace metal mass release is not reduced as a function of temperature, but rather proceeds at the rate observed in the kinetic testing whenever the material temperature is above 0°C. This is also in accordance with the approach used at Diavik (1998).
- 8. The resulting release rates were coupled with flow estimates to provide concentrations. A comparison with the kinetic test results showed that the calculated concentrations in north pile discharge were unreasonably high for most constituents. A scale factor of one-tenth the kinetic test data rates was then applied to the calculated mass loading rates to account for this discrepancy. In support of this approach, two considerations are of importance: 1) As currently modelled, the entire 2 m thick active layer is included in reaction calculations. However, reactions will likely be most pronounced in the upper tens of cm and will likely not proceed at a significant rate at greater depth within the active layer; 2) It is generally acknowledged that the reactivity of geologic materials in humidity cells is enhanced relative to that under field conditions. For instance, the ASTM Standard Test Method for Accelerated Weathering of Solid Materials Using a Modified Humidity Cell (ASTM D5744-96) states that "...this laboratory test method has accelerated metalmine waste-rock weathering rates by at least an order of magnitude greater than observed field rates."
- 9. The geochemical composition of the resultant solution originating from the north pile as determined by the GoldSim model is evaluated to determine if geochemical controls should be taken into account. Solubility constraints are evaluated using the computer speciation code PHREEQC, Version 2 (Parkhurst and Appelo 1999) for the peak average annual modelling results. Based on the results of the PHREEQC speciation modelling, geochemically-credible solubility limits are then imposed (Section 6.4.4 of this document), and the GoldSim model is re-run with these solubility limits.

# 6.4.3 Distribution of North Pile Mass Load

The entire dissolved mass estimated to originate from the interior of the north pile, due to reaction and paste consolidation water is distributed between the temporary pond and direct seepage to Snap Lake. This distribution is based on the relative proportions of the water volumes that generate dissolved mass (*i.e.*, infiltration + PK consolidation water) reporting to each of these locations. In other words, 1% of the dissolved mass is assigned to seepage, and the remaining 99% is assigned to the temporary pond.

Dissolved mass assigned to the temporary pond is mixed with the runoff and the mass load from dust suppression water from the pile to develop concentration estimates in the temporary pond. Dissolved mass assigned to the seepage pathway to Snap Lake is mixed with the seepage volume from the pile and the infiltration volume from the area between the north pile and Snap Lake to develop estimates of seepage concentrations.

# 6.4.4 Geochemical Controls

Potential geochemical controls for the temporary pond and seepage pathways from the north pile were evaluated by considering the peak average annual concentrations derived from preliminary model runs. The geochemical speciation model PHREEQC, Version 2, was used to develop these estimates based on a range of relevant pH and redox conditions indicated by the laboratory data. The database used in the model was that of MINTEQA2 (Allison *et al.*, 1991), a widely-accepted database for use in mining applications. Input and output concentrations for the geochemical model runs are provided in Tables IX.1-24 and IX.1-25.

The geochemically-credible phases included in the evaluation of solubility controls were ferrihydrite [Fe(OH)<sub>3</sub>], gibbsite [Al(OH)<sub>3</sub>], CaSO<sub>4</sub><sup>-2</sup>H<sub>2</sub>O, amorphous silica [am-SiO<sub>2</sub>], nickel and zinc hydroxide [Ni(OH)<sub>2</sub>, Zn(OH)<sub>2</sub>], CaCO<sub>3</sub>, rhodochrosite [MnCO<sub>3</sub>], birnessite [MnO<sub>2</sub>], chromium hydroxide [Cr(OH)<sub>3</sub>], anglesite [PbSO<sub>4</sub>], otavite [CdCO<sub>3</sub>], fluorite [CaF<sub>2</sub>] and brochantite [Cu<sub>4</sub>SO<sub>4</sub>(OH)<sub>6</sub>]. Observations of these phases in mine-waste environments suggest that kinetic impediments to precipitation of these phases are not significant within the time frame used in the GoldSim modelling.

Based on the results of the geochemical speciation modelling, solubility constraints were set in the GoldSim water quality model for the seepage pathway to Snap Lake and in the temporary pond as identified in Tables IX.1-24 and IX.1-25. These constraints will be somewhat conservative for the temporary pond as they are applied to a solution that has been diluted by surface runoff. In actuality, precipitation of secondary minerals will likely occur within the rock mass during movement of infiltration and seepage. Geochemical interaction with aquifer material, resulting in additional reductions in metals concentrations in direct seepage to Snap Lake, was also not taken into account.

Parameter	Input	Equilibrium Concentrations (mg/L)	GoldSim Solubility Limits (ma/L)	Mechanism
pH	7.00	6.67	-	
pe	3.4	8.32	-	
Âq	0.0014	0.0014	-	
AI	1.18	1.02	1.02	Gibbsite precipitation
As	0.039	0.031	0.31	Adsorption
Ba	0.61	0.61	-	
Ca	268	268	-	
Cd	0.0083	0.0083	-	
CI	183	183	-	
Co	0.018	0.018	-	
Cr	0.031	0.0075	0.0075	Cr(OH) <sub>3</sub> precipitation
Cu	0.050	0.047	0.047	Adsorption
Fe	0.19	0.0048	0.0048	Ferrihydrite precipitation
Hg	0.0042	0.0042	-	
K	87	87	-	
Mg	197	197	-	
Mn	0.38	0.38	-	
Мо	0.87	0.87	-	
Na	96.8	96.8	-	
$NH_4$	23.9	0.001	-	
Ni	0.51	0.51	-	
NO <sub>3</sub>	85.1	13.3	-	
Pb	0.081	0.077	0.077	Adsorption
Se	0.071	0.071	0.071	Adsorption
Si	343	38.3	38.3	SiO <sub>2</sub> (a) precipitation
SO <sub>4</sub>	715	714	-	
Sr	4.6	4.6	-	
TI	0.0041	0.0041	-	
U	0.15	0.15	-	
Zn	0.082	0.082	-	
Alkalinity	595	423	422	Geochemical reactions

#### Table IX.1-24 Geochemical Speciation Values and Solubility Constraints for North Pile Seepage

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Input concentrations based on peak average annual concentrations from GoldSim model with infinite solubility limits Equilibrium concentrations based on geochemical speciation modelling using PHREEQC with a MINTEQ database Notes : See unit and acronym list for definitions.

#### 6.5 Results and Discussion – North Pile

During operations, the mass load from the north pile reports to Snap Lake either via the treatment discharge, or via seepage to the North Arm of Snap Lake. At closure, surface runoff from the north pile will no longer be directed to treatment but will report to directly the North Arm of Snap Lake. Results for the north pile seepage and the expected concentrations in the temporary pond prior to either discharge via treatment or, at closure, discharge to the North Arm of Snap Lake are presented and discussed in the following sections. Corresponding figures and tables are located at the end of Section 6.5.

Table IX.1-25	Geochemical Speciation Values and Solubility Constraints for
	North Pile Temporary Pond

Parameter	Input	Equilibrium	GoldSim Solubility	Mechanism
	-	Concentrations (mg/L)	Limits	
			(mg/L)	
рН	7.00	6.89	-	
ре	3.4	8.0	-	
Ag	0.0009	0.0009	-	
AI	0.88	0.88	0.88	Gibbsite precipitation
As	0.025	0.004	0.004	Adsorption
Ва	0.38	0.38	-	
Са	118	118	-	
Cd	0.0052	0.0052	-	
CI	81	81	-	
Co	0.012	0.012	-	
Cr	0.021	0.0045	0.0045	Cr(OH) <sub>3 precipitation</sub>
Cu	0.033	0.025	0.025	Adsorption
Fe	0.59	0.0032	0.0032	Ferrihydrite precipitation
Hg	0.0028	0.0028	-	
K	38	38	-	
Mg	68	68	-	
Mn	0.29	0.29	-	
Мо	0.58	0.58	-	
Na	35.2	35.2	-	
$NH_4$	9.4	0.002	-	
Ni	0.30	0.30	-	
NO <sub>3</sub>	30.9	2.6	-	
Pb	0.050	0.037	0.037	Adsorption
Se	0.053	0.053	-	
Si	122	38.6	38.6	SiO <sub>2</sub> (a) precipitation
SO <sub>4</sub>	179	179	-	
Sr	2.3	2.3	-	
TI	0.0015	0.0015	-	
U	0.10	0.10	-	
Zn	0.063	0.063	0.0633	
Alkalinity	326	258	258	Geochemical reactions

Input concentrations based on peak average annual concentrations from GoldSim model with infinite solubility limits Equilibrium concentrations based on geochemical speciation modelling using PHREEQC with a MINTEQ database Notes: See unit and acronym list for definitions.

# 6.5.1 North Pile Seepage Water

Concentration and loading results for north pile seepage to Snap Lake are provided in Appendix I. A summary table showing average annual concentrations for selected years is provided in Table IX.1-26. Figures IX.1-19 and IX.1-20 are included to illustrate general trends over time for selected dissolved major ion and metal concentrations.

The pH of the seepage from the north pile is expected to be near neutral based on the values observed in the kinetic testing and geochemical speciation modelling on the pile waters. The relatively constant pH largely results from buffering by  $CaCO_3$  present in the PK as determined through geochemical speciation modelling (Section 6.4.4 of this document). Approximately 80% of the pile is located on granite material, which is not
### Table IX.1-26 Summary of Estimated Concentrations for North Pile Seepage Water

			Groundwater						
Parameter			Averag	e Annual			Summa	rv	Baseline Granite <sup>e</sup>
	Units	Year 5	Year 15	Year25	Year 35	Peak Average Annual <sup>d</sup>	Median	Average Post Closure (model year 34 - 39)	Median
Conventional Parameters	s	-							
pH⁵	Hα	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	ma/L	3.8	104	104	104	104	104	104	80.0
Total Dissolved Solids	ma/L	27.0	361	312	157	400	312	156	920
Nutrients				-			-		
Ammonia	ma/L	0.4	4.3	3.1	0.1	5.3	3.2	0.1	4.1
Nitrate-N	ma/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 lons									
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		I							
Aluminium	ug/L	1.6	150	194	244	245	138	244	7.2
Arsenic	ug/L	0.1	7.5	7.6	7.6	7.6	7.5	7.6	1.1
Barium	ug/L	4.0	132	126	79.4	136	126	79.1	55.4
Beryllium	ug/L	0.03	2.8	3.1	3.3	3.3	2.6	3.3	<0.2
Cadmium <sup>c</sup>	ug/L	0.02	1.7	1.8	1.4	1.8	1.6	1.4	<0.05
Chromium	ug/L	0.1	1.8	1.8	1.8	1.8	1.8	1.8	0.1
Cobalt	ug/L	0.1	3.9	3.4	2.7	3.9	3.4	2.7	0.2
Copper	ug/L	0.1	9.6	10.4	9.6	10.4	9.2	9.6	2.8
Iron	ug/L	0.5	1.2	1.2	1.2	1.2	1.2	1.2	21.0
Lead <sup>c</sup>	ug/L	0.1	15.4	16.8	15.8	16.8	14.7	15.8	0.2
Manganese	ug/L	1.1	65.6	65.3	79.8	79.9	64.7	79.8	7.1
Mercury <sup>c</sup>	ug/L	0.01	0.8	0.9	0.9	0.9	0.8	0.9	0.1
Molybdenum	ug/L	5.2	126	160	182	182	125	182	5.6
Nickel	ug/L	2.5	108	99.2	61.7	110	99.2	61.5	0.8
Selenium <sup>c</sup>	ug/L	0.14	13.9	14.8	12.1	14.8	13.4	12.1	<0.4
Silver <sup>c</sup>	ug/L	0.004	0.28	0.29	0.26	0.29	0.27	0.26	<0.1
Strontium	ug/L	43.3	982	935	596	1037	935	595	1760
Thallium	ug/L	0.05	0.8	0.7	0.4	0.9	0.7	0.4	<0.03
Uranium <sup>c</sup>	ug/L	0.3	27.8	32.2	31.5	32.3	26.2	31.5	0.1
Vanadium	ug/L	0.6	65.7	78.9	85.7	85.8	61.4	85.7	1.8
Zinc	ug/I	0.2	137	15.4	171	171	13.2	17.1	34

<sup>a</sup>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.

