9. Hydrogeology Predictive Study

9.1 INTRODUCTION

This chapter describes and quantifies the potential effects of the proposed Brucejack Gold Mine Project (the Project) on groundwater. Groundwater is valued as a source of water for human consumption and for its intrinsic links with surface water. Changes to groundwater fluxes can affect water levels and flows in surface waterbodies, thereby influencing aquatic ecosystems, vegetation, and wildlife. Groundwater is also a potable water resource when water quality is adequate.

Assessment of the Project effects on the intermediate components was conducted based on the results of predictive three-dimensional groundwater flow modelling and on predictive water quality modelling. Groundwater flow modelling studies included calibration to baseline conditions and predictive simulation of effects on groundwater quantity during the Construction, Operation, Closure, and Post-closure phases of the mine life. The results of the hydrogeology predictive studies were used to evaluate changes in water table configuration, groundwater baseflow and groundwater quality which inform predictive studies on surface water quantity and quality. Complete details of the groundwater baseline data and of the applied modelling methodologies and results are provided in Appendix 9-A, Brucejack Project Environmental Assessment – Hydrogeology Baseline Report, and Appendix 9-B, Brucejack Project Environmental Assessment – Numerical Hydrogeologic Model, respectively.

The Project includes the development of an underground mine and associated processing, maintenance and waste management facilities for waste rock and tailings materials near or in Brucejack Lake (Chapter 1, Project Overview). Brucejack Lake and its surrounding catchment area drain via Brucejack Creek towards the Sulphurets Glacier and Sulphurets Creek which ultimately drains to the Unuk River.

Dewatering activities will be necessary to support the underground mining method. This activity will result in lowering of the water table within the footprint of the underground workings and will temporarily reduce groundwater discharge (i.e., baseflow) to Brucejack Lake, Brucejack Creek and some of its tributary streams. Tailings and waste rock will be placed in Brucejack Lake for disposal which will cover a portion of the lake bottom potentially affecting the rate of groundwater discharge into the Lake. Changes in the amount of groundwater discharged to Brucejack Lake and Creek (i.e., changes in groundwater baseflow) during the project may contribute to changes in surface water quantity and quality and therefore may contribute to effects on the downstream aquatic receiving environment, wildlife, vegetation and human health. Alteration of surface water quantity and surface water quality as a result of the project are assessed in Chapter 10, Surface Water Hydrology Predictive Study, and Chapter 13, Assessment of Potential Surface Water Quality Effects.

Alteration of surface water quality could potentially affect receptor Valued Components (VCs) that have linkages with surface water quality; effects of the Project on these receptor VCs are assessed in:

- Chapter 14, Assessment of Potential Aquatic Resources Effects;
- Chapter 15, Assessment of Potential Fish and Fish Habitat Effects;
- Chapter 17, Assessment of Potential Wetlands Effects; and
- Chapter 21, Assessment of Potential Health Effects.

Predictive water quality modelling was focused primarily on evaluating project effects on the surface water receiving environment at groundwater discharge locations (Brucejack Lake and Brucejack Creek); however, source terms were developed to consider potential changes in groundwater chemistry as a result of the Project. Lowering the water table and constructing underground workings within the mineralized area will result in the exposure of potentially acid generating rock and waste rock to variably saturated, oxic conditions. This could contribute to the onset of metal leaching and acid rock drainage (ML/ARD) within the underground, which will result in changes to the chemistry of groundwater that comes into contact with the exposed mine workings and/or waste materials.

During operation of the mine the extracted water will be treated on site. During the reclamation and closure period, changes in the quality of groundwater discharging to Brucejack Creek may contribute to changes in surface water quality and contribute to effects on the downstream surface water receiving environment. Once the mine workings have flooded, suboxic conditions are expected to shut down/attenuate any ML/ARD reactions that may have commenced during the Construction and Operation phases and groundwater quality from the underground is anticipated to return to near predevelopment conditions. Groundwater flooding of the underground, at closure, may result in the flushing (and subsequent mobility) of precipitates/particulates present on wall rock. However, sealing of adits is expected to minimize and/or mitigate this risk to the receiving environment.

9.2 REGULATORY AND POLICY FRAMEWORK

The Regulatory and Policy Framework surrounding the management of groundwater in the proposed Project area, including relevant federal and provincial legislation, applicable provincial regulation and guidelines for assessment of groundwater quality and regional best management practices to be implemented, are summarized in Table 9.2-1.

Table 9.2-1. Groundwater Legislation, Regulation, Standards, and Guidelines

Name	Level of Government	Description
Canada Water Act (1985a)	National	The Act provides for the cooperative management of water resources and water quality. If an agreement cannot be reached with the province, the Act provides for unilateral action by the federal government. The provisions for unilateral action are limited to federal waters and inter-jurisdictional waters of “significant national interest” or where the water quality has become a matter of “urgent national concern”.
Canadian Environmental Protection Act (1999)	National	The Act provides for environmental assessment of projects where the proposed project is on federal land (e.g., Indian Reserve); under federal sponsorship and a federal act applies (e.g., *Fisheries Act* [1985b]).
Fisheries Act (1985b)	National	The federal government has ultimate authority over fish and fish habitat through the *Fisheries Act* (1985b). Water quality is protected through provisions providing for the prevention of the pollution of waters inhabited by fish.
British Columbia (BC) *Mines Act* (1996b)	Provincial (BC Ministry of Energy and Mines)	The BC *Mines Act* (1996b) and its associated Health, Safety and Reclamation Code for Mines in BC (BC MEMPR 2008) require mines to have programs for the environmental protection of land and watercourses throughout mine life, including plans for prediction and prevention of metal leaching and acid rock drainage, and prevention of erosion and sediment release. Watercourses are required to be reclaimed, and the BC Ministry of Energy and Mines has the authority to require monitoring and/or remediation programs to protect watercourses and water quality.

(continued)

Table 9.2-1. Groundwater Legislation, Regulation, Standards, and Guidelines (continued)

Name	Level of Government	Description
Canadian Council of Ministers of the Environment (CCME) Canadian Water Quality Guidelines for the Protection of Aquatic Life(2013)	National	Environmental Quality Guidelines (EQGs) are intended to protect, sustain, and enhance the quality of the Canadian environment. Each jurisdiction determines the degree to which it will adopt CCME recommendations and EQGs should not be regarded as blanket values for national environmental quality; users of EQGs consider local conditions and other supporting information (e.g., site-specific background concentrations of naturally occurring substances) during implementation. Science-based site-specific criteria, guidelines, objectives, or standards may, therefore, differ from the Canadian EQGs. Environment Canada assesses groundwater quality with respect to Canadian federal legislation and the CCME water quality guidelines.
Environment and Land Use Act (1996a)	Provincial (BC Ministry of Forests, Lands and Natural Resource Operations)	This legislation empowers Land Use Committees to ensure that all aspects of the preservation and maintenance of the natural environment, of which groundwater is part, are fully considered in the administration of land use and resource development in BC.
Environmental Management Act (2003)	Provincial (BC Ministry of Environment [BC MOE])	The *Environmental Management Act* (2003) regulates industrial and municipal waste discharge, pollution, hazardous waste, and contaminated site remediation. It also requires preparation of environmental plans for flood control, drainage, soil conservation, water resource management, waste management, and air quality management. The quality of all groundwater within BC is regulated by the BC Contaminated Sites Regulation (BC Reg. 375/96) and Hazardous Waste Regulation (BC Reg. 63/88). Contaminated Sites Regulation groundwater standards that may be applied to the Project are those protective of freshwater aquatic life and drinking water quality.
Fish Protection Act (1997)	Provincial (BC MOE)	The Act protects fish and fish habitat by prohibiting bank-to-bank dams on 17 protected rivers (including the Bell-Irvine and the Nass Rivers); and authorizing designation of "sensitive streams" for fish sustainability; provincial directives for streamside protection, and reduction in water use during periods of drought (temporary) or in accordance with a water management plan. Applies to the extent that surface water chemical or physical quality, flow conditions, or water depth conditions; or habitat conditions within or near surface waterbodies near the proposed Project are affected by proposed Project effects to groundwater flow or quality.
Forest and Range Practices Act (2002b)	Provincial (BC Ministry of Forests, Lands and Natural Resource Operations)	The Act governs how forest activities occur on Crown land; authorizes regulations that set objectives for water that must be addressed through results and strategies identified and undertaken by forest and range agreement holders. It also provides for designation and protection of Community Watersheds and for watersheds with significant downstream fisheries values and significant watershed sensitivity.
Public Health Act (2008)	Provincial (BC Ministry of Health)	The Act and Sewerage System Regulation (BC Reg. 326/2004) covers holding tanks and sewage effluent or onsite sewerage systems that process a sewage flow of less than 22,700 litres per day; serve single –family systems or duplexes; serve different buildings on a single parcel of land; or service one or more parcels on strata lots or on a shared interest of land. The regulation provides requirements for setbacks of holding tanks and sewerage system from wells used to supply a domestic water system.

(continued)

Table 9.2-1. Groundwater Legislation, Regulation, Standards, and Guidelines (completed)

Name	Level of Government	Description
Water Act (1996c)	Provincial (BC MOE)	The Act provides for the allocation and management of surface water by authorizing issuance of water licences and approvals, creation of reserves, development of water management plans, and establishment of water user communities. In a planning area, groundwater development may be regulated by requiring drilling authorizations. The Ground Water Protection Regulation (BC Reg 299/2004), promulgated under the *Water Act* (1996c), sets out requirements for the licensing of well drillers and pump installers, and specifications for construction and abandonment of certain types of wells.
Water Protection Act (1996d)	Provincial (BC MOE)	The Act prohibits bulk export of water and large-scale water transfers between watersheds
British Columbia Approved and Working Water Quality Guidelines	Provincial (BC MOE)	Water quality criteria are defined as maximum or minimum physical, chemical, or biological characteristics of water, biota or sediment; and are applicable province-wide. The guidelines are intended to prevent detrimental effects on water quality or aquatic life, under specified environmental conditions. The quality of groundwater within the Project area is assessed against groundwater quality and criteria that are protective of freshwater aquatic life and drinking water.
Cassiar, Iskut, Stikine Land and Resource Management Plan (CIS LRMP; BC ILMB 2000)	Provincial Policy (BC Integrated Land Management Bureau)	The CIS LRMP provides general directives for aquatic ecosystem and riparian habitat management; those with implications to groundwater resource management include: manage activities for no net loss of fish habitat; maintain integrity of watersheds with high fisheries values and domestic water use (licensed and unlicensed); and, maintain water quality and quantity for naturally occurring aquatic biota within the natural range of variability.
Nass South Sustainable Resource Management Plan (SRMP; BC MFLNRO 2012)	Provincial Policy (BC Ministry of Forests, Lands and Natural Resource Operations)	Nass South SRMP provides management goals for water resources within the plan area. The overriding management goal is to protect and maintain surface and groundwater to: provide a safe and sufficient drinking water supply that supports healthy communities; maintain water quality, quantity, peak and low flows within the range of natural variability in rivers, streams, lakes, and wetlands to protect the hydrological integrity of their watersheds (water quality includes temperature, turbidity and chemistry).
Other Guidance Documents	Provincial and National	• *Policy for Metal Leaching and Acid Rock Drainage at Minesites in British Columbia* (BC MEM and BC MELP 1998) • *Guidelines for Metal Leaching and Acid Rock Drainage at Mine Sites in British Columbia* (Price and Errington 1998) • *Prediction Manual for Drainage Chemistry from Sulphidic Geologic Materials* (Price 2009) • *Water and Air Baseline Monitoring Guidance Document for Mine Proponents and Operators* (BC MOE 2012) • *Guidelines for Groundwater Modelling to Assess Impacts of Proposed Natural Resource Development Activities* (Wels, Mackie, and Scibek 2012) • *British Columbia Field Sampling Manual* (Clark 2003) • *Framework for a Hydrogeologic Study in Support of an Application for an Environmental Assessment Certificate under the Environmental Assessment Act and Regulations* (BC MOE 2014b)

As indicated in Table 9.2-1, groundwater quality and quantity are not directly regulated by federal legislation; however, they may be indirectly regulated by several Acts if deleterious effects to water quality occur in provincial waters (i.e., the *Fisheries Act* [1985b]) or in international waters or inter-jurisdictional waters (i.e., the *Canada Water Act* [1985a]). The *Canadian Environmental Protection Act*

(1999) provides for the assessment of proposed projects on federal land or under federal sponsorship where a federal act applies. Groundwater quality on federal land is assessed with respect to the CCME's (2013) *Canadian Water Quality Guidelines for the Protection of Aquatic Life*; guidelines applicable to the proposed Project are protective of freshwater aquatic life.

With the exception of training and licensing requirements for well drillers and pump installers under the BC Groundwater Protection Regulation *(*BC Reg. 299/2004), the siting, capacity and quantity for groundwater withdrawals in British Columbia is not currently directly regulated by existing provincial legislation (Christensen 2007). Exceptions include hydrogeologic assessment of projects where groundwater extraction will total 75 litres per second, or is required as part of a larger project, which triggers an EA under the BC *Environmental Assessment Act* (2002a).

On April 29, 2014, the *Water Sustainability Act* passed Third Reading in the Legislature and is now considered an Act; royal assent is expected in the near future. The earliest the new Act is anticipated to come into force is the spring of 2015 (April). The current *Water Act* (1996c) will remain in force over the next year to maintain continuity of business, but will be repealed as the *new Water Sustainability Act* comes into force. Because of the size and complexity of the new Act and the number of proposed regulations, a phased approach will be taken, starting with priority regulations related to groundwater and water fees and rentals.