<sup>b</sup>pH values estimated based on geochemical speciation modelling

<sup>c</sup>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.

<sup>d</sup>The peak average annual value is the maximum average annual value from years from 1 through 40

<sup>e</sup>Baseline Granite values based on median groundwater inflow water from the granitic unit as described in Section IX of the EA

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



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Figure IX.1-19 Major Ion Concentrations – North Pile Seepage

Figure IX.1-20 Selected Metal Concentration – North Pile Seepage



expected to appreciably affect the seepage pH. For the remaining 20%, any organic materials in the vicinity of the perimeter containment dykes that may thaw as part of the yearly active layer will be removed (Golder 2001a). It is therefore also not expected that interaction between organic material and north pile seepage will significantly alter the seepage pH.

The calculated concentrations for the north pile seepage show two distinct trends over time. The TDS and major ion concentrations peak during years 5 to 10 of production and then decrease as the pile undergoes progressive closure and covering with granite (Figure IX.1-19). The peak TDS concentrations show moderate levels of 300 to 500 mg/L, decreasing in post production to about 200 mg/L. The calculated metal concentrations are predominantly influenced by production factors, surface area of the pile, infiltration and near-surface rock type of the pile. For instance, Ni, Co and to some degree Cd are concentrations in seepage are highest during production when more kimberlite is exposed at surface. During closure, a granite cap will cover the kimberlite and the mass load of these metals will decrease.

It should be noted that for Al, Hg, Pb, Mo, Ni, Se, and U, the model predictions likely overestimate expected seepage concentrations. This occurs because many of the leachate values observed in the kinetic testing were below detection and the mass load was added at some fraction of the respective detection limits (either one half or one tenth depending on the parameter) (Appendix F). Under field conditions, their dissolved concentrations are expected to be lower than those calculated using the current water quality model. Model concentrations for As, Cr, Fe, and silicon (Si) are controlled by solid equilibrium phases or adsorption as based on the geochemical speciation modelling. As shown in Figure IX.1-20, this results in horizontal trends for such parameters as As and Cr over most of the modelled period.

#### 6.5.2 North Pile Temporary Pond

The concentrations observed in the north pile temporary pond (Table IX.1-27 and IX.1-28) are strongly influenced by the flow characteristics of the pile and the size of the holding pond. For the purposes of estimating concentrations, a holding pond (temporary pond) size of 25,000 m<sup>3</sup> was used. Additional detail on expected concentrations for the various parameters is provided in Appendix J.

### Table IX.1-27Summary of Estimated Total Concentrations for North Pile<br/>Temporary Pond Water

	1	North Pile Temporary Pond <sup>a</sup>							
Parameter		Average Annual Summary							
						Peak		Average Post	
	Units	Year 5	Year 15	Year25	Year 35	Average	Median	Closure (model	
						Annual <sup>d</sup>		year 34 - 39)	
Conventional Parameters									
pH <sup>⊳</sup>	рН	6.5 - 7.1	6.5 - 7.1	6.5 - 7.1	6.5 - 7.1	7.1	-	6.5 - 7.1	
Alkalinity	mg/L	40.4	64.6	89.8	74.6	162.5	86.0	59.2	
Total Dissolved Solids	mg/L	264	299	331	118	605	336	95	
Total Suspended Solids	mg/L	118	406	447	25	464	373	25	
Nutrients									
Ammonia	mg/L	3.6	1.8	1.8	0.0	7.8	1.9	0.0	
Nitrate-N	mg/L	12.4	5.8	6.3	0.3	25.2	6.3	0.2	
Total Phosphorus	mg/L	0.088	0.21	0.30	0.21	0.68	0.28	0.16	
Dissolved Phosphorus	mg/L	0.012	0.03	0.03	0.03	0.04	0.03	0.03	
Total Kjeldahl Nitrogen	mg/L	8.0	4.7	5.5	2.2	16.9	5.5	1.8	
Major Ions									
Calcium	mg/L	33.2	47.6	56.2	23.2	100	55.9	18.5	
Chloride	mg/L	29.6	21.0	22.0	0.7	90.1	24.2	0.6	
Magnesium	mg/L	36.1	64.0	71.8	12.3	90.2	70.9	10.2	
Potassium	mg/L	8.8	10.5	13.2	7.2	23.5	12.8	5.8	
Silica	mg/L	33.6	38.6	24.4	0.02	38.6	36.1	0.0	
Sodium	mg/L	13.7	8.8	9.7	2.9	32.0	10.2	2.4	
Sulphate	mg/L	66.1	44.3	53.0	25.3	143	52.7	20.4	
Metals		-	-						
Aluminium	ug/L	2087	7030	7713	668	8018	6664	617	
Arsenic <sup>c</sup>	ug/L	2.2	7.3	7.6	4.5	7.7	7.1	4.5	
Barium	ug/L	182	528	590	82	637	560	67	
Beryllium <sup>c</sup>	ug/L	0.36	1.1	1.9	2.4	2.7	1.6	1.8	
Cadmium <sup>c</sup>	ug/L	0.55	1.6	2.1	1.1	2.5	1.8	0.9	
Chromium	ug/L	68	220	234	13	242	212	13	
Cobalt	ug/L	5.9	16.4	17.7	3.2	19.5	16.8	2.7	
Copper	ug/L	19.4	44.2	45.0	11.0	57.2	44.0	8.9	
Iron	ug/L	6189	19436	20740	962	21528	18770	962	
Lead <sup>c</sup>	ug/L	3.6	12.7	18.3	12.5	20.3	15.3	9.4	
Manganese	ug/L	189	610	665	111	695	612	95	
Mercury <sup>c</sup>	ug/L	0.16	0.5	0.7	0.7	0.9	0.6	0.5	
Molybdenum	ug/L	46	58	98	132	148	87	99	
Nickel	ug/L	131	381	424	59	447	401	48	
Selenium <sup>c</sup>	ug/L	2.3	11.4	15.5	16.9	18.9	13.3	14.1	
Silver <sup>c</sup>	ug/L	0.2	0.5	0.6	0.3	0.7	0.6	0.2	
Strontium	ug/L	422	509	696	445	1302	664	335	
Thallium	ug/L	0.7	1.3	1.5	0.4	1.7	1.4	0.3	
Uranium <sup>c</sup>	ug/L	3.9	12	21	23	27	17	17	
Vanadium	ug/L	7.9	25	46	62	70	37	46	
Zinc	ug/L	21	71	81	24	84	73	20	

<sup>a</sup>Estimates of concentrations at north pile temporary pond with a pond volume of 25,000 m<sup>3</sup> and a TSS value at closure of 25 mg/l,

values based on average annual values of weekly data as calculated using GoldSim.

<sup>b</sup>pH values estimated based on geochemical speciation modelling

<sup>c</sup>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.

<sup>d</sup>The peak average annual value is the maximum average annual value from years from 1 through 40

### Table IX.1-28Summary of Estimated Dissolved Concentrations for North Pile<br/>Temporary Pond Water

		North Pile Temporary Pond <sup>a</sup>							
Parameter			ry						
			ľ			Peak		Average Post	
	Units	Year 5	Year 15	Year 25	Year 35	Average	Median	Closure (model	
						Annual <sup>d</sup>		year 34 - 39)	
Conventional Parameters									
рН <sup>ь</sup>	pН	6.5 - 7.1	6.5 - 7.1	6.5 - 7.1	6.5 - 7.1	7.1	-	6.5 - 7.1	
Alkalinity	mg/L	40.4	64.6	89.8	70.2	163	86.0	56.2	
Total Dissolved Solids	mg/L	236	207	232	107	537	238	86	
Nutrients									
Ammonia	mg/L	3.6	1.8	1.8	0.0	7.8	1.9	0.0	
Nitrate-N	mg/L	12.4	5.8	6.3	0.3	25.2	6.3	0.2	
Total Phosphorus	mg/L	0.088	0.21	0.30	0.19	0.68	0.28	0.15	
Dissolved Phosphorus	mg/L	0.012	0.03	0.03	0.03	0.04	0.03	0.03	
Total Kjeldahl Nitrogen	mg/L	8.0	4.7	5.5	2.0	16.9	5.5	1.7	
Major Ions								-	
Calcium	mg/L	27.2	28.4	35.7	21.0	82.6	35.5	16.7	
Chloride	mg/L	28.9	18.0	18.4	0.7	75.6	20.5	0.6	
Magnesium	mg/L	21.8	16.0	20.0	9.5	48.7	19.9	7.6	
Potassium	mg/L	8.1	8.0	10.4	6.7	21.1	10.0	5.3	
Silica	mg/L	33.6	38.6	24.4	0.02	38.6	36.1	0.0	
Sodium	mg/L	13.7	8.6	9.5	2.8	31.9	9.9	2.3	
Sulphate	mg/L	66.1	44.3	53.0	23.9	142.6	52.7	19.4	
Metals	-	1	1		1			1	
Aluminium	ug/L	25	136	196	259	272	166	212	
Arsenic <sup>c</sup>	ug/L	1.4	4.3	4.3	4.3	4.3	4.3	4.3	
Barium	ug/L	41	63	91	59	182	85	45	
Beryllium <sup>c</sup>	ug/L	0.36	1.1	1.9	2.3	2.6	1.6	1.7	
Cadmium <sup>c</sup>	ug/L	0.26	0.7	1.1	1.0	1.6	1.0	0.8	
Chromium	ug/L	1	4	4	4	4	4	4	
Cobalt	ug/L	0.8	1.8	2.5	2.4	4.3	2.3	2.0	
Copper	ug/L	1.5	5.2	8.0	8.7	10.7	7.0	6.8	
Iron	ug/L	3	3	3	3	3	3	3	
Lead <sup>c</sup>	ug/L	2.0	5.7	10.2	11.1	14.5	8.8	8.4	
Manganese	ug/L	14	47	64	83	87	58	67	
Mercury <sup>c</sup>	ug/L	0.11	0.3	0.5	0.6	0.7	0.4	0.4	
Molybdenum	ug/L	44	52	92	122	136	80	92	
Nickel	ug/L	25	37	58	42	108	52	32	
Selenium <sup>c</sup>	ug/L	2.3	11.4	15.5	16.2	18.9	13.3	13.6	
Silver <sup>c</sup>	ua/L	0.1	0.2	0.2	0.3	0.3	0.2	0.2	
Strontium	ug/L	396	416	594	409	1214	563	309	
Thallium	ug/L	0.5	0.4	0.5	0.3	1.0	0.5	0.3	
Uranium <sup>c</sup>	ua/l	34	10	19	21	26	16	16	
Vanadium	ug/L	7.9	25	46	58	64	37	43	
Zinc	ug/L	3	12	16	20	21	14	16	