All groundwater quality in BC is regulated by the BC Contaminated Sites Regulation (BC Reg. 375/96) under the *Environmental Management Act* (2003). The Contaminated Sites Regulation sets out generic numerical water standards for the purpose of determining if a site is contaminated. Four water uses are specified: aquatic life (freshwater and/or marine/estuarine), irrigation, livestock and drinking water. Groundwater standards protective of freshwater aquatic life and drinking water uses may be considered applicable to the site depending upon the location of the project activity or component and local hydrogeologic conditions.

For the purposes of EA of the Project against provincial legislation, guidelines and criteria established for freshwater aquatic life under the BC *Working Water Quality Guidelines* (BC MOE 2010) and the BC *Approved Water Quality Guidelines* (BC MOE 2013) are applied.

9.3 BASELINE CHARACTERIZATION

9.3.1 Regional Overview

Groundwater in the BC Coastal Mountains generally occurs within voids and fractures in bedrock and can be irregularly distributed due to the variability of the fractures (Parsons and Quinn 1994). Variations in permeability and topographic relief have a strong effect on the direction of groundwater flow, and mountain springs are common where lower permeability rock impedes the downward movement of groundwater.

Groundwater generally occurs in the intervening valley fill deposits between mountain ranges in granular deposits such as sand and gravel; however, low permeability deposits are often present and are not suitable as sources of groundwater supply. The Insular and Coastal Mountains include significant thicknesses (up to hundreds of metres) of unconsolidated material in the valleys which dissect the mountain ranges due to glacial processes during the Pleistocene ice age (Parsons and Quinn 1994).

Parsons and Quinn (1994) indicate that groundwater quality is generally dependent on the mineral composition of rocks that the groundwater moves through. In areas with base metal mineralization, groundwater may have high concentrations of these metals and may not be suitable for drinking water. In crystalline bedrock of low solubility, the groundwater is typically good quality for drinking water and other uses. Mountainous terrain is considered especially vulnerable to contamination due to generally sparse soil cover and limited natural attenuation and retardation of flow in crystalline fractures.

Consistent with the above generalizations, surface topography is expected to have a dominant influence on groundwater flow in such a system. The water table will be a subdued replica of topography, with depths to groundwater typically greater in the uplands relative to the valley bottoms. The climate in the immediate vicinity of the Project is considered subarctic, with variable temperatures and precipitation generally exceeding 1,900 mm/year. Groundwater primarily enters these mountain flow systems from infiltration of precipitation and snowmelt, with lesser components supplied by surface water infiltration in lakes. Groundwater discharge zones are expected to be generally restricted to lakes, creeks, gullies, breaks in slope and geologic discontinuities.

9.3.2 Historical Activities

Several historical and current human activities occur within and in close proximity to the proposed Project Area. These include mining exploration and production, hydroelectric power generation, forestry, and road construction and use. Historical activities with potential likely interactions with current groundwater quantity and groundwater quality conditions within the mine site area are summarized in Table 9.3-1. The proposed mine site area (Brucejack watershed) itself is an advanced exploration site with a long history of mineral exploration that included underground exploration (5 kilometres [km] of underground workings developed) and excavation of a bulk sample by Newhawk Gold Mines Ltd. (Newhawk; 1986 to1990).

Table 9.3-1. Summary of Exploration and Mining Activities within the Brucejack Watershed, 1935 to 2013

Period	Activity
1935	Discovery of Cu-Mo mineralization on the Sulphurets Property, ~6 km northwest of Brucejack Lake; these claims were staked in 1960.
1935-1959	Project area inactive with respect to prospecting.
1960-1979	Granduc exploration, lithogeochemical sampling, trenching and diamond drilling north and northwest of Brucejack Lake.
1980	Esso Minerals Canada Ltd. optioned the Property from Granduc; completed an extensive program consisting of mapping, trenching, and geochemical sampling.
1982-1983	Exploration and drilling activities confined to Au- and Ag-bearing vein systems in the Brucejack Lake area at the southern end of the property, including the Near Shore and West zones, located 800 m apart near Brucejack Lake. Drilling started on the Shore Zone.
1982-1985	Small-scale mining of the Catear (Goldwedge) area (Catear Creek a tributary of Brucejack Lake); included on-land and lake disposal of an un-quantified volume of waste rock and approximately 4,000 t of tailings from a small underground mine.
1986-1999	Various operators explored the Sulphurets Property; an underground program was completed on the West Zone of the Brucejack Property by the Newcana JV.; waste rock placed as shallow pad along the southern boundary of Brucejack Creek (~124,000 t).
1986-1989	Adit excavation and active de-watering of underground water.
1990	Project halted due to economic constraints, underground workings allowed to flood.
1990- May 2011	Adit passively draining into Brucejack Creek.
July 27 to Aug. 27, 1999	Waste rock and lime deposition in Brucejack Lake (~124,000 t).
July 2009 to Oct. 2010	Silver Standard exploration program
May 1, 2011 to present	Current exploration and drilling program (Pretivm).
Nov. 6 to Dec. 5, 2011	Underground dewatering test, discharge to Brucejack Creek.
Sept. 1 to Dec. 31, 2012	Waste rock deposition into Brucejack Lake.
January 2013	Water treatment plant commissioning, followed by operations through 2013.

The Granduc Mine was a copper mine located approximately 25 km south of the Project which operated from 1970 to 1978 and 1980 to 1984. The mine included underground workings, a mill site near Summit Lake, and an 18.4-km tunnel connecting them. In addition, a 35-km all-weather access road was built from the communities of Stewart, BC and Hyder, Alaska to the former mill site near Summit Lake. The area of the former mill site near Summit Lake is currently used as staging for several mineral exploration projects in the region. Its terminus of the Granduc Access Road is 25 km south of the proposed Brucejack Mine Site and is currently used by mineral exploration traffic and tourists accessing the Salmon Glacier viewpoint. Past activities at the Granduc Mine area will not affect baseline characterization of groundwater quantity and groundwater quality for the proposed Project.

Exploration, litho-geochemical sampling, trenching and diamond drilling to the north and northwest of Brucejack Lake may have had minor, localized influences on both groundwater flow directions and quality.

Newhawk's Sulphurets Project was an advanced underground exploration project located at the currently proposed Brucejack Mine Site. Underground workings were excavated between the fall of 1986 and late 1990 as part of an advanced exploration and bulk sampling program (Newhawk 1989; Price 2005). Excavation of the underground workings and associated exploration activities (e.g., exploration drilling) has resulted in localized changes in groundwater flow directions and quantity from pre-disturbance conditions. Localized changes to groundwater quality from pre-disturbance conditions where groundwater comes into contact with partially saturated historical workings may have affected baseline groundwater quality characterization.

The waste rock generated from the underground workings was used as a shallow pad for the foundation of camp facilities along the southern boundary of Brucejack Creek, adjacent to Brucejack Lake. Two small piles of ore were placed at the back of the pad, and two small streams, Camp and Little Camp Creek, were piped under the pad. Reclamation efforts following the Newhawk advanced exploration work included deposition of waste rock and ore within Brucejack Lake. Roughly 60,000 m^3 of waste rock was removed from the pads along lower Brucejack Creek and deposited in Brucejack Lake during July and August of 1999 (Price 2005). These prior activities may have resulted in localized effects to groundwater recharge and discharge areas as well as to groundwater quality.

The exploration phase of the proposed Brucejack Gold Mine Project commenced in 2011 and has included a drilling program, bulk sample program, construction of an exploration access road from Highway 37 to the west end of Bowser Lake and rehabilitation of an existing access road from the west end of Bowser Lake to Brucejack Mine Site. Adit dewatering activities, exploration drilling, and additional underground development for bulk sampling activities have affected local groundwater recharge and discharge patterns, flow directions and groundwater quality. Review of the baseline data collected in these areas to screen out some of these affects (e.g., to identify groundwater samples potentially affected by adjacent or nearby drilling) was carried out to the extent practicable. In some instances, these activities contributed to a better understanding of the project hydrogeology (e.g., data collected during adit dewatering activities provided analogues for groundwater quality used to support mine water treatment plant design, and provided the opportunity for additional calibration of the groundwater flow model developed for the Project, see Section 9.3.3).

In 2010, construction began on the Long Lake Hydroelectric Project which is located approximately 42 km south of the Project (CEA Agency 2012). It includes re-development of a 20-m-high rockfill dam located at the head of Long Lake, and a new 10-km-long 138-kV transmission line. This project has recently (November 2013) begun operations. Activities associated with the Long Lake Hydroelectric Project will not affect baseline groundwater quantity and quality characterization for the Brucejack Gold Mine Project.

Historical forestry activities occurred within the immediate Project area between Highway 37 and Bowser Lake, south of the Wildfire Creek and Bell-Irving River confluence. Additional details regarding historical and current human activities nearby the Project are included in Section 1.4, Project Location Access and History.

9.3.3 Baseline Studies

Hydrogeological data specific to the Project site have been collected since 2010 by BGC Engineering Inc. (BGC), through site investigations associated with a Preliminary Economic Assessment, a Feasibility Study, and an environmental assessment (EA). These investigation methods and data are documented in Appendix 9-A, Brucejack Project Environmental Assessment - Hydrogeology Baseline Report. Furthermore, numerical modelling studies were performed to simulate steady-state and transient baseline conditions. The model parameters and boundary conditions were calibrated to baseline average (steady-state), seasonal (transient) and dewatering (transient) observations, plus the model was benchmarked to adit dewatering observations. Sensitivity analyses were performed. The modelling work for baseline conditions, and future predictions, is fully documented in Appendix 9-B, Brucejack Project Environmental Assessment - Numerical Hydrogeologic Model.

The reasons for conducting the baseline studies were to:

- understand existing baseline conditions in the vicinity of the Project;
- determine physical parameters necessary for characterizing hydrogeology in the vicinity of the Project;
- determine existing groundwater flow rates and directions, and groundwater chemistry;
- provide a benchmark for evaluating the potential effects of the Project; and
- characterize pre-disturbance conditions for the purpose of potential reclamation activities.

The baseline methods described in the Application Information Requirements (AIR; BC EAO 2014) and Environmental Impact Statement (EIS) Guidelines (CEA Agency 2013b) were followed for the hydrogeology baseline studies, which included comprehensive numerical modelling.

9.3.3.1 Data Sources

Regional groundwater resources were assessed by reviewing information available from the BC MOE Water Stewardship Division and other online resources. The BC MOE online British Columbia Water Resources Atlas (BC MOE 2014a) did not show any aquifers mapped in the vicinity of the proposed mine. The nearest wells shown in the British Columbia Water Resources Atlas are located approximately 40 km to the east, northeast and northwest of the Project site. Based on the absence of public-domain hydrogeologic information, the preliminary evaluation of groundwater resources within the local study area is based entirely on site investigations and numerical modelling conducted by BGC. Additional hydrogeologic data were available to the west of the Project location, from site investigations at the neighbouring KSM Project (Wardrop 2011; Tetra Tech 2013).

Hydrogeologic characterization is based on baseline data that have been collected since 2010 for the Project, and on data collected since 2008 from the KSM Project, under a data sharing agreement with Seabridge Gold Inc. Project effects are assessed in terms of predicted changes to baseline conditions for the intermediate components of groundwater quantity and groundwater quality.

9.3.3.2 Methods

The baseline hydrogeologic study for the Project involved the compilation and review of available geological, geotechnical, hydrogeologic, and geochemical data obtained from investigations of the Brucejack site, comprising:

- the drilling and hydraulic response testing completed in boreholes at the site;
- installation, development and hydraulic response testing of groundwater monitoring wells;
- water level monitoring and groundwater sampling conducted at the site; and
- numerical modelling of steady-state and transient baseline conditions within the watershed.

Temporal boundaries for the baseline covered by this work extend back to 2010, when initial geotechnical investigations commenced at the site. Data available through late 2013 and early-2014 were used in interpretations plus numerical model development, calibration, and benchmarking.

Baseline Study Area

The detailed field investigation focused on the Local Study Area (LSA). The LSA is defined as the Project footprint (all physical structures and activities that comprise the Project) and surrounding area within which there is a reasonable potential for immediate effects on a specific intermediate component or receptor VC due to an interaction with a Project component(s) or physical activity.

In general, the study focused on collecting data to support the assessment of project effects that would result in direct changes to waterbodies within the LSA. For the purposes of a hydrogeologic assessment, such effects may broadly include: 1) drawdown of the water table or hydraulic heads due to mine dewatering; 2) accompanying changes in groundwater recharge and/or discharge rates; and/or, 3) changes to groundwater chemistry from geochemical reactions within the mine or waste materials, or within any zones that are dewatered.

It is anticipated that the above effects on the groundwater system at the Project site will be focused around the underground mine development, and that the LSA from a hydrogeologic perspective will extend over a radial distance of a few kilometres from the proposed mine. This assumption is supported by results from the numerical modelling exercises, discussed further in Section 9.6.

The groundwater flow model covers the Regional Study Area (RSA), but with particular emphasis on the groundwater flow system within the LSA in the immediate vicinity of the Project site. The RSA is defined as the Sulphurets Creek watershed upstream of the confluence of Sulphurets Creek and Ted Morris Creek. Figure 9.3-1 shows the LSA, primary hydrological features and hydrogeological instrumentation within the context of the RSA and the numerical model domain.

Hydrogeological Monitoring Wells and Piezometers

Figure 9.3-1 shows hydrogeologic instrumentation installed within the LSA for the Project (Appendix 9-A), plus instrumentation in the RSA within and around the KSM Project (Wardrop 2011; Tetra Tech 2013).