<sup>a</sup>Estimates of DISSOLVED concentrations at temporary pond discharge from north pile with a pond volume of 25,000 m<sup>3</sup>

values based on average annual values of weekly data as calculated using GoldSim.

<sup>b</sup>pH values estimated based on geochemical speciation modelling

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.

<sup>d</sup>The peak average annual value is the maximum average annual value from years from 1 through 40

The pH in the temporary pond is expected to be near neutral, similar to that observed in the kinetic test work completed as part of the geochemistry baseline work (Appendix III.2 of the EA). Dissolved major ion (Figure IX.1-21) and trace metal (Figure IX.1-23) concentrations show a significant decrease during the spring freshet due to the large amount of water releases from snowmelt. During the summer months, concentrations increase and stabilize as the result of reduced flow rates and enhanced evaporation. Values in the summer months stabilize at values as high as three times the spring freshet concentrations. However, the spring freshet values dominate the average annual loadings since the majority of flow is released during this period. This is particularly obvious when the particulate contribution to the temporary pond is taken into account (Figure IX.1-22). In this figure, which shows the sum of the dissolved and particulate load for a few selected parameters, the spikes during the spring freshet caused by runoff are clearly identifiable, and coincide with the reductions in dissolved concentrations shown in Figure IX.1-21.

A comparison of the total concentrations (*i.e.*, particulate plus dissolved mass) and the dissolved concentrations indicates that the metals Al, Cd, Cr, Cu, Fe, Mn, and Ni are strongly associated with TSS and sediment release. Of these parameters, Fe concentrations are most highly elevated in the solid phase relative to the dissolved phase (several thousand times) with the remaining concentrations ranging from two to 50 times dissolved phase values. These high concentrations will be removed through settling in the temporary pond and treatment prior to discharge to Snap Lake.

The dissolved phase concentrations for the north pile pond discharge show a distinct trend over time (Figure IX.1-21). The TDS and major ion concentrations peak during production years 5 and 10, after which they decrease as the pile undergoes progressive closure and covering with granite. A further decrease occurs at closure when there is no longer a contribution from consolidation of PK paste. As for the seepage quality, the calculated metal concentrations in the temporary pond are predominantly influenced by production factors, surface area of the pile, infiltration and near-surface rock type of the pile, and the same relationships as for seepage are generally observed.

It should be noted that for Al, Hg, Pb, Mo, Ni, Se, and U, the model predictions likely overestimate expected concentrations in the temporary pond as was the case for seepage concentrations. Similarly, model concentrations for As, Cr, Fe, and Si are controlled by solid equilibrium phases or adsorption as based on geochemical speciation modelling.

# Figure IX.1-21Selected Major Ion Dissolved Concentrations and TotalSuspended Solids – North Pile Temporary Pond



Figure IX.1-22 Selected Metal Concentrations (including solid phase mass) – North Pile Temporary Pond



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#### Figure IX.1-23 Selected Metal Concentrations (Dissolved) – North Pile Temporary Pond



#### 6.5.3 Mass Load Distribution – North Pile

Mass load from the north pile is distributed between four components: solids release in runoff (particulate load only); mass due to dissolution of PK and dilution rock (dissolved load only); mass contained in paste PK consolidation water (dissolved load only); and mass added as dust suppression water (dissolved load only).

Major ion mass release is influenced most strongly by release of solid phase mass during the spring freshet and release of dissolved mass from consolidation of paste backfill material. In Figure IX.1-24, the particulate (TSS load) is compared against the dissolved contributions from the various sources for major ions. Both of these mass loads are greatest in the spring. The solid phase mass load is greatest in the spring due to the large volume of water released, whereas the mass load originating from paste consolidation water will be released mainly in the spring due to thawing. The dust suppression water contribution to TDS is significant in the summer, accounting for up to 30% of the loading during the summer months.

With respect to metal release, the large majority of mass release from the north pile for Al, Cd, Cr, Cu, Fe, Mn, and Ni occurs in particulate form during the spring freshet, as is illustrated for Cr in Figure IX.1-25. This mass will be removed through settling in the ponds and through treatment prior to discharge. Figure IX.1-26 shows the dissolved mass load for Cr for comparison to the total concentrations as presented in Figure IX.1-25. As is immediately obvious, the dissolved Cr concentrations are approximately 2.5 orders of magnitude lower than those of the particulate phase are. Evaluation of dissolved Cr loading shows that the principal contribution occurs from dissolution in the north pile. Peak loading for metals released from paste consolidation water occurs during the spring freshet while peak loading for metal release dominated by dissolution is in the mid-summer months (Figure IX.1-26). Major ion release through dissolution reactions in the pile is defined by kinetic reaction rates that are a function of temperature, and as such little mass is released through this mechanism in the winter months. For trace metals, release occurs independent of temperature, although no reaction is accounted for when temperatures are zero degrees or less.

At closure, the solid phase mass load (TSS load) from the north pile is expected to decrease significantly due to covering of the pile (Figure IX.1-24). The load due to consolidation of paste material and dust suppression water will no longer be present and the only contribution to dissolved mass load will be due to reactions and dissolution mechanisms within the pile. As shown in Figure IX.1-24, this load is also expected to be reduced, albeit to a lesser degree than the particulate load. After closure, all mass will be released directly to the North Arm of Snap Lake. More detail on expected mass load from the north pile both during and after closure is provided in Appendix J.

#### 6.5.4 Variability of Key Parameters

Model runs were completed to investigate potential effects of changes in precipitation and pile properties on dissolved loading at the temporary pond as indicated in Table IX.1-29. The resulting changes relative to the expected conditions are summarized in Figures IX.1-27 through IX.1-30.

Model Run	Description	Value	Results
R1	EXPECTED CASE		
R3	NORTH PILE		
R3a	Active layer excludes granite cover	2.0 m of Processed Kimberlite (PK) Paste	Figure IX.1-27, Figure IX.1-28
R3b	Vary rate of reaction	+- Factor of 10	Figure IX.1-29, Figure IX.1-30
R3c	Decrease in runoff	20%	Figure IX.1-27, Figure IX.1-28
R3d	Increase Temporary Pond Size	Increase from 25,000 to 100,000 m <sup>3</sup>	Figure IX.1-31

Table IX.1-29	Variability Runs -	- North Pile
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Note: See unit and acronym list for definition.

Figures IX.1-27 and IX.1-28 show changes in dissolved concentrations in the temporary pond that might result from changing the amount of PK in the active layer (model run R3a) and from a 20% decrease in precipitation on the pile (model run R3c). Increasing the PK proportion could be considered the functional equivalent of having no cover material over the PK given that the coarse granite in the cover would not be expected to contribute significantly to the dissolved load. As is illustrated in these figures, the effect of decreasing the amount of precipitation by 20% results in perhaps a 10% increase in concentrations. In essence, the same amount of mass generated from reactive rock reports to a smaller volume of precipitation. Effectively removing the cover material results in more active layer PK mass and, consequently, in an increase in those parameters that are more readily released from the PK than from granite. The magnitude of this increase will vary on a parameter-by-parameter basis. For TDS, this results in about a 20% increase in concentrations at later time. Since Ni is more strongly associated with kimberlite, the increase in the amount of reactive kimberlite mass results in concentrations that are approximately 35% greater.

Figure IX.1-29 and IX.1-30 show the variability in dissolved concentrations that might be expected under different reaction conditions (model run R3b). As can be observed, a change in reactivity by an order of magnitude can result in significant differences in



### Figure IX.1-24 Total Dissolved Solids and Total Suspended Solids Loading – North Pile

IX.1-76

Figure IX.1-25 Metal Loading for Chromium – North Pile





#### Figure IX.1-26 Dissolved Chromium Load – North Pile

Figure IX.1-27 Total Dissolved Solids Variability as a Function of Precipitation and Pile Cover (model run R3a/c)



### Figure IX.1-28 Nickel Variability as a Function of Precipitation and Pile Cover (model run R3a/c)



### Figure IX.1-29 Total Dissolved Solids Variability as a Function of Reaction Rate (model run R3b)





#### Figure IX.1-30 Ni Variability as a Function of Reaction Rate (model run R3b)

dissolved concentrations, from 5 to 10 times depending on the parameter as illustrated for TDS and Ni. For parameters governed by solubility controls (such as As, Cr, Fe, and Si) the concentrations only increase to the solubility limit as defined, however these limits may vary somewhat depending on the concentrations.

Figure IX.1-31 shows the effect of temporary pond size on discharge concentrations (model run R3d). The larger pond size allows for retention of spring freshet water over a greater period of time in the summer months, which then mixes with the load from the pile, resulting in lower concentrations. As is illustrated by comparing concentrations in Figures IX.1-30 and IX.1-31, an increase from 25,000 m<sup>3</sup> to 100,000 m<sup>3</sup> results in a decrease in peak concentration of up to 50%. The pond size will not, however, affect total load release from the pile, and will have little effect on average annual concentrations in the pond discharge. It should be noted that for concentrations governed by solubility controls, changes in properties of the pile or pond and recharge characteristics will also have little effect on concentrations, although the mass load may vary somewhat as the result of precipitate formation.