No pre-disturbance groundwater quantity and quality data are available for the mine site area. Initial data on groundwater quantity and quality were obtained from geotechnical site investigations completed by BGC in 2010. Three geotechnical drill holes were completed by BGC at Brucejack in 2010 as part of a geotechnical site investigation that also included bore-hole televiewer surveys, packer testing and the installation of vibrating wire piezometers (VWPs). Nested shallow and deep VWPs were installed in two of the angled geotechnical drill holes with a single VWP installed in the third. In the spring and fall of 2012, an additional 17 geotechnical drill holes were completed and a total of 18 VWPs were installed in 12 of the drill holes. Data loggers set to record measurements of pressure and temperature at 6-hour intervals were attached to all VWP installations. Standpipe piezometers (i.e., monitoring wells) were installed in three of the shallow geotechnical bore holes drilled in 2012.

In the fall of 2011, nine groundwater monitoring wells were installed at six different locations in the vicinity of the existing underground workings and proposed new development areas for the purposes of characterizing baseline groundwater levels and quality. The monitoring wells were completed as three sets of nested shallow and deep wells and three individual wells. Between June and August 2012, an additional twelve groundwater monitoring wells at two existing locations and five new locations were installed at the Brucejack site. The locations for the installation of monitoring wells were selected based on the following considerations:

- locations of the mineral deposits and possible surface water receptors (e.g., Brucejack Creek and Brucejack Lake);
- good spatial distribution of groundwater elevation data;
- locations of existing installations;
- access to wells during the winter; and
- proximity to Brucejack Fault.

Following well completion, development and testing, pressure transducers with integrated data loggers were installed in all monitoring wells to record water level measurements at 6-hour time intervals. Well logs and drill-hole details for the Brucejack site groundwater monitoring wells and vibrating wire piezometers are provided in Appendix 9-A, Brucejack Project Environmental Assessment - Hydrogeology Baseline Report. The locations of monitoring wells are shown on the inset of Figure 9.3-1.

Hydrogeological Response Testing

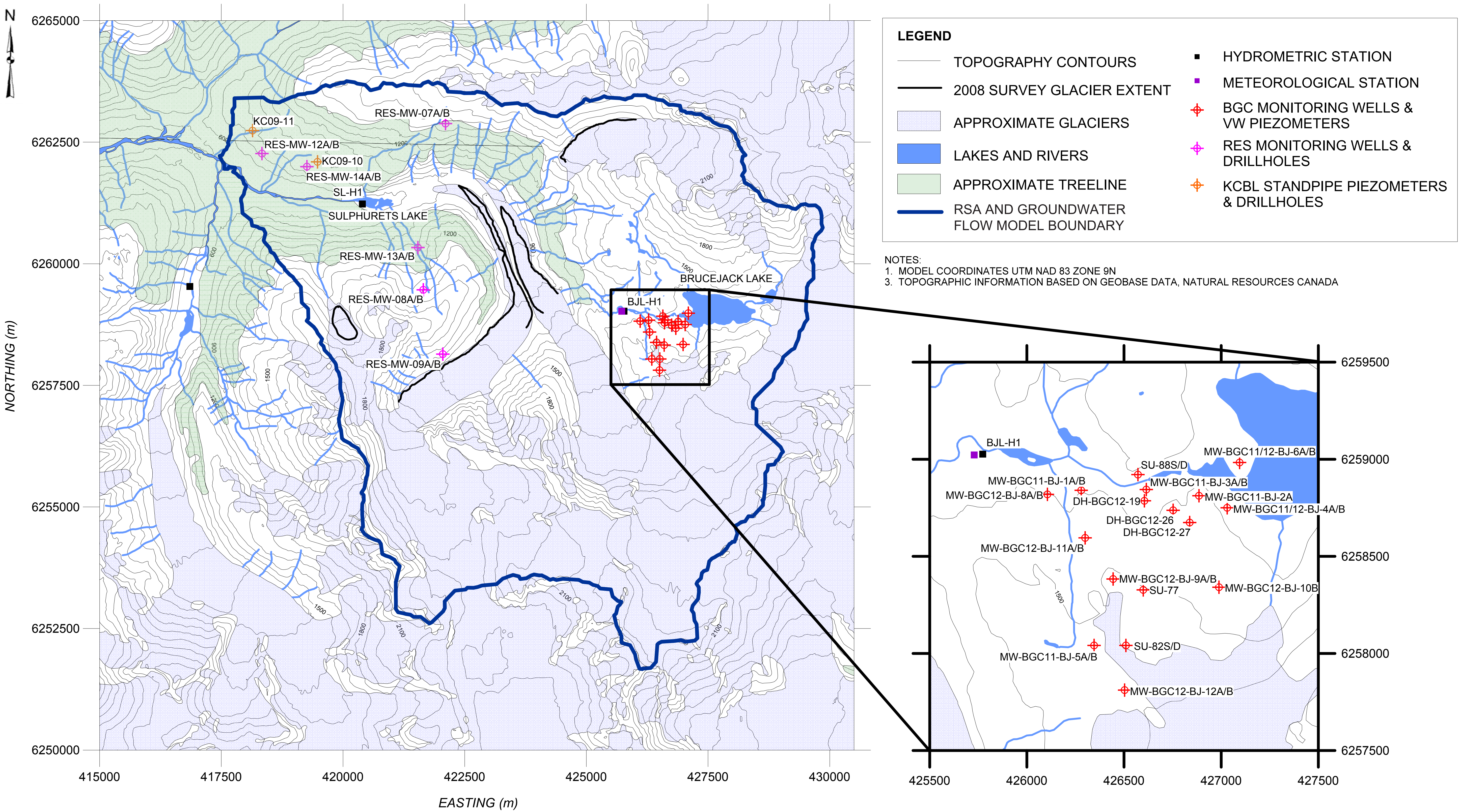
A total of 67 hydraulic tests were performed in bore holes and monitoring wells to measure hydraulic conductivity, K, at the Project Site. Six packer tests results were available from 2010 investigations, with an additional 46 results obtained during the 2012 site investigations. Slug tests completed in monitoring wells at the Project in 2012 provide another 15 estimates of hydraulic conductivity. Detailed information is included in Appendix 9-A, Brucejack Project Environmental Assessment - Hydrogeology Baseline Report.

Hydrogeological Water Levels

Hydraulic head data were collected at six hour intervals by the network of dataloggers attached to VWPs and pressure transducers, described above, supplemented by manual water-level measurements in standpipe piezometers. The VWPs installed in 2010 have the longest continuous record of groundwater elevation at the site, with data extending back to September of 2010. Plots of groundwater elevation through time for the majority of the instruments installed at the Project are included in Appendix 9-A, Brucejack Project Environmental Assessment - Hydrogeology Baseline Report.

Figure 9.3-1

Regional Study Area Site Plan



Source: BGC Engineering Inc. (June 2014).

Hydrogeological Water Sampling

Groundwater samples were collected from monitoring wells at the mine site on a quarterly basis since installation, though weather and site access conditions occasionally prevented a monitoring well from being sampled during a given sampling event, particularly during winter months. The general methodology for groundwater sampling and quality assurance and quality control (QA/QC) followed industry standards and is generally consistent with the principles and procedures outlined in the *British Columbia Field Sampling Manual* (Clark 2003). The procedure involved purging the wells with dedicated equipment until stable in-situ indicator parameters (i.e., pH, temperature) were observed, filtering and/or preserving the samples as required by the laboratory, and storing samples in coolers with ice packs until they were transported under chain of custody to ALS Environmental Laboratories (ALS) in Burnaby, BC for analysis. ALS is an accredited environmental laboratory.

During the baseline groundwater sampling program (2011 to 2013), over 90 groundwater samples (including QA/QC samples) were collected and submitted to ALS. Groundwater samples were submitted for analysis of physical parameters, major cations and anions, nutrients, cyanides, organic carbon, total metals, and dissolved metals. QA/QC samples including field blanks, travel blanks and field duplicates were submitted as required, and were tested for the same parameters as the groundwater samples. In general, one set of field blanks and one set of travel blanks were included with each sampling event, along with one set of duplicates, which equates approximately to a 1:10 duplicate ratio. Groundwater sampling procedures and QA/QC are fully documented in Appendix 9-A, Brucejack Project Environmental Assessment - Hydrogeology Baseline Report.

In compliance with the EIS and AIR, the groundwater data collected as part of the baseline study are compared with BC MOE and CCME guidelines. Specifically, as outlined in Section 8.3.1 of the AIR, groundwater data are compared to:

- *British Columbia Water Quality Guidelines for Protection of Freshwater Aquatic Life and Drinking Water* (BC MOE 2010); and
- *Canadian Water Quality Guidelines for the Protection of Aquatic Life* (CCME 2013).

Within the *Environmental Management Act* (2003), the water quality guidelines provide numerical concentrations for the evaluation of groundwater quality. The groundwater standards are divided into different categories based on specified uses, such as aquatic life (AW), irrigation, livestock watering or drinking water (DW). The BC MOE AW and DW guidelines specify total concentrations of heavy metals, metalloids, and inorganic ions as well as dissolved concentrations for aluminum and iron. Additionally, the guidelines are divided into 30-day average concentrations and maximum one-time concentration. For the purpose of this assessment, all results have been compared to the 30-day average concentrations. In scenarios of 30-day threshold exceedance, the concentrations are then compared to the maximum one-time concentration to determine if the higher threshold is also exceeded.

The *Canadian Water Quality Guidelines* set by the CCME for the protection of Freshwater Aquatic Life (FW) include numerical concentrations to support and maintain the freshwater aquatic environment (CCME 2013). The CCME FW guideline values apply to the total element or substance in an unfiltered sample. Within the guidelines, there are thresholds for short-term and long-term concentrations. All results in this assessment are compared with the long-term concentration thresholds.

The BC MOE and CCME guidelines applied for the characterization of baseline groundwater quality of the Project are summarized in Table 9.3-2 and Table 9.3-3. Complete results of this study are documented in Appendix 9-A; a summary of the resulting baseline groundwater characterization is provided in Section 9.3.4.3.

Table 9.3-2. Provincial Water Quality Guidelines for the Protection of Freshwater Aquatic Life and Drinking Water, and Federal Water Quality Guidelines for the Protection of Freshwater Aquatic Life

		BC MOE[1]				CCME FW[2]
		Drinking Water (DW)		Aquatic Life (AW)		Long-term
Parameter	Unit	30-day Avg.	Max.	30-day Avg.	Max.	Max
Physical Tests						
Colour, True	CU	-	-	-	-	BD[3]
Conductivity	uS/cm	-	-	-	-	-
Hardness (as $CaCO_3$)	mg/L	-	-	-	-	-
pH	pH	6.5 - 8.5		6.5 - 9.0		6.5 - 9.0
Total Suspended Solids	mg/L	-	-	BD		BD
Total Dissolved Solids	mg/L	-	-	-	-	-
Turbidity	NTU	BD		BD		BD
Anions and Nutrients						
Acidity (as $CaCO_3$)	mg/L	-	-	-	-	-
Alkalinity, Bicarbonate (as $CaCO_3$)	mg/L	-	-	-	-	-
Alkalinity, Carbonate (as $CaCO_3$)	mg/L	-	-	-	-	-
Alkalinity, Hydroxide (as $CaCO_3$)	mg/L	-	-	-	-	-
Alkalinity, Total (as $CaCO_3$)	mg/L	-	-	-	-	-
Ammonia (as N)	mg/L	-	-	0.131 - 2.08[4]	0.681-28.3[4]	0.021 - 231[5]
Bromide (Br)	mg/L	-	-	-	-	-
Chloride (Cl)	mg/L	250		150	600	120
Fluoride (F)	mg/L	1	1.5	0.4[6]		0.12
Nitrate (as N)	mg/L	-	10	40	200	13
Nitrite (as N)	mg/L	-	1.0	0.02-0.20[7]	0.06	0.06
Total Kjeldahl Nitrogen	mg/L	-	-	-	-	-
Total Nitrogen	mg/L	-	-	-	-	-
Orthophosphate - Dissolved (as P)	mg/L	-	-	-	-	-
Phosphorus (P)-Total	mg/L	-	-	-	-	-
Sulphate (SO_4)	mg/L	500	500	128-429[8]	-	-
Cyanides						
Cyanide, Weak Acid Diss	mg/L	-	-	<0.005	0.01	0.005 as free
Cyanide, Total	mg/L	0.2	0.20	-	-	-
Organic/ Inorganic Carbon						
Dissolved Organic Carbon	mg/L	-	-	BD	BD	-
Total Organic Carbon	mg/L	4	4	BD	BD	-

(continued)

Table 9.3-2. Provincial Water Quality Guidelines for the Protection of Freshwater Aquatic Life and Drinking Water, and Federal Water Quality Guidelines for the Protection of Freshwater Aquatic Life (continued)

		BC MOE[1]				CCME FW[2] Long-term Max
		Drinking Water (DW)		Aquatic Life (AW)		
Parameter	Unit	30-day Avg.	Max.	30-day Avg.	Max.	
Total Metals						
Aluminum (Al)	mg/L	-	-	-	-	0.005 - 0.1[9]
Antimony (Sb)	mg/L	-	-	-	-	-
Arsenic (As)	mg/L	0.025[10]		0.005		0.005
Barium (Ba)	mg/L	-	-	-	-	-
Beryllium (Be)	mg/L	-	-	-	-	-
Bismuth(Bi)	mg/L	-	-	-	-	-
Boron (B)	mg/L	5	5	1.2	1.2	1.5
Cadmium (Cd)	mg/L	-	-	-	-	0.00009[11]
Calcium (Ca)	mg/L	-	-	-	-	-
Chromium (Cr)	mg/L	-	-	-	-	0.001[12]
Cobalt (Co)	mg/L	-	-	0.004	0.110	-
Copper (Cu)	mg/L	-	0.5	0.002-0.01[13]	0.002-0.026[13]	0.002-0.004[14]
Iron (Fe)	mg/L	-	-	1.0	1.0	0.3
Lead (Pb)	mg/L	None proposed	0.05	0.004-0.016[15]	0.003-0.33[15]	0.001-0.007[16]
Lithium (Li)	mg/L	-	-	-	-	-
Magnesium (Mg)	mg/L	-	-	-	-	-
Manganese (Mn)	mg/L	-	-	0.605-1.9[17]	0.54-3.8[17]	-
Mercury (Hg)	mg/L	-	0.001	0.00000125-0.0002	-	0.000026
Molybdenum (Mo)	mg/L	-	0.25	1	2	0.073
Nickel (Ni)	mg/L	-	-	-	-	0.025-0.150[18]
Phosphorus (P)	mg/L	-	-	-	-	-
Potassium (K)	mg/L	-	-	-	-	-
Selenium (Se)	mg/L	-	0.010	0.002	-	0.001
Silicon (Si)	mg/L	-	-	-	-	-
Silver (Ag)	mg/L	-	-	0.00005-0.0015[19]	0.0001-0.003[19]	0.0001
Sodium (Na)	mg/L	-	-	-	-	-
Strontium (Sr)	mg/L	-	-	-	-	-
Thallium (Tl)	mg/L	-	-	0.0003[20]		0.0008
Tin (Sn)	mg/L	-	-	-	-	-
Titanium (Ti)	mg/L	-	-	-	-	-
Uranium (U)	mg/L	-	-	0.3[20]		0.015
Vanadium (V)	mg/L	-	-	-	-	-
Zinc (Zn)	mg/L	5	5	0.0075-0.240[21]	0.033-2.65[21]	0.03

(continued)

Table 9.3-2. Provincial Water Quality Guidelines for the Protection of Freshwater Aquatic Life and Drinking Water, and Federal Water Quality Guidelines for the Protection of Freshwater Aquatic Life (completed)

		BC MOE[1]				
		Drinking Water (DW)		Aquatic Life (AW)		CCME FW[2]
Parameter	Unit	30-day Avg.	Max.	30-day Avg.	Max.	Long-term Max
Dissolved Metals						
Aluminum (Al)	mg/L	-	0.2	0.005-0.05[22]	0.02-0.1	-
Iron (Fe)	mg/L	-	-	-	0.35	-

[1] BC MOE (2014)
[2] CCME (2013)
[3] Background dependent
[4] Ammonia concentration is pH and temperature dependent based on tabulations.
[5] Ammonia concentration is pH and temperature dependent, see Table 9.3-3.
[6] Fluoride concentration - 0.4 as a maximum where the water hardness is 10 mg/L $CaCO_3$ otherwise use the equation: LC50 fluoride = -51.73 + 92.57 log10 (Hardness) and multiply by 0.01
[7] Nitrite concentration – dependent on chloride concentration (0.06 mg/L as a maximum, 0.2 mg/L as a 30-day average)
[8] Sulphate concentration - dependent on water hardness: very soft (0-30 mg/L) - 128 mg/L SO_4; soft to moderately soft (31-75 mg/L) - 218 mg/L SO_4; moderately soft/hard to hard (76-180 mg/L) – 309 mg/L SO_4; very hard (181-250 mg/L) - 419 mg/L SO_4.
[9] Aluminum concentration - 5 µg/L if pH < 6.5; 100 µg/L if pH ≥ 6.5
[10] Arsenic interim guideline
[11] Cadmium concentration - When the water hardness is > 0 to < 17 mg/L: 0.04 µg/L; At hardness ≥ 17 to ≤ 280 mg/L, calculated using this equation: cadmium (µg/L) = $10^{\{0.83\ (\log[\text{hardness}])\ -\ 2.46\}}$; At hardness > 280 mg/L: 0.37 µg/L
[12] Chromium concentration is for Chromium hexavalent CrVI
[13] Copper concentration (BC MOE)- 30-day average: at hardness ≤ 50 mg/L then less than or equal to 2 µg/L, at hardness > 50 mg/L then less than or equal to 0.04 (mean hardness) in µg/L; maximum concentration: concentration is (0.094(hardness)+2) in µg/L
*[14] Copper concentration (CCME) -When the water hardness is 0 to < 82 mg/L, 2 µg/L; At hardness ≥82 to ≤180 mg/L, calculated using this equation: copper (µg/L) = 0.2 * $e^{\{0.8545\ [\ln(\text{hardness})]-1.465\}}$; At hardness >180 mg/L, 4 µg/L. If the hardness is unknown, 2 µg/L.*
[15] Lead concentration (BC MOE) – 30-day average: at hardness greater than 8 mg/L, calculated using the equation 3.31 + $e^{(1.273\ \ln\ (\text{mean hardness})\ -\ 4.704)}$ in µg/L; maximum concentration: at hardness ≤ 8 mg/L then 3 µg/L total lead, at hardness > 8 mg/L calculated using $e^{(1.273\ \ln\ (\text{hardness})\ -1.460)}$ in µg/L.
[16] Lead concentration (CCME) - When the hardness is 0 to ≤ 60 mg/L, maximum is 1 µg/L; at hardness >60 to ≤ 180 mg/L maximum is calculated using this equation concentration (µg/L) = $e^{\{1.273\ [\ln(\text{hardness})]-4.705\}}$; at hardness >180 mg/L, the CWQG is 7 µg/L. If the hardness is unknown, the CWQG is 1 µg/L.
[17] Manganese concentration – 30 d average: calculated from 0.0044 hardness + 0.605; maximum concentration: calculated from 0.01102 hardness + 0.54
[18] Nickel concentration - When the water hardness is 0 to ≤ 60 mg/L, 25 µg/L; at hardness > 60 to ≤ 180 mg/L, calculated using this equation CWQG (µg/L) = $e^{\{0.76\ [\ln(\text{hardness})]+1.06\}}$; at hardness >180 mg/L, the CWQG is 150 µg/L. If the hardness is unknown, the CWQG is 25 µg/L.
[19] Silver concentration – 30-day average: at hardness ≤ 100 mg/L concentration is 0.05 µg/L, at hardness > 100 mg/L concentration is 1.5 µg/L; maximum concentration: at hardness ≤ 100 mg/L concentration is 0.1 µg/L, at hardness > 100 mg/L concentration is 3.0 µg/L.
[20] Working guideline based on the water quality guidelines for Ontario.
[21] Zinc concentration – 30 d average: use the equation 7.5 + 0.75 x (hardness -90); maximum concentration: use the equation 33 + 0.75 x (hardness -90)
[22] Aluminum (dissolved) concentration – 30 d average: at pH ≥ 6.5, 0.05 mg/L, at pH <6.5, calculated using $e^{(1.6\ -\ 3.327\ (\text{median pH})\ +\ 0.402\ K)}$ where K = $(\text{median pH})^2$; maximum concentration at pH ≥ 6.5, 0.1 mg/L, at pH <6.5, calculated using $e^{(1.209\ -\ 2.426\ (\text{pH})\ +\ 0.286\ K)}$ where K = $(\text{pH})^2$.

Table 9.3-3. Ammonia Concentration as a Function of pH and Temperature

Temperature (°C)	pH							
	6.0	6.5	7.0	7.5	8.0	8.5	9.0	10.0
0	231	73.0	23.1	7.32	2.33	0.749	0.25	0.042
5	153	48.3	15.3	4.84	1.54	0.502	0.172	0.034
10	102	32.4	10.3	3.26	1.04	0.343	0.121	0.029
15	69.7	22.0	6.98	2.22	0.715	0.239	0.089	0.026
20	48.0	15.2	4.82	1.54	0.499	0.171	0.067	0.024
25	33.5	10.6	3.37	1.08	0.354	0.125	0.053	0.022
30	23.7	7.50	2.39	0.767	0.256	0.094	0.043	0.021

Note: Ammonia concentration is expressed in mg/L NH_3.

The Brucejack Property contains a wide range of rock types, with 24 unique rock lithologies identified by Pretivm geologists from drill core (see Section 5.4, Regional and Project Geology and Mineralization). Mapping within the Brucejack area shows many of these rock types are intensely altered and this, in addition to a diverse range of mineral assemblages, adds to the difficulty in relating logged drill core to stratigraphic sequences. Pretivm developed a geological model to relate these logged lithologies to seven model units that best categorize the rock composition (Table 9.3-4). For the geochemical characterization of the site, sample materials are classified as one of the seven geological model units based on geochemical assay results (i.e., Ti/V) and/or its proximity to intensely silicified rocks located within the central part of the deposit (Section 5.6, Geochemical Characterization).

Table 9.3-4. Description of Pretivm Main Geological Model Units

Model Unit	Description	Sulphides
P2	Megacrystic, plagioclase, K-feldspar and hornblende phyric flow.	Pyrite with minor sphalerite and trace chalcopyrite
Fragmental	Hornblende and/or feldspar phyric latite to andesite fragmental volcanic rocks and subordinate flows with minor ash and lapilli tuff.	Pyrite with minor sphalerite and trace chalcopyrite
Conglomerate	Heterolithic boulder to course cobble conglomerate with sandstone.	Pyrite with minor sphalerite and trace chalcopyrite
Silicified Cap	Silicified rocks; typically poorly sorted heterolithic conglomerate, lesser sandstone and local mudstone; commonly includes rhyolite fragments.	Pyrite with minor sphalerite and trace chalcopyrite
Volcanic Sedimentary Facies (VSF)	Volcanically derived siltstone and sandstone with minor arenite and pebble conglomerate.	Pyrite with minor sphalerite and trace chalcopyrite
Office P1	Hornblende, feldspar phyric latite flows.	Pyrite with minor sphalerite and trace chalcopyrite
Bridge P1	Hornblende, feldspar phyric latite flows. Same general rock type as Office P1 but with a different age and geochemical signature.	Pyrite with minor sphalerite and trace chalcopyrite

Note: reproduced from Table 5.6.1 in Section 5.6, Geochemical Characterization.

To facilitate comparison with the geochemical characterization of the mine site, groundwater quality was evaluated by considering sample results from monitoring wells completed in the main geological model units.

Surficial project geology and monitoring well locations within the LSA are shown on Figure 9.3-2. Specifically, monitoring wells 1A/B and 8A/B are screened in Office P1 material. Volcanic sedimentary facies (VSF) host well screens pertaining to MWs 4A/B, 5A/B and 6A/B. The geological model unit P2 bear MWs 2A and 3A/B and Bridge P1 hosts 12A/B. The grouping of monitoring wells in this manner will assist with identifying the presence of trends specific to a geological model unit.

As described in Section 9.3.2, historical mining and mineral exploration activities, as well as current exploration activities have affected groundwater quality within the Brucejack watershed; no pre-disturbance baseline groundwater quality data are available. As such, the sample suite was curated to remove those samples with a high likelihood of contamination from on-site drilling activities. Specifically, these quality control measures include a timing comparison between sampling and on-site activities (e.g., drilling and dewatering), and a statistical analysis to identify outliers. Following this review, it was determined that 18 samples should be removed from the data set:

- MW-BGC11-BJ-03A (n = 1);
- MW-BGC11-BJ-03B (n = 1);
- MW-BGC11-BJ-04A (n = 1);
- MW-BGC12-BJ-04B (n = 4);
- MW-BGC11-BJ-05A (n = 2);
- MW-BGC11-BJ-05B (total metals concentrations only);
- MW-BGC11-BJ-06A (n = 2);
- MW-BGC12-BJ-06B (n = 3);
- MW-BGC12-BJ-08B (n = 3); and
- MW-BGC12-BJ-12A (n = 1).

For complete details of this analysis and the approach to baseline groundwater quality characterization, refer to Appendix 9-A, Brucejack Project Environmental Assessment - Hydrogeology Baseline Report.