### Figure IX.1-31 Concentrations Assuming Larger Temporary Pond Size (model run R3d)



### 6.5.5 Key Results and Discussion

Based on the model results, the following processes, trends and influences are considered most relevant with respect to the north pile discharge.

- Concentrations and loading in the temporary pond for Al, Cd, Cr, Cu, Fe, Mn, and Ni are dominated by the solid phase component of the TSS. These concentrations will be reduced in settling ponds and treatment and will not discharge to Snap Lake.
- With respect to the dissolved phase load, the calculated concentrations are predominantly influenced by production factors, surface area of the pile, infiltration and the nature of the near-surface rock type. The major ion concentrations are mainly associated with dust suppression water and from consolidation of paste PK and, consequently, their concentrations decrease at closure when these two sources are no longer present.
- Sensitivity analyses on the size of the north pile temporary pond indicate that the pond size affects peak concentrations. Lower peaks are associated with larger storage pond volumes since more of the spring freshet is retained and available for mixing

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with the summer mass load. However, the average annual concentrations and loading are similar in both instances.

- Sensitivity analyses conducted relative to cap thickness show that the kimberlite signature in the mass loading from the north pile increases as the cap thickness decreases.
- Based on the geochemical modelling, the concentrations of As, Cr, Fe, and, Si are controlled by solubility limitations or adsorption on to iron hydroxide minerals.

Relative to other areas of the mine site, the north pile mass load is the most difficult to predict since it is not possible to use site monitoring results. For this reason, it is necessary to evaluate potential conditions based on design criteria and laboratory data. Several key factors that might affect the estimates of north pile water quality are as follows:

- Pile Distribution and Properties the pile distribution, thickness of active layer, cover material, retention pond volumes and runoff volumes all affect the estimates of north pile water quality. The pile design and characteristics were based on the best available data at the time of model construction (Draft North Pile Optimization Study, Golder 2001a). The pile as modelled is thought to be a reasonable representation of expected conditions within the pile. As the design of the pile is refined and/or monitoring data become available, the estimates of water quality should be adjusted accordingly.
- Representativeness of kinetic test data Significant efforts were made to ensure that the samples selected for testing and analysis were a fair representation of the three rock types that might be associated with the pile. Initially, a large number of samples spatially distributed from the different rock types were selected and analyzed to determine their typical properties (chemistry, short-term leaching characteristics, acid base accounting). These data were then used to direct kinetic test work and to ensure that the samples selected were representative of a given unit as discussed in the Geochemistry Baseline Report (Appendix III.2 of the EA).
- Temperature and particle size distributions Reactions rates can vary significantly based on temperature and particle size distribution of the pile. The temperature effects have been incorporated based on the work completed at Diavik (1998) which is considered to be an acceptable analogue for the Snap Lake site. Since the particle size of the north pile material will be fine, a correction factor for the fine-grained particle distribution used in laboratory testing has not been incorporated into the calculations.

• Attenuation – Attenuation is accounted for in the model in the temporary pond, where mixing of runoff and seepage takes place. However, these reactions are more likely to take place along the flow paths within or underneath the pile, in which case the mass would never reach the pond. Therefore, application of these solubility constraints is thought to be conservative.

### 7.0 SITE AND NON-POINT SOURCE DISCHARGES

#### 7.1 Overview

Site components impacting water quality include flow and chemical loading from site runoff (developed and undeveloped land), process material discharges, potable water intake and sewage discharge. Water used for processing ( $60 \text{ m}^3/\text{hr}$ ) will originate from the WMP, occasionally augmented by some make-up water from Snap Lake. Water will be recovered in the paste plant and recycled with, only a small proportion being incorporated in the paste. There will be no direct water discharge from processing to the WMP or lake. Of the water in the paste, only a small fraction reports as consolidation water to the mine water or to north pile discharge.

The majority of the site runoff (estimated at 80%) reports to the WMP, while the remainder will report directly to Snap Lake as non-point source discharges. Potable water is taken from the North Arm of Snap Lake at the intake. Potable water use is estimated to be  $200 \text{ m}^3/\text{d}$ , which will ultimately report as treated sewage to the discharge line downstream of the water treatment plant. The treated sewage release is not included in the GoldSim model; however, it is included in the impact assessment completed for the EA (Section 9 of the EA).

Non-point sources reporting to Snap Lake include:

- north pile seepage through fractured granite bedrock (Section 6 of this document);
- site runoff;
- runoff from the airstrip;
- runoff from the explosive storage area; and,
- seepage from the WMP.

#### 7.2 Flow Summary

Flow and chemical loading from most of the site sources will report to Snap Lake in areas not tracked as independent components by the GoldSim model. However, flow and mass loading for seepage from the north pile are evaluated separately in GoldSim as discussed in Section 6 of this document. All non-point source flows and loadings are assigned entry points into the lake as discussed in Section 9 of the EA.

An average flow of 57,000 m<sup>3</sup>/yr from the site is expected as seepage and runoff (Appendix D). This water reports either to the WMP (80%) or as a non-point source discharge to Snap Lake (20%). Runoff from the airstrip and the explosives plant area is estimated at 4,950 m<sup>3</sup>/yr distributed over the summer months (Appendix D). Seepage

from the WMP is estimated at 12,000  $m^3/d$  applied over the summer months in the proportions identified in Table IX.1-21.

#### 7.3 Mass Load

Mass load applied to developed site runoff locations, including the airstrip and explosives plant, is based on observed water quality results from AEP monitoring data (Table IX.1-30). These results are based on 5 monitoring events in 1999 and 2000 at the BSMRP (Appendix E). This monitoring location receives runoff from the waste rock pad created through bulk sample activities. Based on visual estimates, the waste rock pad is composed of about 90% metavolcanic material and 10% granite material with trace amounts of kimberlite located near the bulk sample pits.

The laboratory test work confirms that the sulphide concentrations observed in the rock of the BSMRP are not expected to result in acid generating conditions. Since these rocks appear to be chemically stable with respect to acid generation and no long-term changes in environmental behaviour are anticipated, it is reasonable to conclude that the results from the monitoring data are representative of potential site runoff water quality. The monitoring data are collected under ambient field conditions, and are therefore considered more reliable than laboratory results.

The loading estimates based on the runoff data are considered conservative from an environmental perspective since the proportion of metavolcanic rock at the BSMRP sampling location is higher than is expected for other developed site areas. The laboratory testing has demonstrated that leachates from metavolcanic rock samples generally have higher concentrations of dissolved metals than leachates from granitic samples. Granite free of sulphide minerals, which is less reactive than metavolcanic rock, will be used for construction purposes throughout the site.

Mass load applied to runoff from undeveloped portions of the site is based on water quality results obtained during the baseline study. This water quality is discussed in the EA and is provided in Table IX.1-30.

There may be some loading from the explosives plant associated with washing of explosives. However, wash water from the explosives plant is expected to be collected and discharged via the treatment plant. As the approach used to determine the mass loading from explosives accounts for all explosives brought to the site, the loading from the explosives plant is implicitly accounted for.

#### Table IX.1-30Site Runoff Concentrations

Parameter	Unit	Site Runoff from Developed Areas
		based on average data from monitoring
		point BSMRP
		$(n = 3)^{2}$
рН	pH units	6.7
-		
Ag	ug/l	0.05
Al	ug/l	49.8
As	ug/l	0.10
Ba	ug/l	53.0
Ca	mg/l	37.0
Cd	ug/l	0.10
	mg/l	49.1
	ug/l	8.13
Cr	ug/l	0.62
Cu	ug/l	7.67
Fe	ug/l	0.09
Hg	ug/l	0.005
K	mg/l	3.16
Mg	mg/l	27.0
Mn	ug/l	314
Mo	ug/l	3.00
Na	mg/l	4.55
NH <sub>4</sub>	mg/l	0.63
Ni	ug/l	14.4
NO₃	mg/l	5.63
Pb	ug/l	0.43
Se	ug/l	1.33
Silica	mg/l	4.53
SO <sub>4</sub>	mg/l	72.8
Sr	ug/l	129
TI	ug/l	0.05
U	ug/l	0.17
Zn	ug/l	21.8
Alkalnity - CaCQ	mg/l	20.7
Total_P	mg/l	0.02
PO <sub>4</sub>	mg/l	0.0027
TKN	mg/l	0.81
Be	ug/l	0.10
V	ug/l	0.43

Notes:

Developed Site runoff based on average dissolved concentration of data from BSMRP (Appendix E). <sup>a</sup> for the majority of parameters n = 3, for silica n = 1, for NO  $_3$  n =2 for other variations see Appendix E. See unit and acronym list for definitions

The water quality of the seepage below the WMP dam will be predominantly influenced by the dissolved-phase water quality in the WMP. This water quality is calculated based on relative contributions from the mine (Section 5 of this document), north pile (Section 6 of this document) and site (Section 7.4.1 of this document) reporting to the WMP.

#### 7.4 Results

#### 7.4.1 Site Runoff and Non-point Source Discharge

Concentrations and mass loading applied to the site runoff and NPS discharge are provided in Tables IX.1-30 and IX.1-31 and in Appendix K. Given that the site footprint is not expected to change over the course of operations once facilities are in place, the mass loading as calculated does not change over time.

Relative to the loadings to Snap Lake from the mine and north pile, the NPS loading are not significant as is illustrated and discussed in Section 9 of this document.

#### 7.4.2 Water Management Pond Seepage Water Quality

Seepage from the WMP migrates below Dam 1 and reports to Snap Lake just south of the northwest peninsula. The seepage volume is estimated to be about 12,000 m<sup>3</sup>/yr and is released during periods where the ground is thawed as indicated in Table IX.1-21. 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 in GoldSim based on relative contributions from the mine, north pile, and site reporting to the WMP.

The pH of the seepage below Dam 1 is expected to be near neutral based on the pH expected from the mine water and measured in 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 as Table IX.1-32. Figures IX.1-32 and IX.1-33 are presented to illustrate general trends over time for selected major ion and metal concentrations of WMP seepage. Additional results are provided in Appendix L.