Hydrogeological Dewatering Activities

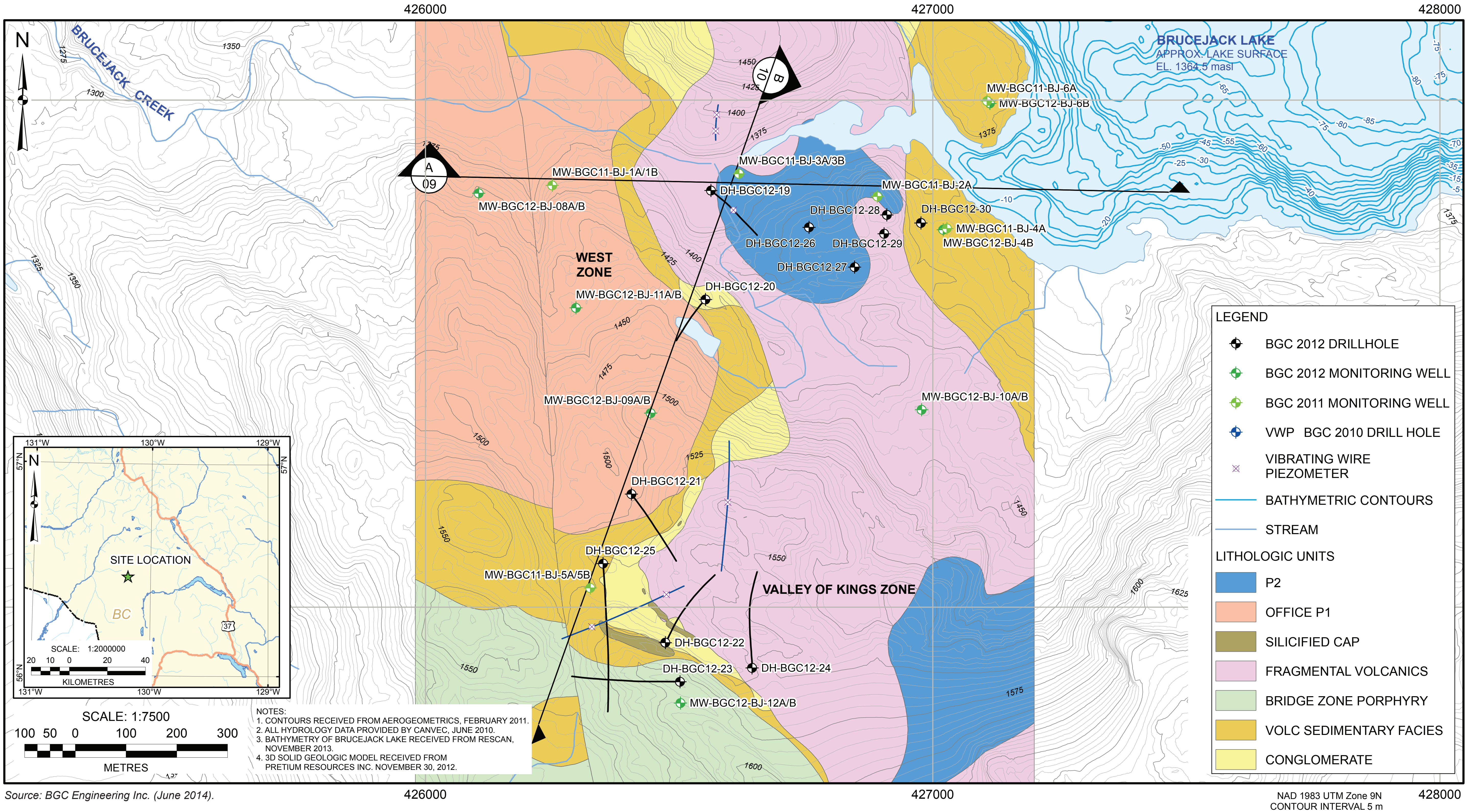
Pretivm commenced dewatering of the existing underground workings in late fall 2011, and proceeded for a period of approximately three months, terminating in February 2012. Dewatering of the existing and expanded workings resumed in August 2012, and has been ongoing since that time. During this time, “drawdown” in the workings was monitored by Pretivm, as was volumetric discharge from the underground workings via an in-line flow gauge. These data were used to evaluate the large-scale hydraulic behaviour of the site with a numerical model.

Hydrogeological Numerical Modelling

A detailed numerical model was constructed to simulate baseline conditions and to calibrate hydraulic parameters (Appendix 9-B, Brucejack Gold Mine Project: Environmental Noise Modelling Study). The same model, with appropriately adjusted boundary conditions, was used to perform the predictive simulations reported later.

Figure 9.3-2

Monitoring Well and Drill Hole Locations



Source: BGC Engineering Inc. (June 2014).

Baseline conditions were simulated for three different scenarios, plus a sensitivity analysis was performed to evaluate uncertainty in the models. A steady-state simulation was run by assigning boundary conditions to represent average annual conditions. A transient simulation was run using boundary conditions to simulate seasonal trends in groundwater recharge and evapotranspiration, hydraulic heads and creek flows. Winter conditions were simulated over a six-month period, from November to April, with summer conditions occurring over a six-month period, from May to October. Hydraulic parameters were also calibrated to head observations during initial dewatering activities. These three sets of simulations were used to calibrate the input parameters and boundary conditions. Subsequently the calibrated model was benchmarked to flow rate data from the large-scale adit dewatering program.

Groundwater Vistas (Version 6.22, Build 2; Environmental Simulations Inc. 2011), a graphical user interface, was used to develop the MODFLOW-Surfact groundwater flow model for the Project and surrounding regional study area. MODFLOW is an industry standard 3-Dimensional (3-D), finite-difference groundwater flow model developed by the U.S. Geological Survey (Harbaugh et al. 2000). Surfact (Version 4.0; HydroGeoLogic 2011) allows the simulation of variably saturated flow, seepage faces, and time-varying hydraulic properties, all of which were important features for this site. Groundwater discharge to mine workings and to surface-water receptors was quantified using the US Geological Survey (USGS) ZONEBUDGET program (Version 3.01; Harbaugh 1990). For predictive simulations, discussed later, a particle-tracking, post-processing program MODPATH (Version 6.0.01; Pollock 2012), was used to define transport pathways from underground workings to surface water receptors.

Inputs to the model include (1) hydraulic parameters that control the flow of water within the model domain, and (2) boundary conditions that control the addition and removal of water to and from the model domain. The model inputs were calibrated and benchmarked using the available site data.

The 3-D groundwater model domain encompassed the entire watershed of the RSA. The model grid consisted of 220 columns and 183 rows, covering an area of approximately 12 by 12 km. Ten model layers were used to discretize the domain in the vertical dimension for a total of 402,600 grid blocks. Uniform 25 m by 25 m grid blocks were defined in the vicinity of the existing and proposed underground workings (LSA). The horizontal dimensions of the grid blocks were expanded away from this operational area by a factor of approximately 1.5 to a maximum size of 120 m by 150 m at the outer regions.

The elevation of the top layer was set at ground surface. In the vertical direction, the upper 300 m was divided into 7 layers, with layers increasing in thickness from 5 m in layer 1 to 100 m in layer 7. The three underlying layers ranged from approximately 50 m thick in the valley bottoms to 1,100-m thick below the ridge tops. The base of the model domain was set at sea level, which is approximately 1,000 m below the deepest extent of the proposed underground mine workings.

In mountainous areas with abundant precipitation it is usual that hydrogeologic processes are dominated by topography and surface-water processes. Thus, groundwater divides correspond to topographic divides. Consequently a groundwater divide was inferred along ridge tops (i.e., topographic divide) that form the upper reaches of the Sulphurets Creek watershed, which is the hydrogeologic area of interest. Grid blocks lying outside of this region were deactivated within the model.

The conceptual models and boundary conditions implemented in the numerical model are presented in the following section, after a summary of findings from the site investigations.

9.3.4 Characterization of Hydrogeology Baseline Conditions

9.3.4.1 Hydrogeological Parameters

Site wide, a general trend of decreasing bedrock hydraulic conductivity with depth is observed, although hydraulic conductivity varies by two to three orders of magnitude at any given depth. Based on available data there is no apparent relationship between hydraulic conductivity and the major structure in the immediate vicinity of the Project, the Brucejack Fault. Final distributions of hydraulic conductivity were calibrated in the model, as shown in Figure 9.3-3 along with field-observed K values. Detailed results are documented in Appendices 9-A and 9-B.

9.3.4.2 Groundwater Levels and Flow Directions

In general, groundwater elevations are observed to mimic topography (i.e., higher groundwater elevations in instrumentation completed at higher elevations and vice versa), and show greater seasonal variation at higher elevations. It follows that, in general, groundwater flow at the site follows topography, with groundwater recharge occurring at higher elevations and groundwater discharge occurring in the vicinity of Brucejack Creek and Brucejack Lake. A component of groundwater flow also occurs westwards, towards the Brucejack Fault and Sulphurets Glacier.

Groundwater elevation time series plots (Appendix 9-A) show pronounced annual variations in groundwater elevation for a given location, with water levels slowly decreasing 10 to 20 m over the course of the winter season, and recovering rapidly with the recharge that occurs during snowmelt. In general, groundwater elevations are observed to mimic topography (i.e., higher groundwater elevations in instrumentation completed at higher elevations and vice versa), and show greater seasonal variation at higher elevations. Observed hydraulic heads at the Project ranged from at or just above ground surface, typically at lower elevations, to 60 to 70 m below ground surface. Figure 9.3-4 through Figure 9.3-7 show measured and interpreted hydraulic heads, in maps and sections, for the LSA.

9.3.4.3 Groundwater Quality

For the purposes of this baseline hydrogeologic study, concentrations of physical parameters, total metals, and dissolved metals were compared to BC MOE AW and DW guidelines (BC MOE 2010) and to CCME FW guidelines (CCME 2013). In general, the pH of the groundwater is moderately alkaline (~ pH 8) and groundwater temperatures are approximately 2°C, with minimal seasonal variation. Chloride and nutrient concentrations (i.e., ammonia, nitrate and nitrite) from all samples are observed to be below the lowest guideline values.

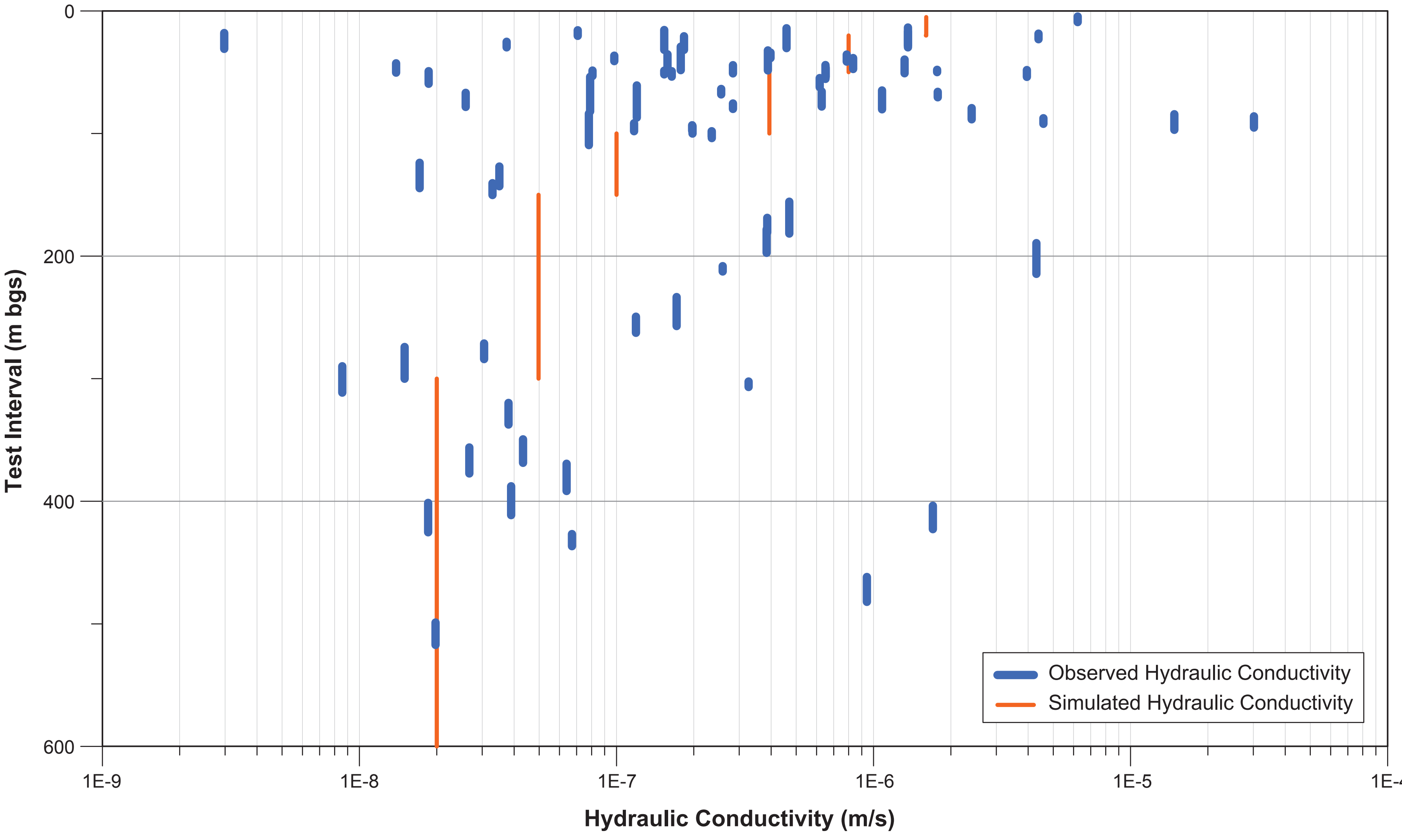
Groundwater water quality sample results were also considered based on the geological model unit surrounding the well screens. Specifically, groundwater samples are associated with four materials: Office P1, P2, VSF, and Bridge P1.

<u>Office P1</u>

Two sets of nested monitoring wells have screens seated in Office P1 material: MW-BGC11-BJ-1A/B and MW-BGC12-BJ-8A/B. Groundwater chemistry reflecting the Office P1 groundwater type was measured from a total of 11 samples, with the majority collected in MW-BGC12-BJ-8A/B (n = 9). Groundwater chemistry appears to be relatively constant for the Office P1 material type, with pH that ranges between 7.0 and 8.3, and modest total suspended solids and turbidity concentrations (i.e., < 200 mg/L and < 100 NTU). Total alkalinity values are typically around 75 mg/L, while ammonia, nitrite and orthophosphate are generally below detection limits. Sulphate values do not show seasonal variation and are, on average, 35 mg/L.

Figure 9.3-3

Observed and Model-Calibrated Hydraulic Conductivity vs. Depth



Source: BGC Engineering Inc. (June 2014).

P2

A total of 21 samples were taken from 3 monitoring wells situated in P2 material (MW-BGC11-BJ-2A: n = 8; MW-BGC11-BJ-3A: n = 7; MW-BGC11-BJ-3B: n = 6). One sample from the MW-BGC11-BJ-3B dataset was identified as "likely contaminated" and removed from the baseline dataset. In general, groundwater samples taken from these wells show moderately alkaline pH values (i.e., pH 8.0) with little variation (i.e., ± 0.2 pH units). These waters are typically more turbid than groundwater wells from the Office P1 unit, with ranges between 2 to 777 NTU. Alkalinities and sulphate concentrations are also similar between these locations with average values between 75 to 95 mg $CaCO_3$/L and 48 to 101 mg/L, respectively.

Volcanic Sedimentary Facies

Three nested monitoring well sets are installed in VSF material (i.e., MW-BGC11/12-BJ-4A/B, MW-BGC11-BJ-5A/B, and MW-BGC11/12-BJ-6A/B) for a total of 18 samples. Groundwater chemistries measured from VSF material typically show moderately alkaline pHs (i.e., pH ~ 8.0) and modest sulphate ranges (i.e., 69 to 140 mg/L) relative to those values observed from Office P1 and P2. Alkalinities from the VSF grouped dataset range between 40 to 126 mg $CaCO_3$/L.

Bridge P1

One monitoring well (MW-BGC12-BJ-12A) was situated in Bridge P1 material. Two samples from this well are used in the baseline analysis and, due to the limited sample suite, these results should be considered preliminary. In general, these waters are characterized as very hard (> 181 mg/L), moderately alkaline (pH 7.8) with high sulphate (177 mg/L) and moderate alkalinity (104 mg $CaCO_3$/L).

Summary of Groundwater Qualities

An analysis of bulk chemistries from each material revealed several metals presented common exceedances of guideline values. Median total metal concentrations of Al, Ag, As, Cr, Cu, and Fe are enriched in all groundwaters. Additional material-specific metals exceedances included total Cd and Pb (VSF and Bridge P1), total Co (VSF), total Hg (P2), and F and total Zn (P2, VSF and Bridge P1).

Piper diagrams (Figure 9.3-8) show all groundwater samples present similar major cation concentrations; however, anion constituents appear to show material-specific trends. Office P1 is representative of one end member, with low sulphate and high alkalinity, and Bridge P1 is highlighted as the opposite end-member. These results, coupled with the previous discussion of metal exceedances, imply that groundwater from Office P1 and Bridge P1 units likely represent the baseline groundwater end-members present at the Brucejack Mine Site.

9.3.4.4 Hydrogeological Dewatering Activities

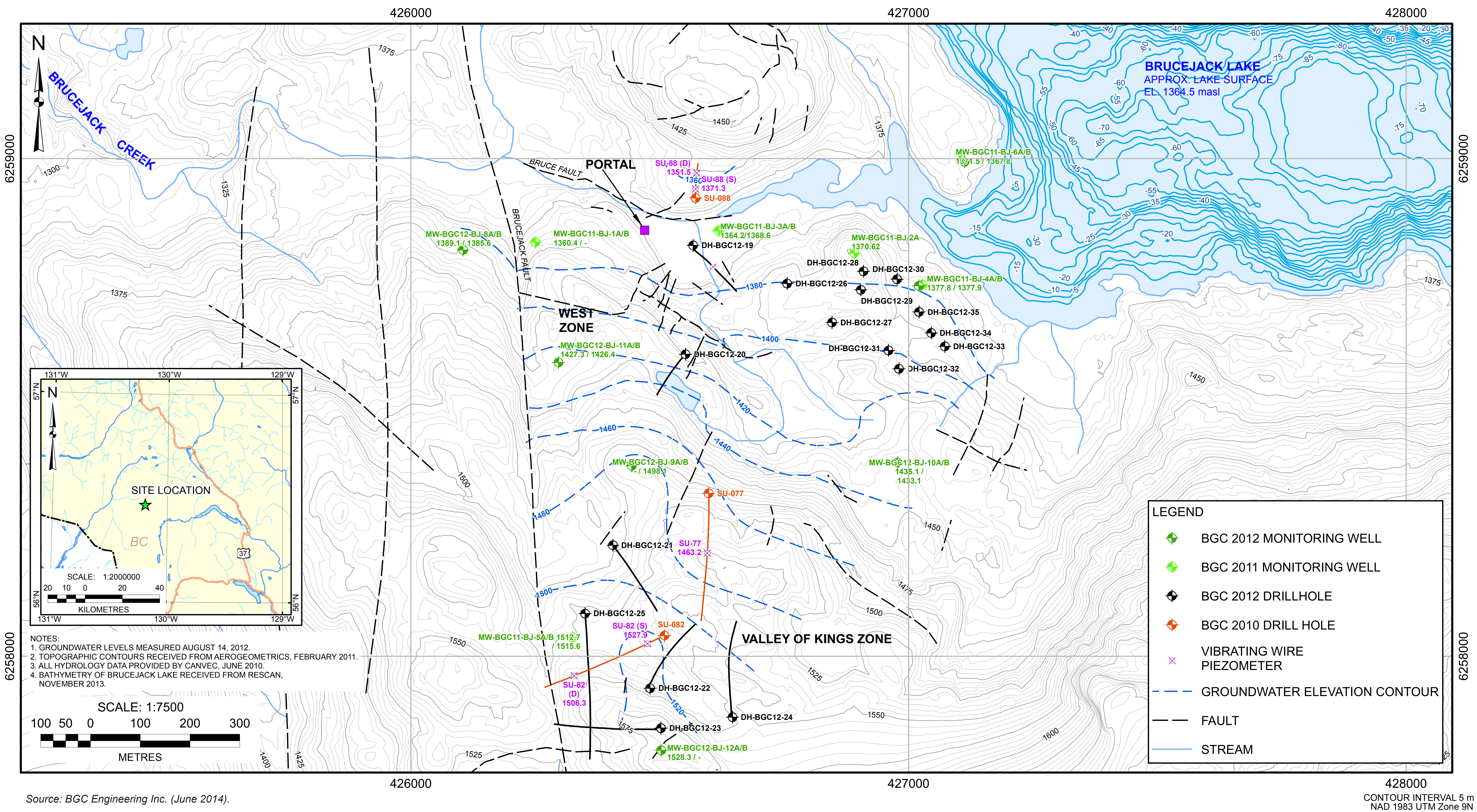
Adit dewatering, which occurred from November 2011 to February 2012 and August 2012 onwards, created a pronounced decrease in groundwater elevation in nearby monitoring wells. Dewatering activities also changed hydraulic head gradients, leading to increasingly large gradients associated with downward groundwater flow in areas affected by dewatering. These observations created the opportunity to subject the numerical model to a benchmarking test, discussed below, to provide further confidence in the model.

9.3.4.5 Hydrogeological Numerical Modelling and Sensitivity Analyses

The basic framework for the numerical model was introduced in Section 9.3.3.2. Here the details that depend upon the field observations are introduced prior to the model simulation results.

Figure 9.3-4

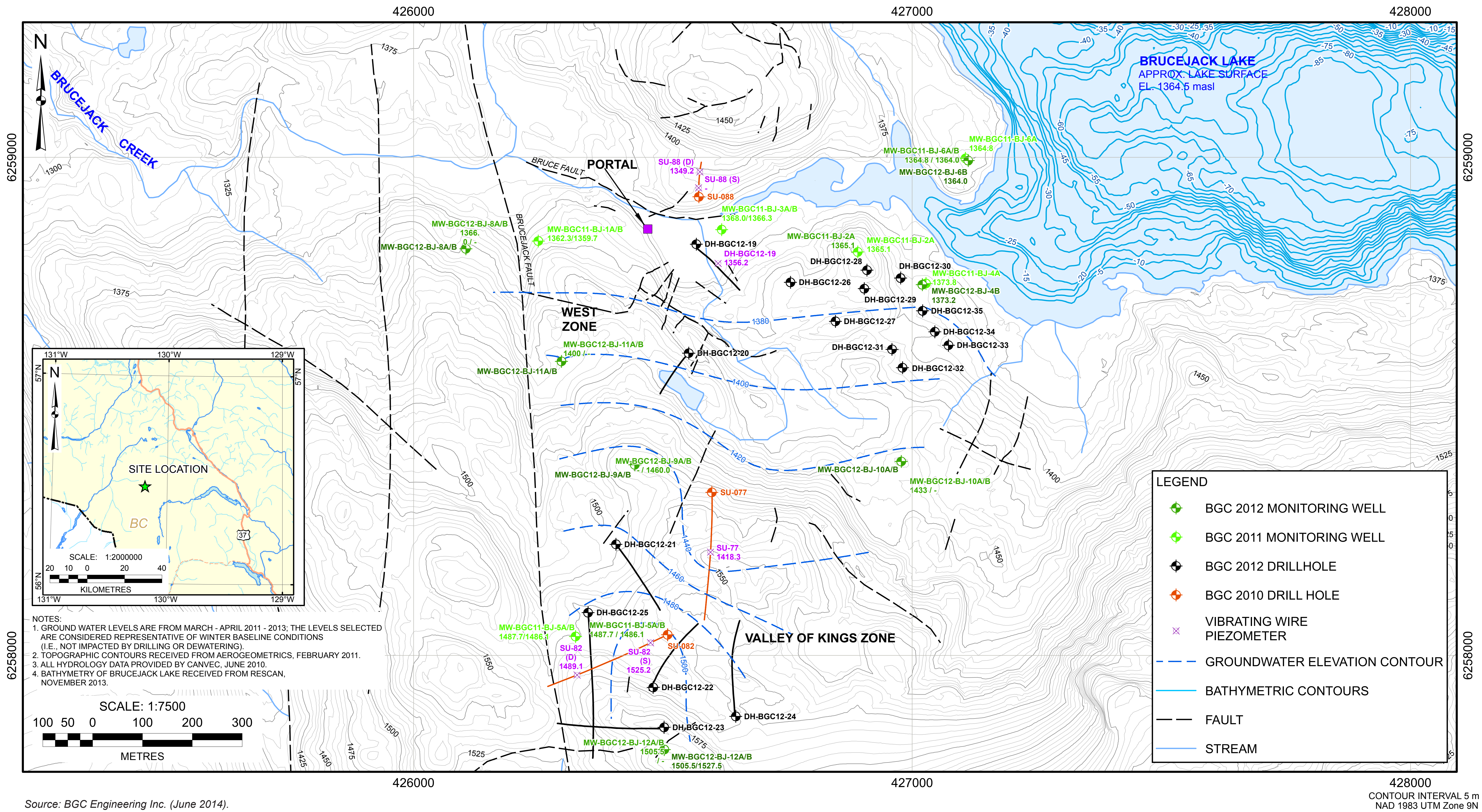
Interpreted Groundwater Elevation Contour Map — Summer



Source: BGC Engineering Inc. (June 2014).

Figure 9.3-5

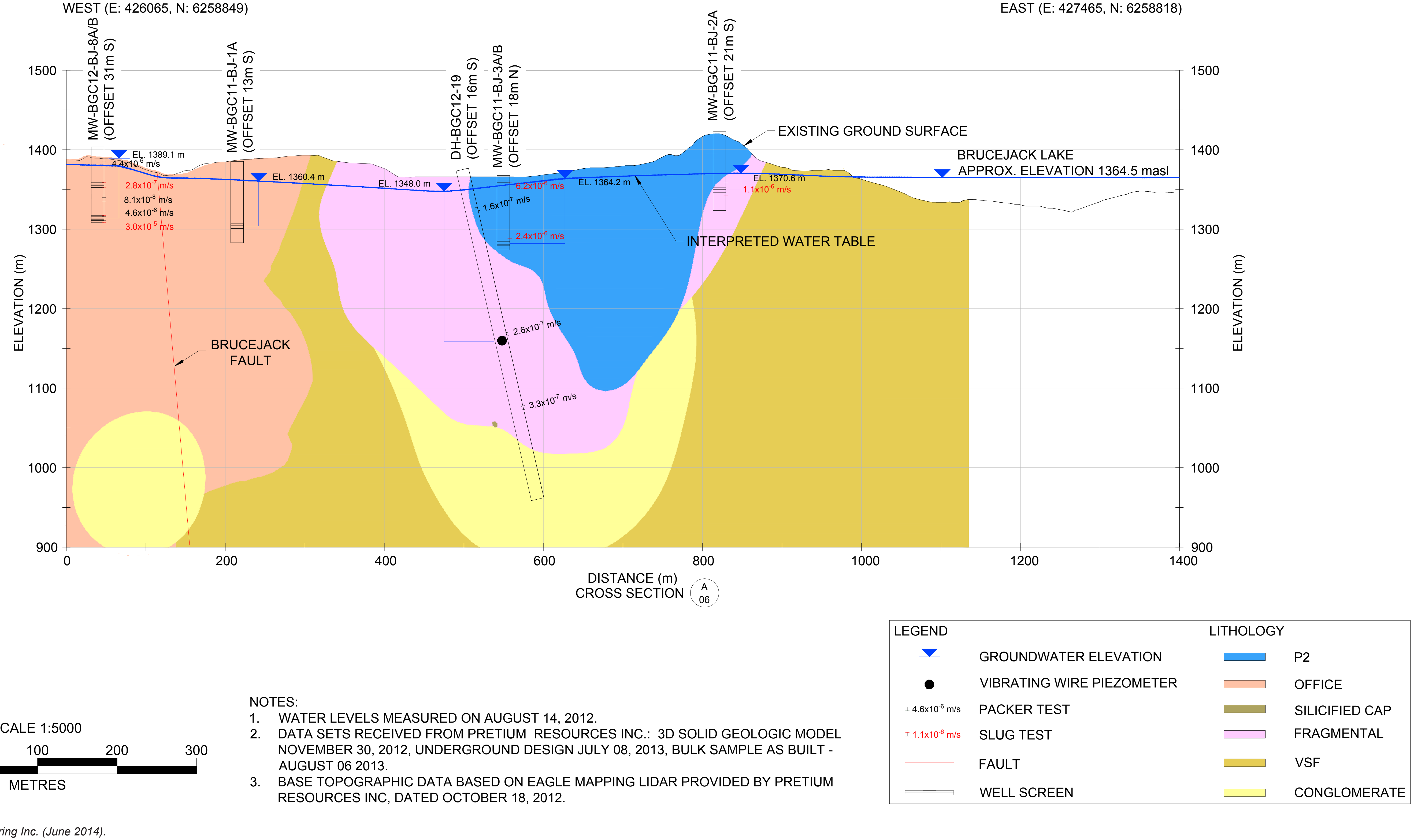
Interpreted Groundwater Elevation Contour Map — Winter



Source: BGC Engineering Inc. (June 2014).