8.52E-07

8.49E-04

1.70E-06

9.03E-04

6.31E-01

1.70E-06

8.37E-01

1.39E-04

1.05E-05

1.31E-04 1.53E-06

8.52E-08

5.38E-02

4.61E-01

5.36E-03

5.11E-05

7.76E-02

1.08E-02

2.45E-04

9.59E-02

7.38E-06

2.27E-05

7.72E-02

Ag AI

As

Ba

Са

Cd

CI

Co

Cr

Cu

Fe

Hg

Mg

Mn

Mo

Na

 $NH_4$ 

 $NO_3$ 

Pb

Se

Sr

ΤI

υ

Zn

Be

Silica

Ni

kg/d

kq/d

kg/d

kg/d

kg/d

kg/d

kg/d

kg/d

kg/d

kg/d

2.12E-07

2.11E-04

4.25E-07

2.25E-04

1.57E-01

4.25E-07

2.09E-01

3.45E-05

2.62E-06

3.26E-05

3.81E-07

2.12E-08

1.34E-02

1.15E-01

1.33E-03

1.27E-05

1.93E-02

2.69E-03

6.12E-05

2.39E-02

1.84E-06

5.66E-06

1.92E-02

	Location	Site to WMP	NPS Discharge to North Arm	NPS Discharge to Main Basin
	Average Annual Flow (m <sup>3</sup> /yr) <sup>a</sup>	31080	1550	6220
Parameter	Unit		Average Annual Loading kg/d <sup>1</sup>	)

4.26E-06

4.24E-03

8.52E-06

4.51E-03

3.15E+00

8.52E-06

4.18E+00

6.93E-04

5.25E-05

6.53E-04

7.64E-06

4.26E-07

2.69E-01

2.30E+00

2.68E-02

2.55E-04

3.88E-01

5.38E-02

1.23E-03

4.79E-01

3.69E-05

1.14E-04

3.86E-01

#### Table IX.1-31 Average Annual Loading from Site Runoff

kg/d SO<sub>4</sub> kg/d 6.20E+00 3.09E-01 1.24E+00 5.50E-04 1.10E-02 2.21E-03 kg/d 4.26E-06 2.12E-07 8.52E-07 kg/d kg/d 1.42E-05 7.08E-07 2.84E-06 1.86E-03 9.27E-05 3.72E-04 kg/d Alkalnity - CaCO3 kg/d 1.76E+00 8.78E-02 3.52E-01 Total\_P 2.07E-03 1.03E-04 4.15E-04 kg/d  $PO_4$ 2.27E-04 1.13E-05 4.54E-05 kg/d TKN 6.85E-02 3.42E-03 1.37E-02 kg/d kg/d 8.52E-06 4.25E-07 1.70E-06 kg/d 3.69E-05 1.84E-06 7.38E-06

<sup>a</sup> average annual flow rates based on Golder 2001a water balance.

<sup>b</sup> calculated values based on site runoff concentrations as provided in Table 7.1 and average annual flows.

Notes: See unit and acronym list for definitions.

Initial concentrations in the WMP seepage are primarily influenced by the discharge of mine water in the pond during the AEP and reflect the baseline groundwater and mine water discharges with relatively high concentrations of major ions and nutrients. As currently modelled, the site runoff becomes the major influence on the WMP water quality after year 5 (2005). As a consequence, the concentrations of TDS and major ions decrease over time whereas the concentrations of some metals (e.g., Fe, Cu, Mn, Zn) increase to a steady level reflective of the observed site runoff.

## Table IX.1-32Summary of Estimated Concentrations for the Water<br/>Management Pond Seepage Water

		WMP Seepage <sup>a</sup>						Groundwater
Parameter			Baseline Granite <sup>e</sup>					
	Units	Year 5	Year 15	Year 25	Year 35	Peak Average Annual <sup>d</sup>	Average Post Closure (model year 34 - 39)	Median
Conventional Parameters	1	-	-		1	<b>-</b>		
рН <sup>р</sup>	pН	6.5 - 9.3	6.5 - 7.1	6.5 - 7.1	6.5 - 7.1	6.5 - 9.3	6.5 - 7.1	9.2
Alkalinity	mg/L	53.1	1.4	1.2	1.1	174	1.2	80.0
Total Dissolved Solids	mg/L	257	147	147	193	647	193	920
Nutrients				-		-		
Ammonia	mg/L	1.7	0.9	0.9	0.9	7.1	0.9	4.1
Nitrate + Nitrite	mg/L	-	-	-	-	-	-	2.4
Nitrate-N	mg/L	4.5	4	4	4.1	8	4.1	-
Total Phosphorus	mg/L	0.16	0.003	0.002	0.002	1.1	0.002	0.1
Dissolved Phosphorus	mg/L	0.004	0.003	0.003	0.003	0.007	0.003	0.035
l otal Kjeldahl Nitrogen	mg/L	1.0	0.42	0.42	0.42	4.6	0.42	3.2
		55.0	05.0	05.4	05.4	040	05.4	110
Calcium	mg/L	55.0 88.7	25.0 /8.7	25.4 /8.4	25.4	213	25.4 18.4	248
Magnesium	mg/L	18.1	17.7	17.7	17.7	18.9	17.7	7.8
Potassium	ma/l	3.0	18	1.8	1.8	9.0	1.8	9.3
Silica	mg/L	1.6	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	76.7
Sulphate	ma/L	43.7	44.4	44.3	44.3	44.4	44.3	10.0
Dissolved Metals	1 2							
Aluminium	ug/L	48.8	42.2	42.1	42.1	61.8	42.1	7.2
Arsenic <sup>c</sup>	ug/L	0.03	0.03	0.03	0.03	0.03	0.03	1.1
Barium	ug/L	59.8	32.4	32.2	32.2	195	32.2	55.4
Beryllium <sup>c</sup>	ug/L	0.05	0.05	0.05	0.05	0.07	0.05	<0.2
Cadmium <sup>c</sup>	ug/L	0.08	0.09	0.09	0.09	0.09	0.09	<0.05
Chromium	ug/L	1.1	0.7	0.7	0.7	2.5	0.7	0.1
Cobalt	ug/L	4.2	4.7	4.7	4.7	4.8	4.7	0.2
Copper	ug/L	2.9	2.9	2.9	2.9	2.9	2.9	2.8
Iron	ug/L	2.9	2.9	2.9	2.9	2.9	2.9	21.0
Lead <sup>c</sup>	ug/L	0.09	0.09	0.09	0.09	0.09	0.09	0.2
Manganese	ug/L	189	211	211	211	211	211	7.1
Mercury <sup>c</sup>	ug/L	0.013	0.003	0.003	0.003	0.04	0.003	0.1
Molybdenum	ug/L	2.4	1.7	1.6	1.6	4.5	1.6	5.6
Nickel	ug/L	7.8	7.5	7.5	7.5	8.3	7.5	0.8
Selenium <sup>c</sup>	ug/L	2.2	1.9	1.9	1.9	2.6	1.9	<0.4
Silver <sup>c</sup>	ug/L	0.04	0.03	0.03	0.03	0.05	0.03	<0.1
Strontium	ug/L	336	89.5	88.2	88.1	1306	88.2	1760
Thallium	ug/L	0.04	0.03	0.03	0.03	0.06	0.03	<0.03
Uranium <sup>c</sup>	ug/L	0.1	0.1	0.1	0.1	0.2	0.1	0.1
Vanadium	ug/L	0.3	0.2	0.2	0.2	1.1	0.2	1.8
Zinc	ug/L	15.8	16.8	16.8	16.8	16.8	16.8	3.4

<sup>a</sup>Estimates at seepage discharge from WMP to Snap Lake,

values based on average annual values of weekly data as calculated using GoldSim.

<sup>b</sup>pH values estimated based on geochemical speciation modelling except for year 5 which is based AEP monitoring data

<sup>c</sup>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.

<sup>d</sup>The peak average annual value is the maximum average annual value from years from 1 through 40.

<sup>e</sup>Baseline Granite values based on median groundwater inflow water from the granitic unit as described in Appendix IX.2 of the EA "<" denotes values below the detection limit.



#### Figure IX.1-32 Major Ion Concentration – Water Management Pond Seepage





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During operation, there will likely be times where the WMP is 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 discharge. Regardless of the ultimate water quality in the WMP, the current overall water quality estimates for treatment discharge take into account the entire dissolved component of the predicted load from the north pile, mine, and site runoff. As presently envisioned, treatment only consists of removal of suspended sediments. 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.

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.

In comparison with the median baseline water quality (connate water) from the granitic unit, the TDS values from the WMP seepage are expected to be lower by two to five times. For the major ions, chloride values estimated for WMP seepage are about one fifth of those observed in the connate water. The estimates for the other major ion concentrations in WMP seepage are typically one fifth to one tenth those observed in the connate water, with the exception of magnesium and sulphate, which are two to five times that of the connate water.

With respect to metal concentrations, values for Fe, Sr, and V are lower in the expected WMP seepage than in the median baseline granite groundwater. Other metal concentrations in the estimated WMP seepage results typically range from about 1 to 10 times those of the median baseline granite water. Concentrations of Mn, Cr, and Co are greater than 10 times baseline granite 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.

#### 8.0 TREATMENT AND WATER MANAGEMENT POND

#### 8.1 Overview

Flows and chemical loading from the mine, the site, and the north pile will report either to the WMP or to the treatment plant. The WMP will collect runoff from the site and will provide backup and upset storage capacity during operations. The volume of the WMP will be increased during the mine life (Golder 2001a) to provide the required storage capacity. Direct discharge from the WMP to Snap Lake is not expected during operations. The capacity of the treatment plant will be tailored to meet discharge volumes and limits, with an initial capacity of 10,000 m<sup>3</sup>/d (see EA). At closure, the WMP will be decommissioned and water from the site will drain through the former WMP. For the water quality estimates, an average discharge value of 25 mg/L TSS was applied to this water at closure.

The quality of water treatment plant discharge during operations is dependent on the level of treatment both necessary and attainable. A discussion of treatment alternatives and the selected treatment method is provided in the EA. For the purposes of estimating water quality, it was assumed that treatment would consist of removal of TSS to a level of 5 mg/L, and that there would be no change in dissolved concentrations. Treated water will be discharged to Snap Lake via a diffuser located offshore (underwater). A small component of the treated water will be directed to the north pile for dust suppression, and to the process plant for use in processing. The treated camp sewage will be piped into the discharge line after the mine water treatment circuit and is not included in the results or discussion. The sewage discharge concentrations and impact assessment are presented in the Section 9 of the EA.

#### 8.2 Flow and Mass Load Components

Total flow reporting to, and discharging from, the treatment plant will be the summation of flow from the mine, north pile, and WMP (Figure IX.1-34). All mass load components are accounted for in the mine, north pile, and site as discussed in Sections 5, 6, and 7 of this document, respectively. The mass reporting to treatment is based on the summation of the mass load from these three sources as discussed in Section 8.3 below.

Geochemical solubility constraints for treatment plant feed are incorporated in GoldSim based on solubility considerations for CaSO<sub>4</sub><sup>-</sup>2H<sub>2</sub>O, CaCO<sub>3</sub>, and CaMg(CO<sub>3</sub>)<sub>2</sub>. The geochemical speciation model PHREEQC was used to determine upper concentrations for the pertinent constituents based on the peak average annual dissolved concentrations that might report to treatment as indicated in Table IX.1-33. As per the modelling results,



IX.1-92

Figure IX.1-34 Flow Reporting to Treatment

the limits for alkalinity, Ca, Mg, and,  $SO_4$  were set at 500 mg/L, 600 mg/L, 500 mg/L and 1,600 mg/L, respectively. Mine water concentrations of these parameters are typically lower than these values, however during periods of grouting there is some potential to increase calcium concentrations to levels above its solubility limit.