Figure 9.3-6

Hydrogeological Cross-Section A

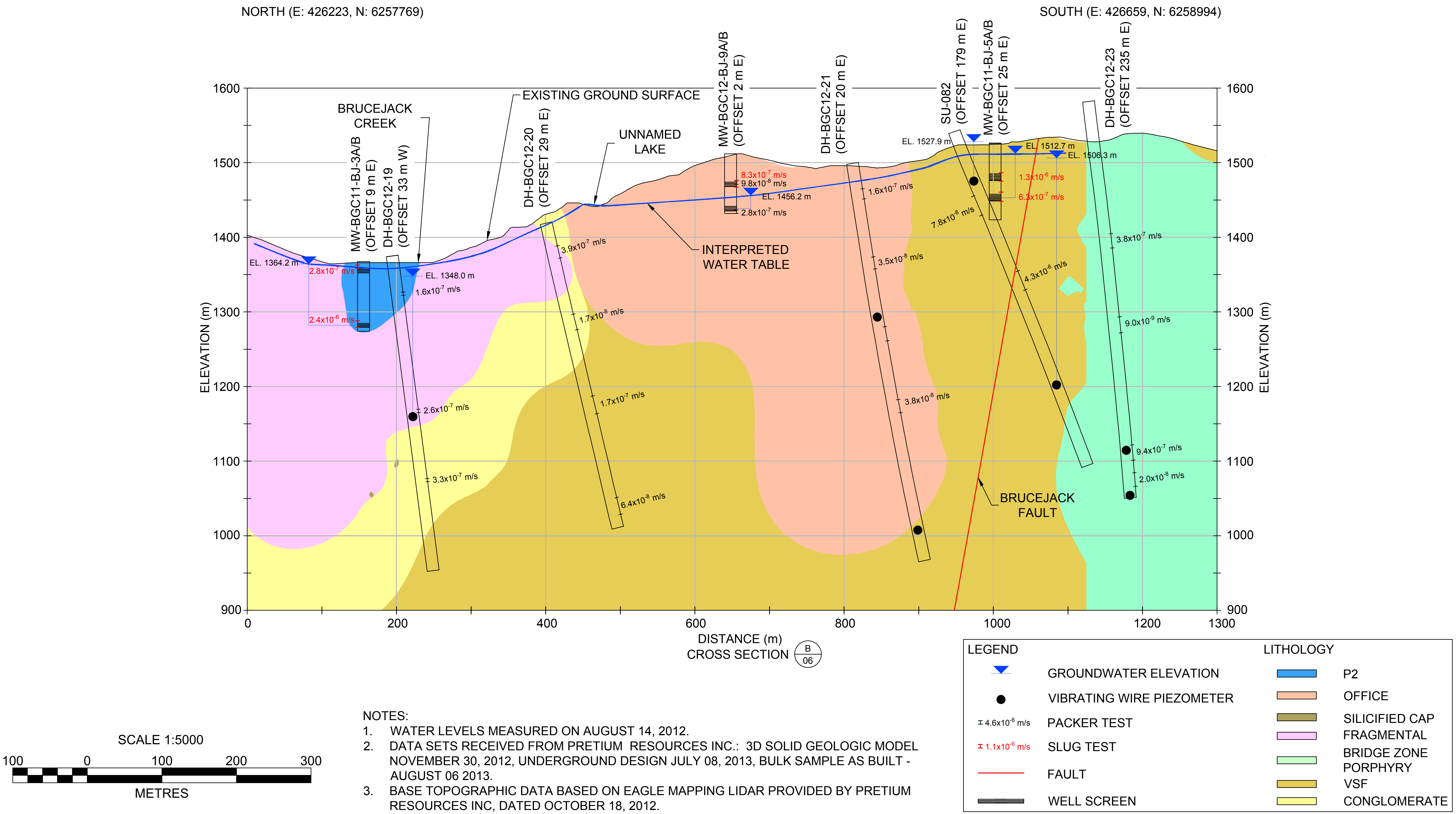


NOTES:
1. WATER LEVELS MEASURED ON AUGUST 14, 2012.
2. DATA SETS RECEIVED FROM PRETIUM RESOURCES INC.: 3D SOLID GEOLOGIC MODEL NOVEMBER 30, 2012, UNDERGROUND DESIGN JULY 08, 2013, BULK SAMPLE AS BUILT - AUGUST 06 2013.
3. BASE TOPOGRAPHIC DATA BASED ON EAGLE MAPPING LIDAR PROVIDED BY PRETIUM RESOURCES INC, DATED OCTOBER 18, 2012.

Source: BGC Engineering Inc. (June 2014).

Figure 9.3-7

Hydrogeological Cross-Section B



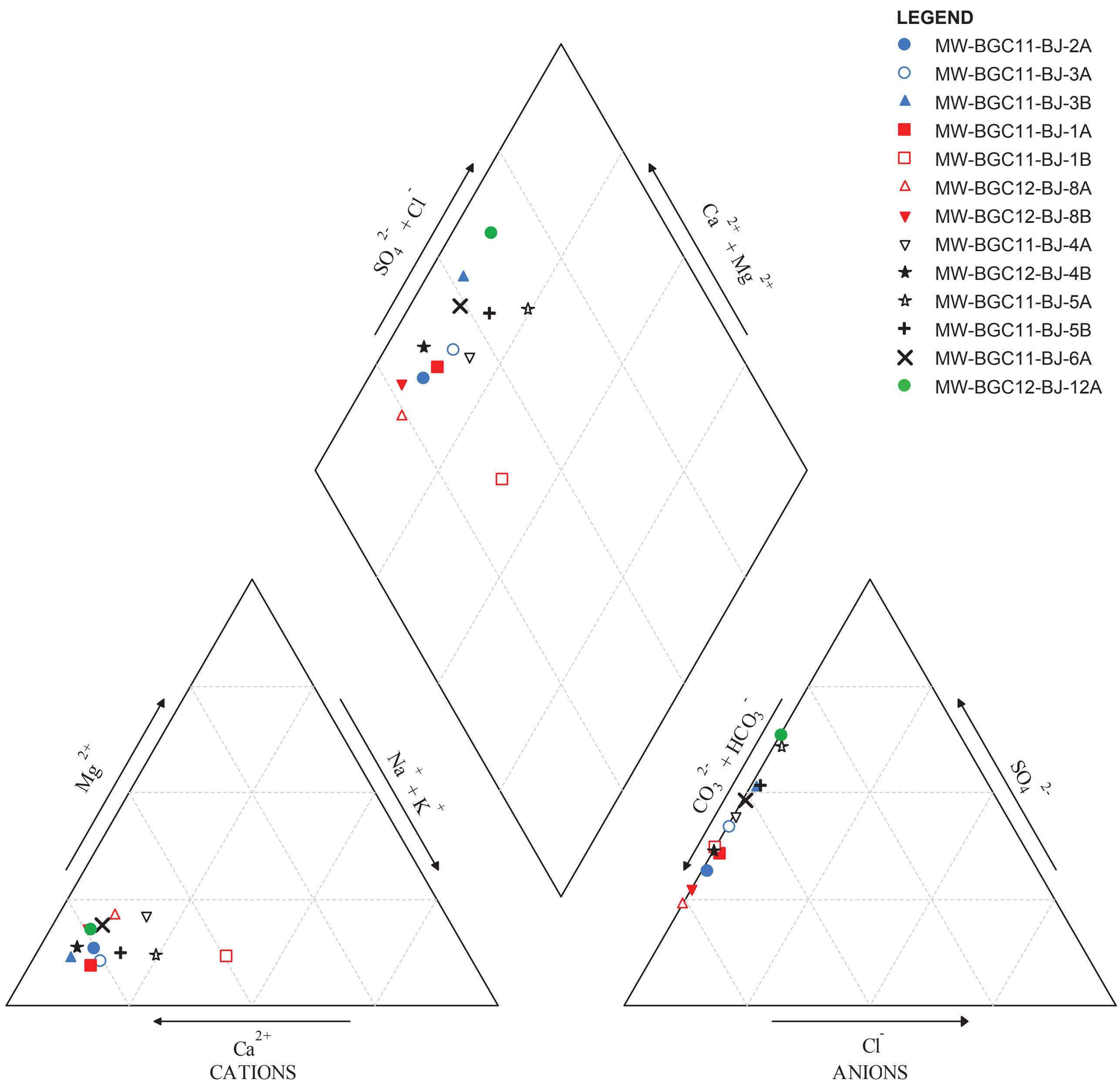
NOTES:

1. WATER LEVELS MEASURED ON AUGUST 14, 2012.
2. DATA SETS RECEIVED FROM PRETIUM RESOURCES INC.: 3D SOLID GEOLOGIC MODEL NOVEMBER 30, 2012, UNDERGROUND DESIGN JULY 08, 2013, BULK SAMPLE AS BUILT - AUGUST 06 2013.
3. BASE TOPOGRAPHIC DATA BASED ON EAGLE MAPPING LIDAR PROVIDED BY PRETIUM RESOURCES INC, DATED OCTOBER 18, 2012.

Source: BGC Engineering Inc. (June 2014).

Figure 9.3-8

Piper Diagram Showing Median Groundwater Concentrations Measured from Brucejack Monitoring Wells



Note: Blue symbols = P2; Red symbols = Office P1; Black symbols = VSF; Green symbol = Bridge P1

Source: BGC Engineering Inc. (June 2014).

Conceptual Model Overview

Measured groundwater elevations suggest that the water table is a subdued replica of topography, with depths to groundwater typically greater in the uplands relative to the valley bottoms. Elevations in the vicinity of the Project range from approximately 500 m in the Sulphurets Creek Valley to over 2,000 m at the highest peaks.

Groundwater enters the flow system from infiltration of precipitation and snowmelt, with lesser components supplied by surface water infiltration from lakes. There are pronounced seasonal fluctuations in groundwater levels, particularly at higher elevations. Groundwater discharge zones are generally restricted to lakes, creeks, gullies, and breaks in slope. Only a minor component of groundwater discharge is anticipated to occur via evapotranspiration.

Regionally and at depth groundwater flow occurs westwards following topography within the RSA, towards the Sulphurets Glacier and further west towards the Unuk River system. The bedrock hydraulic conductivity is sufficiently low that regional head boundaries representing the Unuk River are unnecessary.

Hydrostratigraphy

The distribution of hydrogeologic units within the groundwater model domain is shown on Figure 9.3-9, and the hydraulic parameters assigned are described in Table 9.3-5. These parameters were based on field results and ranges, but refined through model calibration, as described below. Throughout the model domain, hydraulic conductivity was specified to decrease with depth. A distinct model layer for the surficial unconsolidated material model layer was not included because the material is thin and discontinuous, it has a geometric mean hydraulic conductivity that is similar to that of the shallow bedrock unit, and it is generally absent in the area of interest (LSA). Thus, the unconsolidated material was assumed to have properties similar to that of the shallow bedrock within the upper model layer.

Table 9.3-5. Calibrated Hydraulic Parameters Assigned to Hydrogeologic Units

Hydrogeologic Unit	Model Layer(s)	Model Depth Extent (m bgs)[1]	Hydraulic Conductivity[2] (m/s)		S_s[3] (m^{-1})	S_y[3] (-)
			K_h	K_h:K_v		
Hazelton Group	1	0 - 5	2.E-06	1	1.E-05	0.1
	2	5 - 20	2.E-06	1	1.E-06	0.01
	3	20 - 50	8.E-07	1	1.E-06	0.01
	4	50 - 100	4.E-07	1	1.E-06	0.01
	5	100 - 150	1.E-07	1	1.E-06	0.01
	6-7	150 - 300	5.E-08	1	1.E-06	0.01
Stuhini Group	1	0 - 5	1.E-07	1	1.E-05	0.1
	2-4	5 - 100	1.E-07	1	1.E-06	0.01
	5-7	100 - 300	2.E-08	1	1.E-06	0.01
Undifferentiated Bedrock	8-9	300 - 950[4]	2.E-08	1	1.E-06	0.01
	10	950 - 1,600[4]	5.E-09	1	1.E-06	0.01

Notes:

1. "m bgs" indicates metres below ground surface.