#### 8.3 Results – Treatment

For the purposes of estimating discharge water quality it is assumed that treatment will occur during the operational phase of the project and while preparations for closure are underway (*i.e.*, to the end of year 2026). At closure, site waters will report directly to Snap Lake.

			TION	
	Initial	Fauilibrium	n values	GoldSim
	initia	1	2	Solubility Limit
Parameter				
(Dissolved)		ooncentaat	ions (ing/i)	
pН	8.7	8.0	7.9	
ре	1.7	2.4	3.0	
Alk	83.5	44.4	34.6	500
Ag	0.00005	0.00005	0.00005	
AI	0.015	0.015	0.015	
As	0.00197	0.00197	0.00197	
Ba	0.12	0.12	0.12	
Ca	123	115	340	600
Cd	0.00037	0.00037	0.00037	
CI	264	264	264	
Cr	0.0012	0.0008	0.0008	
Cu	0.0013	0.0013	0.0013	
Fe	0.015	0.001	0.001	
Hg	0.00007	0.00007	0.00007	
К	26.1	26.1	26.1	
Mg	107	102	267	500
Mn	0.0295	0.0295	0.0295	
Na	70.8	70.8	70.8	
Ni	0.0758	0.0758	0.0757	
Pb	0.00043	0.00043	0.00043	
Se	0.0008	0.0008	0.0008	
Si	334	18.1	18.0	
SO4	375	375	1572	1600
Sr	2.25	2.25	2.25	
TI	0.00351	0.00351	0.00351	
U	0.00143	0.00143	0.00143	
Zn	0.005	0.005	0.005	
Input concentratio	ns based on peak ave	erage annual		
	from GoldSim model	I with infinite solub	oility limits	
Equilibrium conce	ntrations based on ge	ochemical speciat	ion modelling	
	using PHREEQC wit	th a MINTEQ data	base	
Solubility limits ap	proximated based on	simulation values	or	
	movimum concentrat	iona observed in t	ha mina diaah	2500

Note: See unit and acronym list for definitions.

The bulk of the flow to the treatment plant results from mine water discharge as can be observed in Figure IX.1-34. Significant flows from the north pile will report during the spring freshet, however, this water will likely be retained in temporary ponds around the north pile and will be treated as capacity is available during the summer months. This temporary storage is not currently accounted for in the GoldSim model, but rather the water is assumed to be treated and released as it reports from the various locations. The temporary storage of the spring freshet waters would result in smoothing of the peak flows currently observed in the weekly data, and would result in concentrations closer to the tabulated average annual values (Table IX.1-34). Additional results for the treatment feed-water and the treated discharge are provided in Appendix M and N respectively.

#### 8.3.1 Concentrations – Treatment

Figure IX.1-35 presents the concentrations of TSS, and of TDS reporting to treatment. Figures IX.1-36 through IX.1-38 show concentrations for major ions, nutrients, and trace metals in treatment discharge.

As can be observed in Figure IX.1-35, the TSS concentrations in treatment plant feed can be significant, with values up to approximately 2,000 mg/L. Most of this TSS originates in the mine as this is the main source of flow and particulate load. As mining proceeds, the TSS contributions from the mine decrease due to increased flow proportions from inactive working areas as discussed in Section 5 of this document.

The pH of the treatment feed is expected to be neutral to moderately alkaline depending on the amount of grout being used in the mine at any given time. The pH of the treatment discharge will be maintained at a level near that of the lake through addition of small amounts of  $H_2SO_4$ , if necessary. This will ensure that there will be no net change in the pH conditions of the lake. Potential influences on lake pH due to treatment discharge are addressed separately (Appendix G). Based on the assessment presented in Appendix G, the addition of acid to control pH has the potential to slightly increase sulphate concentrations in the discharge (by up to about 40 mg/L).

Total concentrations in the treatment feed and treated discharge are summarized in Table IX.1-34, Table IX.1-35 and in Appendix M, and N. A comparison of Table IX.1-34 and IX.1-35 shows that the concentrations in the treated discharge are significantly lower for many trace metals, in particular for those metals preferentially associated with the particulate fraction. These parameters include Al, Cr, Cu, Fe, Mn, Ni, and Zn, all of which show several orders of magnitude reduction in treated concentrations relative to the treatment feed.

Figures IX.1-36 through IX.1-38 are provided to illustrate concentration trends over time for treated discharge. There are essentially two trends that can be observed in the discharge concentrations. Most parameters are elevated in early time after which they decrease. This is due to high proportions of connate water in the mine at early stages and addition of mass as a function of interaction with active mine workings, which is also proportionally higher at early time (Section 5 of this document). For parameters with similar concentrations in connate water and that do not gain mass from the active mine workings (*e.g.*, Al, Cr, Hg, Ag, Tl, and Zn), the concentrations are essentially stable over time. Runoff from the site and north pile contributes to the seasonal concentration spikes; however, they have a limited effect on overall concentration trends in the treatment plant discharge.

### 8.3.2 Mass Load Distribution – Treatment

Figures IX.1-39 through IX.1-41 show TDS, Ni, and Cr loading in the treatment feed water, treated discharge and the relative contributions from three treatment plant inputs (mine water, north pile, and WMP). In these graphs the total discharge from treatment includes solid phase mass, whereas the remaining components are for the dissolved-phase

#### Table IX.1-34 Summary Treatment Feed Concentrations

		Treatment Feed (Solids + Dissolved)							
Parameter		Average Annual				Sum	mary		
	Units	Year 5	Year 15	Year 25	Year 35	Peak Average Annual <sup>d</sup>	average post closure		
Conventional Parameters									
рН <sup>ь</sup>	pН	6.5 - 7.1	6.5 - 7.1	6.5 - 7.1	-	6.5 - 7.1	-		
Alkalinity	mg/L	235	174	158	-	344	-		
Total Dissolved Solids	mg/L	1267	835	746	-	1397	-		
Total Suspended Solids	mg/L	2019	1217	1299	-	2059	-		
Nutrients		•							
Ammonia	mg/L	9.2	5.1	2.7	-	12.9	-		
Nitrate-N	mg/L	9.8	5.6	3.3	-	13.3	-		
Total Phosphorus	mg/L	2.29	1.96	2.09	-	2.68	-		
Dissolved Phosphorus	mg/L	0.010	0.008	0.007	-	0.011	-		
Total Kjeldahl Nitrogen	mg/L	8.2	6.2	5.7	-	8.6	-		
Major Ions									
Calcium	mg/L	306	205	184	-	340	-		
Chloride	mg/L	321	218	165	-	374	-		
Magnesium	mg/L	277	170	179	-	282	-		
Potassium	mg/L	28.3	19.5	19.1	-	29.3	-		
Silica	mg/L	0.6	0.9	0.9	-	1.1	-		
Sodium	mg/L	57.1	35.2	21.7	-	69.6	-		
Sulphate	mg/L	23.2	15.6	12.1	-	39.9	-		
Metals									
Aluminium	ug/L	35044	21128	22521	-	35750	-		
Arsenic <sup>c</sup>	ug/L	16.8	10.4	10.8	-	16.9	-		
Barium	ug/L	2915	1837	1944	-	3013	-		
Beryllium <sup>c</sup>	ug/L	0.09	0.11	0.16	-	0.16	-		
Cadmium <sup>c</sup>	ug/L	5.1	3.1	3.3	-	5.3	-		
Chromium	ug/L	1185	714	758	-	1208	-		
Cobalt	ug/L	79.9	48.1	51.1	-	81.5	-		
Copper	ug/L	211	127	133	-	214	-		
Iron	ug/L	102955	61934	65774	-	104928	-		
Lead <sup>c</sup>	ug/L	33.1	20.3	22.0	-	33.8	-		
Manganese	ug/L	3101	1865	1977	-	3154	-		
Mercury <sup>c</sup>	uq/L	1.0	0.7	0.7	-	1.1	-		
Molybdenum	ug/L	39.1	26.2	29.8	-	40.2	-		
Nickel	ug/L	1906	1148	1221	-	1945	-		
Selenium <sup>c</sup>	ua/L	0.5	0.6	0.9	-	2.0	-		
Silver <sup>c</sup>	ug/L	1.9	1.2	1.3	-	2.0	-		
Strontium	ua/L	2540	1677	1351	-	2834	-		
Thallium	ua/L	4.6	2.8	3.0	-	4.8	-		
Uranium <sup>c</sup>	ua/L	8.5	5.6	6.5	-	8.9	-		
Vanadium		17	2.0	31	-	31	-		
Zinc	ug/L	318	196	209	-	326	-		

<sup>a</sup>Estimates of treatment feed concentrations, including both dissolved and solid phase contributions

values based on average annual values of weekly data as calculated using GoldSim.

<sup>b</sup>pH values estimated based on geochemical speciation modelling, and is dependant on grout use in mine

<sup>c</sup>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.

<sup>d</sup>The peak average annual value is the maximum average annual value from years from 1 through 40

"-" indicates no value is available (treatment at closure is not currently included in the model calculations)

#### Table IX.1-35 Summary of Treated Discharge Concentrations

IX.1-96

		I		Treated Disc	harge to Sna	ap Lake <sup>e</sup>	
Parameter			Average	Sum	mary		
	Units	Year 5	Year 15	Year 25	Year 35	Peak Average Annual <sup>d</sup>	average post closure
<b>Conventional Parameters</b>	-	-					
рН <sup>ь</sup>	pН	6.5 - 7.1	6.5 - 7.1	6.5 - 7.1	-	6.5 - 7.1	-
Alkalinity	mg/L	235	174	158	-	344	-
Total Dissolved Solids	mg/L	786	546	439	-	929	-
Total Suspended Solids	mg/L	5.0	5.0	5.0	-	5.0	-
Nutrients							
Ammonia	mg/L	9.2	5.1	2.7	-	12.9	-
Nitrate-N	mg/L	9.8	5.6	3.3	-	13.3	-
Total Phosphorus	mg/L	2.29	1.96	2.09	-	2.68	-
Dissolved Phosphorus	mg/L	0.010	0.008	0.007	-	0.011	-
Total Kjeldahl Nitrogen	mg/L	8.2	6.2	5.7	-	8.6	-
Major Ions	-	-	1	1	1		
Calcium	mg/L	200	141	117	-	235	-
Chloride	mg/L	321	218	165	-	374	-
Magnesium	mg/L	18.6	14.4	13.6	-	20.7	-
Potassium	mg/L	14.9	11.4	10.5	-	16.0	-
Silica	mg/L	0.6	0.9	0.9	-	1./	-
Sodium	mg/L	56.1	34.6	21.1	-	68.6	-
Sulphate	mg/L	23.2	15.6	12.1	-	43.4	-
Aluminium		142	120	149		252	-
Argania <sup>c</sup>	ug/L	142	139	140	-	200	-
Arsenic	ug/L	1.7	1.3	1.1	-	1.9	-
Danum Bandium <sup>c</sup>	ug/L	309	309	320	-	410	-
Beryillum	ug/L	0.09	0.11	0.16	-	0.16	-
Cadmium	ug/L	0.05	0.07	0.10	-	0.10	-
Chromium	ug/L	7.4	7.5	7.4	-	7.5	-
Cobalt	ug/L	0.58	0.54	0.62	-	4.8	-
Copper	ug/L	3.9	3.0	2.5	-	4.5	-
Iron	ug/L	541	436	368	-	600	-
Lead	ug/L	0.6	0.7	0.9	-	0.9	-
Manganese	ug/L	38.6	27.9	24.5	-	212	-
Mercury	ug/L	0.08	0.07	0.06	-	0.09	-
Molybdenum	ug/L	8.1	7.6	10.0	-	10.0	-
Nickel	ug/L	13.2	13.0	14.9	-	15.1	-
Selenium	ug/L	0.48	0.55	0.87	-	2.0	-
Silver	ug/L	0.06	0.06	0.06	-	0.06	-
Strontium	ug/L	2048	1382	1036	-	2346	-
Thallium	ug/L	0.12	0.11	0.13	-	0.13	-
Uranium <sup>c</sup>	ug/L	0.3	0.6	1.2	-	1.2	-
Vanadium	ug/L	1.7	2.0	3.1	-	3.1	-
Zinc	ug/L	14.7	13.4	14.8	-	17.9	-

<sup>a</sup>Estimates at treated discharge to Snap Lake, does not include treated sewage

values based on average annual values of weekly data as calculated using GoldSim.

<sup>b</sup>pH values estimated based on geochemical speciation modelling

<sup>c</sup>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.

<sup>d</sup>The peak average annual value is the maximum average annual value from years from 1 through 40

"-" indicates no value is available (treatment at closure is not currently included in the model calculations)

### Figure IX.1-35 Total Dissolved Solids and Total Suspended Solids Treatment Feed Concentrations

![](_page_103_Figure_3.jpeg)

### Figure IX.1-36 Total Dissolved Solids and Major Ion Concentrations – Treated Discharge

![](_page_103_Figure_5.jpeg)

![](_page_104_Figure_3.jpeg)

Figure IX.1-37 Nutrient Concentrations – Treated Discharge

Figure IX.1-38a Selected Metal Concentrations – Treated Discharge

![](_page_104_Figure_6.jpeg)

![](_page_105_Figure_2.jpeg)

#### Figure IX.1-38b Selected Metal Concentrations – Treated Discharge

![](_page_105_Figure_4.jpeg)

![](_page_105_Figure_5.jpeg)

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![](_page_106_Figure_2.jpeg)

#### Figure IX.1-40 Nickel Mass Load to Treatment

![](_page_106_Figure_4.jpeg)

![](_page_106_Figure_5.jpeg)

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mass from the various sources. As can be observed in Figure IX.1-39, treatment only reduces concentrations attributable to the particulate load; the dissolved load remains unchanged. It can also be seen that the dissolved load from the mine water dominates the overall dissolved loading from the Snap Lake Diamond Project. The dissolved loads from the north pile and WMP load are small relative to that of the mine, and primarily result in seasonal spikes in the loading trends.

Figures IX.1-40 and IX.1-41, which show loading for Ni and Cr, are presented to illustrate typical trends for trace metals. In these figures, the "Treatment Feed" values are presented for dissolved mass only, whereas the "Treated Discharge" values include both dissolved and solid-phase mass, thus the difference between these two curves represents the solid-phase mass load discharged to Snap Lake. It is observed in these figures that the Ni load is more strongly associated with the north pile temporary pond discharge, as can be observed in the seasonal, (spiky) loading trend. Such is the case for parameters with very low concentrations in the mine water and elevated concentrations in the north pile discharge. The Cr load (Figure IX.1-41), however, is similar to that of the TDS in that it is governed by the mine water. The Cr trend is indicative of the majority of trace metal loading trends.

#### 8.3.3 Summary of Key Results and Discussion

Based on the model results, the following processes, trends and influences are considered most relevant with respect to treatment feed and treated discharge:

- Concentrations of several trace metals in the treatment feed are strongly influenced by sediment loadings that originate in the mine and are seasonally influenced by TSS from the north pile.
- Treatment consisting of removal of TSS to a level of 5 mg/L results in a marked reduction in mass load discharged to Snap Lake.
- Typical major ion trends show concentrations and loadings consistent will those of the mine water.
- Parameters with very low concentrations in the mine water and elevated concentrations in the north pile discharge show the more pronounced seasonal variability in concentration and load typical of the north pile discharge trends.
- The results presented are based on the selection of a treatment option designed to remove TSS to a level of 5 mg/L. Additional discussion on the rationale for selection of this option and other possible treatment alternatives is provided in the EA.
# 9.0 RELATIVE CONTRIBUTION OF SITE DISCHARGE COMPONENTS

GoldSim modelling results from the various Snap Lake components (mine, north pile, site, and treatment) are provided and discussed individually in Sections 5 through 8 of this document, respectively. To assess the relative contributions of these components to the overall discharge and loading to Snap Lake, this section presents a comparison of model results from a number of discharge locations including:

- treatment plant discharge (Q19,C16);
- WMP contribution (post treatment);
- north pile seepage to Snap Lake (Q9,C11);
- north pile runoff to Snap Lake (post closure); and,
- non-point source discharge from the site, airstrip, and explosive storage to Snap Lake (split between North Arm and Main Basin of Snap Lake) (Q14 + Q16 + Q17, C14).

The mine water, north pile discharge, and WMP contribution all report to the treatment plant during operations, and their potential impact on Snap Lake is largely controlled by treatment plant operation. However, the contributions of these sources are provided to help illustrate the relative importance of these components in the overall discharge during operations and post closure.

# 9.1 Flow Distribution

Figure IX.1-42 shows the recharge and discharge associated with Snap Lake as affected by the mining operation. The only change in flow out of Snap Lake results from a minor amount of additional flow reporting to Snap Lake via the mine water due to aquifer storage.

Figures IX.1-43 and IX.1-45 show site discharges during operations and closure respectively with the flow plotted on a logarithmic scale. The flow from the treatment discharge is largely governed by the expected pumping rate from the mine with seasonal spikes resulting from spring freshet runoff from the north pile and site as discussed in Section 8 of this document. As is immediately evident in Figure IX.1-43, relative to the treatment discharge during operations (typically greater than 20,000 m<sup>3</sup>/d), discharge from the remainder of the site is insignificant (less than a total of 200 m<sup>3</sup>/d during peak events when averaged on a monthly basis).

At closure, there will be no treated discharge. Instead, the entire site will be rehabilitated and the site runoff will report to both the North Arm and Main Basin of Snap Lake. Runoff and seepage from the north pile will discharge directly to the North Arm of Snap Lake. Discharge at closure will be limited to the summer months, and flow from the north pile to the North Arm of Snap Lake will dominate the site discharge

(Figure IX.1-44). The total peak flows (5,500  $\text{m}^3/\text{d}$ ) from the site at closure represents about 30% of the average annual natural discharge from the Snap Lake Basin (about 18,000  $\text{m}^3/\text{d}$ ). On an average annual basis, the total flow from site at closure (about 650  $\text{m}^3/\text{d}$ ) represents less than 4% of the average annual natural flow from the Snap Lake Watershed.





Figure IX.1-43	Site Discharge –	Operations
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Figure IX.1-44 Site Discharge – Closure



### 9.2 Mass Load Distribution of Project Discharges

Figures IX.1-46 through IX.1-49 illustrate general trends in relative mass load distribution from the various site discharge locations. Relative mass loads for TDS, NH<sub>4</sub>, Cr, Cu, and Cd are provided for illustrative purposes with loadings along the y axis plotted on a logarithmic scale where large differences in loading between site components occur. As can be observed, the general trends for TDS load follow the patterns of the flow discharges from the site, with the load from the treated discharge dominating the overall load to Snap Lake during operations. Trends for the trace metal load during operations are similar to that of TDS, with the treated discharge providing the majority of the loading during operations.

At closure, the loading follows a seasonal trend similar to the flow distribution. TDS loading resulting from north pile runoff to the North Arm of Snap Lake and loading from site runoff contribute the majority of load originating from the former Snap Lake Project Site area to Snap Lake at closure. However, the peak TDS load at closure still represents less than 4% of the total TDS load during operations. The average annual TDS load at closure represents less than 1% of the total TDS load during operations. Trace metal load released at closure is governed by the dissolved metal release rate from the north pile and the seasonal flow distribution. Those parameters associated with dissolved metal release due to reactions in the pile exhibit elevated peak loading discharged to the North Arm of Snap Lake during the spring freshet. Additional discussion of loading from the mine and north pile is provided in Sections 5 and 6 of this document.

#### 9.3 Principal Results and Discussion – Overall Discharge

Based on the model results, the following processes, trends and influences are considered the most relevant with respect to the overall discharge from the site:

- De-watering of the mine causes pronounced changes in discharge from Snap Lake to the groundwater system. Changes to surface water discharge volumes are minor (See Section 9 of EA).
- During operations, discharge and loading from the site and north pile to Snap Lake are insignificant relative to the discharge and loading originating from treatment.
- Typical major ions show concentrations and loading trends consistent will those of the mine water. The influence of the north pile and site discharge can be observed in seasonal "spikes" added to the mine load trend.
- The chemical load released at closure is governed by runoff from the north pile and the site. This mass load follows a seasonal trend similar to that of the flow

distribution, with the total amount of loading typically at some small fraction of that released during operations.

• Additional discussion on factors affecting loading trends for individual site components is provided in Section 5 through 8 of this document.

### Figure IX.1-45a Total Dissolved Solids Mass Load Distribution of Site Discharges – Operations



### Figure IX.1-45b Total Dissolved Solids Mass Load Distribution of Site Discharges – Closure



Figure IX.1-46 Ammonium Mass Load Distribution of Site Discharges





# Figure IX.1-47 Chromium Mass Load Distribution of Site Discharges

Figure IX.1-48 Copper Mass Load Distribution of Site Discharges







# **10.0 MANAGEMENT/MITIGATION OPTIONS AND STRATEGIES**

The expected load from the site will be mitigated/reduced through the use of treatment for removal of suspended sediment. A review of evaluated treatment alternatives and the rationale for selection of the preferred option is presented in the EA. Possible mitigation options and strategies for some of the other site components are provided below.

### 10.1 Mine Water

As demonstrated throughout this document, groundwater inflow has the most significant impact on overall discharge quality and loading. However, mitigation options related to minimizing groundwater inflow are limited. Although grouting on a large scale may appear attractive from a technical perspective, the cost associated with such a program would be prohibitive. In addition, it can be qualitatively argued that a large, ongoing grouting program to limit groundwater inflows is not feasible for three reasons:

- 1. Grouting would slow down production in the working area, which would leave large portions of the mine open for a longer period. This would, in turn, promote more groundwater inflow since these areas would not be backfilled for a longer period of time.
- 2. The aggressive grouting program implemented during the AEP achieved limited benefit with respect to reducing mine inflows.
- 3. The use of large amounts of grout in the mine would result in release of significant TDS loading. Furthermore, alkaline conditions would become more prevalent, which could enhance mobilization of certain constituents from the kimberlite (*e.g.*, Cr, Al).

Based on the above considerations, the selected strategy of using cemented paste backfill in the worked-out areas of the mine and selectively grouting high-flow structures is considered the most effective means to limit inflow.

Additional mitigation options relevant to the mine relate to limiting the amount of explosives waste and TSS discharge from the mine workings. Good housekeeping practices and use of a workforce that is educated with respect to these issues are paramount. Another alternative would be to change the type of explosive used to further reduce the NH<sub>3</sub> and NO<sub>3</sub> contribution from explosives. This option would have to be investigated in more detail if it was deemed necessary. Should TSS load to the treatment plant become an issue, additional sumps could be installed underground to limit sediment loading to the treatment system.

A final mitigation option that could be considered pertains to minimizing the amount of open area. Reductions in open area, both active and inactive, will generally reduce the loading originating from those portions of the mine.

# 10.2 Mine Rock

A generic discussion of various mitigation options for mine rock, many of which were assessed for this project, is given in Price and Errington (1998). They present and discuss avoidance, underwater storage, chemical treatment, blending and covers, and waste segregation as potential mitigation alternatives. In addition to these measures, temperature reduction or establishment of permafrost can provide an effective mitigation strategy in the north by reducing or eliminating weathering reactions (DIAND 1992).

The feasibility of an individual option may be affected by any number of site-specific conditions, such as site location, site design, mine layout, the nature and amount of rock to be disposed of, regulatory considerations, *etc.* Some factors currently influencing mitigation alternatives include volume of materials and timing of material production/removal.

The following measures were selected as the most effective means of mitigating potential water quality impacts, and were included during development of the currently proposed mine plan:

- elimination of open pit mining; and,
- disposal of any rock with PAG rock in the north pile below a thick layer of processed kimberlite.

The current mine plan calls for exclusively underground mining on the Northwest Peninsula, thus minimizing the PAG rock that would be extracted from this unit, following the primary strategy of avoidance as discussed in Price and Errington (1998).

Any PAG rock that does report to surface will be placed at the base of the north pile upon removal from the mine and covered with PK as soon as practical. Placement of a thick layer of PK over any mine rock reporting to surface minimizes oxygen diffusion to the PAG material, thereby reducing the rate of any acid generation. The material will also serve to help permafrost aggrade into the rock, which will curtail the reactions necessary to produce acidic drainage and may reduce or eliminate transport of what little oxidation products might be produced.

A large part of the mitigation strategy is based on selection of an appropriate mine plan. As discussed earlier in this document, approximately 22.8 Mt of kimberlite and dilution rock will be processed based on the current mine plan. Approximately half of this material will be returned to the mine as paste backfill. The remainder will be placed on the north pile as paste, or as coarse material used to build the retention berms. It is currently expected that only a minor amount of PAG rock will be extracted from the mine, and only during the first few years of operations. After the first few years, all mine development rock will be used underground in high strength paste backfill. The deposition plan calls for disposal below a significant thickness (up to 5 m) of PK of any PAG rock extracted to surface. PAG rock currently on surface, such as the mine ramp development rock, will also be relocated to the base of the north pile and covered with PK. The resulting site layout is not expected to have any PAG rock exposed on the surface.

An additional approach to minimizing environmental impacts is by restricting use of construction rock to non-acid generating material. All construction rock will consist of "clean" granite, which does not contain metavolcanic material, contains visible sulphides, and/or shows evidence of fracturing. The geochemical characterization program has demonstrated that such granite has no potential to generate acid and metal-rich leachates.

### **10.3 North Pile Discharge**

With respect to discharge from the north pile, the majority of discharge occurs as peak loadings during the spring freshet. Depending on actual sediment erosion rates and pile reaction rates, these occurrences could be mitigated through the following measures:

- Sediment load to treatment and at discharge is currently modelled as released during peak flow events. The predictions could be refined through incorporation of expected sediment reduction rates due to settling in the series of temporary ponds. Should sediment concentration be of concern during operations, an increase in pond volumes and settling time would allow for reduction of TSS loading.
- Mass released due to geochemical reactions in the pile is currently modelled as peaks released during the spring freshet and in late summer. Given that the pond size will be larger during operations than was modelled, these peaks are expected to be reduced relative to the scenarios simulated in GoldSim. During operations, monitoring of dissolved mass loadings, including high-intensity events, will be conducted. Should reduction of peak dissolved loads be required, it may be possible to address these with larger storage volumes.

# 10.4 Site Runoff/Discharge

The strategy to limit loading from the site is to maintain as small a site "footprint" as possible, since this will minimize potential interaction of mine and quarry rock with surface runoff. Should site runoff be deemed problematic, mitigation options include:

- Re-directing any non-point runoff previously reporting to Snap Lake to the WMP and treatment.
- Removal of organic material (*i.e.*, bogs) where interaction between bogs, surficial rock, and runoff is thought to result in enhanced loading to Snap Lake. The displaced bog material should be handled such that it could be used for reclamation purposes.
- Identification of problematic surficial rock and disposal in the north pile, under a significant thickness of PK.

# 11.0 SUMMARY OF KEY CONCLUSIONS

Based on the above assessment and predictions of site water quality, conclusions resulting from preliminary model calculations are as follows:

# **Operations:**

- The mine water accounts for the majority of loading to treatment and to overall site discharge during operations. The influence of the north pile and site discharge can be observed in seasonal "spikes" added to the mine load trend.
- During operations, loading from non-point sources and seepage to Snap Lake are insignificant relative to the discharge and loading reporting from treatment discharge.
- A significant amount of mass load reports to the treatment plant in the form of suspended solids from both the mine and north pile. Removal of these solids to a level of 5 mg/L total, results in a significant decrease in the mass discharged from site, with the majority of the remaining mass load occurring in dissolved form.
- The dissolved mine water concentrations and loading are typically dominated by groundwater inflow characteristics, and to a lesser extent by interaction with sediments on the mine floor or material usage, with explosive use accounting for less than 25% of the NO<sub>3</sub> and NH<sub>3</sub> load, and grout use accounting for less than 5% of the overall TDS load.
- Consolidation of backfill and release of backfill water has a very minor influence on the overall concentrations discharging from the mine.
- Loading to Snap Lake is associated with groundwater inflows, as more water enters the mine, more load to Snap Lake results.

# Post-Closure:

- The chemical load released at closure is governed by the dissolution/reactions release rates from the north pile and site, and the seasonal flow distribution. This mass load follows a seasonal trend similar to that of the flow distribution, with the total amount typically at some small fraction of that released during operations, the exceptions being metals such as Cd and Cu, where additional mass is released from the north pile due to metal leaching.
- Sensitivity analyses on the size of the north pile temporary pond indicates that the pond size affects peak concentrations, with lower peaks being associated with larger

storage pond volumes since more of the spring freshet is retained and available for mixing with the summer mass load. The average annual concentrations and loading are similar in both instances.

• Based on the geochemical modelling, the concentrations of As, Cr, Fe, and, Si from the north pile seepage and discharge during both operations and at post-closure are controlled by solubility limitations or adsorption on to iron hydroxide minerals.

# General:

The two main contributors to water quality are the mine and north pile. The proportion of connate water and the degree of recycling of water between the lake and mine are the dominant influences on water quality predictions from the mine. With respect to the north pile, the pile properties (including distribution of rock types, thickness of active layer, cover material, retention pond volumes, runoff volumes) as well as scaling from laboratory to field scale measurements have significant influence on calculated north pile water quality.

The mine, north pile, and site as modelled, are thought to be a reasonable representation of expected conditions that might exist on-site based on available information as described in the project description (Section 3 of the EA). As mine inflow conditions and the design of the pile is refined and/or monitoring data become available, the estimates of water quality should be adjusted accordingly.

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# 13.0 UNITS AND ACRONYMS

# UNITS

cm	centimetre
°C	degrees Celsius
ha	hectares
kg	kilograms (table)
kg/d	kilograms per day
kg/t	kilograms per tonne
m	metres
m <sup>3</sup>	cubic metres
m <sup>3</sup> /d	cubic metres per day
m <sup>3</sup> /s	cubic metres per second
m <sup>3</sup> /month	cubic metres per month
m <sup>3</sup> /hr	cubic metres per hour
m <sup>3</sup> /yr	cubic metres per year
mg/kg/week	milligrams per kilogram per week
mg/L	milligrams per litre
mgCO <sub>3</sub> /L	milligrams per litre expressed as carbonate
mm	millimetres
mm/yr	millimetres per year
Mm	million metres
Mm <sup>3</sup>	million cubic metres
Mt	million tonnes

pH unit	unit of pH measurement	
t	tonnes/ton	
t/yr	tonnes per year	
tpd	tonnes per day	
µg/L (ug/l)	micrograms per litre	
µS/cm (uS/cm)	microSeimens per centimetre	
alkalinity is expressed as calcium carbonate		
nitrate, nitrite, and ammonia are reported as nitrogen		

# ACRONYMS

AEP	advanced exploration program
ANFO	ammonium nitrate/fuel oil
ANSI	American National Standards Institute
ASME	American Society of Mechanical Engineers
BSMRP	bulk sample mine rock pad
EA	environmental assessment
IEEE	Institute of Electrical & Electronic Engineers
NPS	non-point source
NQA	nuclear quality assurance
NWT	Northwest Territories
PAG	potential acid generation
PHREEQC	pH redox equilibrium C
РК	processed kimberlite

TDS	total dissolved solids
TKN	total Kjeldahl nitrogen
TSS	total suspended solids
TSStotal	total suspended solids in all main rock types
TSSk	total suspended solids in kimberlite
TSSgt	total suspended solids in granite
TSSmtvc	total suspended solids portion in metavolcanic
WMP	water management pond