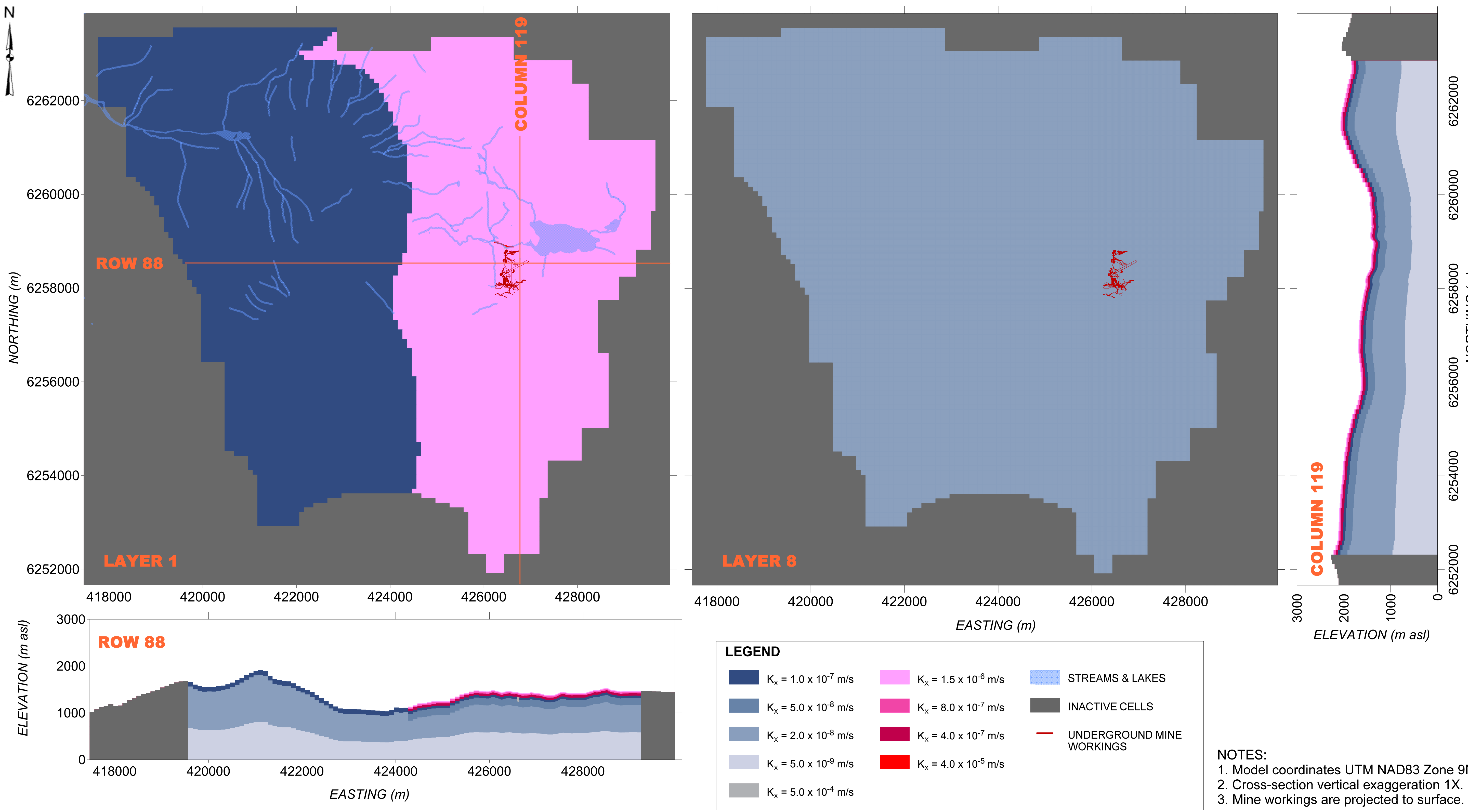
2. "K_h" indicates horizontal hydraulic conductivity; "K_v" indicates vertical hydraulic conductivity.

3. "S_s" indicates specific storage; "S_y" indicates specific yield.

4. Thickness of model layers 8 and 9 ranges from 52 m to 555 m, averaging 325 m. Thickness of model layer 10 ranges from 105 m to 1,110 m, averaging 651 m.

Figure 9.3-9

Model Hydraulic Conductivity Distribution



NOTES:
1. Model coordinates UTM NAD83 Zone 9N.
2. Cross-section vertical exaggeration 1X.
3. Mine workings are projected to surface.

Source: BGC Engineering Inc. (June 2014).

Aquifer storage parameters (i.e., specific storage (Ss) and specific yield (Sy) were assigned based on representative values from reference materials (Maidment 1992; Freeze and Cherry 1979), and were assessed on the basis of transient adit dewatering response observed in monitoring wells in the LSA.

Boundary Conditions

Boundary conditions applied to all model simulations are discussed below. Boundary conditions specific to each calibration or predictive simulation are discussed at the start of appropriate sections later.

Areal recharge was assigned to the water table to represent groundwater recharge from precipitation and runoff. To represent differences in the areal or topographic distribution of precipitation recharge was divided into four zones: valley, mid-slope, uplands, and glacier-covered areas. The areal zonation was held constant while recharge rates were modified as part of the calibration process to best match hydraulic head and stream flow targets. The four recharge zones are shown on Figure 9.3-10, with calibrated rates summarized in Table 9.3-6. Areal evapotranspiration (ET) was only applied at elevations below 1,200 metres above sea level (masl), where vegetation is common, with an extinction depth (i.e., the water table depth at which ET ceases) of 5 m. For transient, seasonal simulations, recharge and ET were only applied during summer stress periods, i.e., May through October.

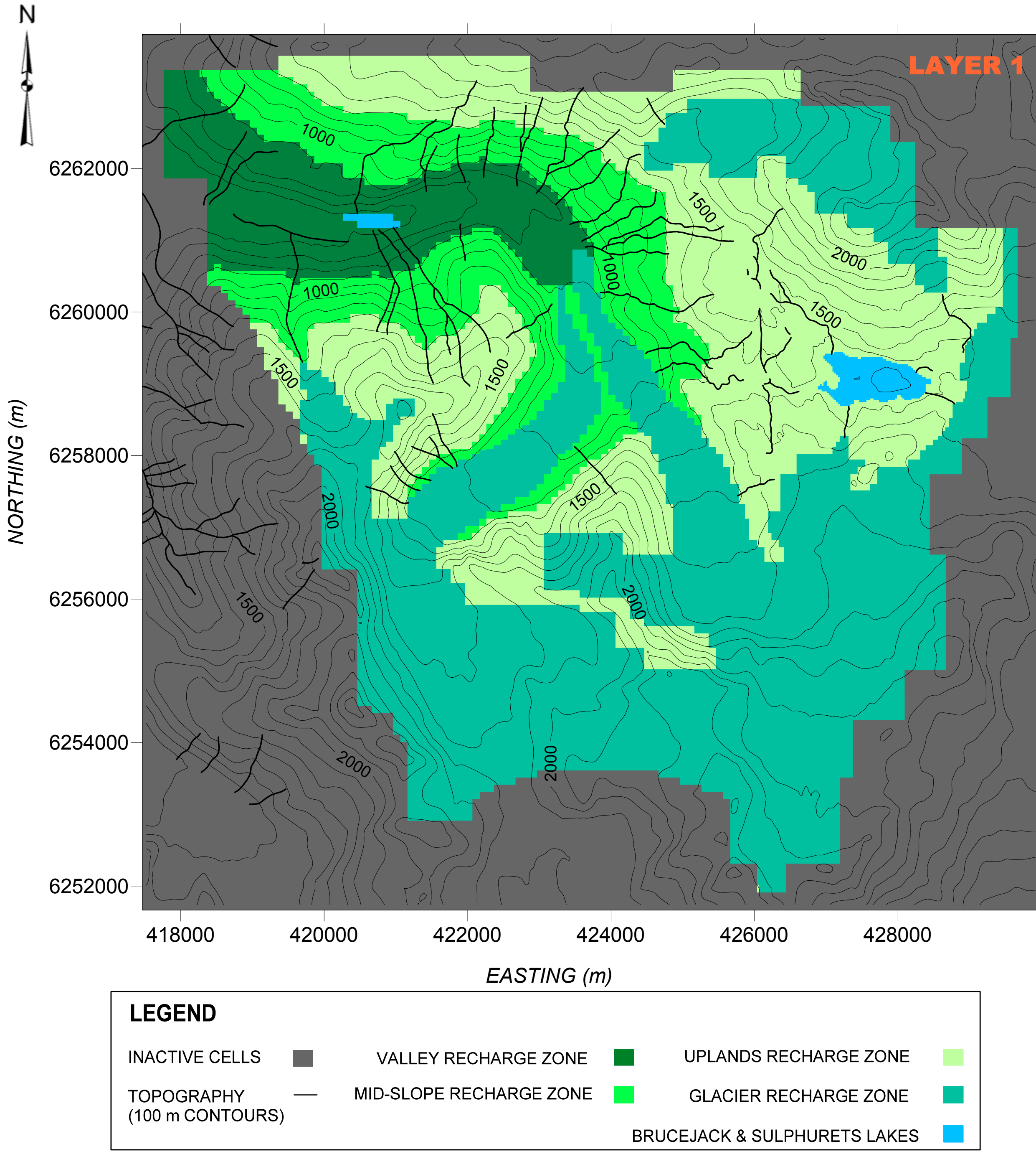
Table 9.3-6. Calibrated Recharge Rates Applied to the Numerical Model

Recharge Zones	Recharge Rates			% of Mean Annual Precipitation
	Steady State (m/d)	Transient (m/d)	Average Annual (mm/year)	
< 900 masl (valley bottom and no glacier coverage)	0.00105	0.00210	384	19%
900 to 1300 masl (mid-slope and no glacier coverage)	0.00123	0.00246	449	22%
> 1300 masl (uplands and no glacier coverage)	0.00150	0.00300	548	27%
glacier coverage	0.00096	0.00096	350	17%

Notes:
1. "masl" indicates metres above sea level.
2. Steady state recharge rate (metres per day [m/d]) applied to year-long (12 month) simulations; transient recharge rate (m/d) applied to summer stress periods only (6 months per year).
3. Recharge rates compared with mean annual precipitation at Unuk River - Eskay Creek meteorological station; comparison does not account for anticipated differences in the areal or topographic distribution of precipitation within the RSA.

The small creeks within the model domain were simulated as drains. The drain representation allows groundwater to discharge to surface when the water table is higher than the specified drain elevation, but does not allow any groundwater recharge from streams. The section of Brucejack Creek downstream of Brucejack Lake and above the Sulphurets Glacier, as well as the stream that runs along the trace of the Brucejack Fault were simulated as rivers. The river representation allows water to both enter and exit the model domain at these boundaries, which are in close proximity to the proposed underground workings. Sulphurets Creek downstream of Sulphurets Lake was also modelled using a river boundary.

Figure 9.3-10
Model Recharge Distribution



NOTES:
1. Model coordinates UTM NAD83 Zone 9N.

Source: BGC Engineering Inc. (June 2014).

The two lakes lying within the model domain, Brucejack Lake and Sulphurets Lake, were simulated using head-dependent and specified-head boundaries, respectively. The general-head boundary (GHB) at Brucejack Lake was set at the approximate current lake level, 1364.5 masl. As limited information on the Brucejack Lake bed was available at the time of modelling, lakebed conductance was calculated based on an assumed bed thickness of 1 m and vertical hydraulic conductivity of $1x10^{-6}$ metres per second (m/s). The constant head boundary at Sulphurets Lake was set at the approximate lake elevation of 590 masl. In the absence of sufficient data, lake elevations did not vary seasonally for the transient model.

Steady-state Calibration and Baseline Results

The model was calibrated to average annual heads using the average annual (i.e., steady-state) boundary conditions described above. Initial hydraulic properties were assigned to each material using best estimates from field studies and were manually adjusted within measured or estimated parameter ranges; such adjustments were performed in conjunction with calibration to transient data outlined in the next section.

Groundwater elevation data were available for 20 instruments in the LSA plus 12 instruments installed during site investigations at the KSM Project (Figure 9.3-1). The frequency and duration of data collection varied widely between calibration targets; for some locations two or more years of monitoring data were available, while for others only two to three months of baseline data (i.e., hydraulic head measurements not impacted by drilling or dewatering) were available. Calculated average annual groundwater elevations were used as calibration targets for the steady-state model where sufficient data were available to capture seasonal fluctuations in water levels. Where sufficient data un-impacted by drilling or dewatering within the LSA were not available, average annual groundwater elevations were estimated by visual assessment of groundwater hydrographs.

Simulated versus observed hydraulic heads for the calibrated steady-state model are presented graphically on Figure 9.3-11 for head targets in the immediate vicinity of existing and proposed underground workings as well as for targets outside the LSA. A normalized root mean square error (NRMSE) of 10% is generally suggested as a guideline for the maximum difference between simulated and measured target values (Wels, Mackie, and Scibek 2012). The NRMSE of the Brucejack model calibration is 1.8% for all hydraulic head targets within the RSA, 8.3% for all head targets within the LSA (i.e., including both geotechnical instrumentation and monitoring wells), and 4.6% for monitoring well targets only in the LSA.

Simulated steady-state groundwater discharge (i.e., baseflow) to Brucejack Lake and the creeks reporting to BJL-H1 was 4,600 m^3/d (0.053 m^3/s). This rate is on the same order as the average annual 7-day low-flow rate of 0.073 m^3/s reported for the BJl-H1 gauging station by Rescan Environmental Services Ltd. (2013) for 2008 to 2011.

A map of the calibrated steady-state simulated water table contours is provided as Figure 9.3-12. In general, the water table is predicted to mimic the surface topography, consistent with the conceptual model of the hydrogeologic system. Within the LSA, the predicted direction of groundwater flow is from areas of higher elevation towards Brucejack Lake and Brucejack Creek. There is a component of deeper groundwater flow that occurs westwards, towards the Sulphurets Glacier.

Transient Seasonal and Dewatering Calibration and Baseline Results

The model was further calibrated to trends in seasonal hydraulic heads and low-flow stream flow measurements using the seasonal (i.e., transient) boundary conditions described above. The emphasis for this transient simulation was matching winter low-flow stream flow data.

Rescan Environmental Services Ltd. (2013) provided daily observed and estimated stream flow data from 2007 through 2012 at BJL-H1. Winter low-flow measurements at BJL-H1 ranged from a daily low of 0.015 m^3/s (1,270 m^3/d) on November 20, 2012 to an estimated mean monthly low flow of 0.065 m^3/s (5,630 m^3/d) during February, and averaged 0.18 m^3/s (15,200 m^3/d) from the months of October through May.

Simulated groundwater discharge (i.e., baseflow) to Brucejack Lake and the creeks reporting to BJL-H1 averaged 7,300 m^3/d (0.084 m^3/s) over the 6-month winter season. Observed and estimated low-flow stream flow and simulated baseflow are summarized in Table 9.3-7 for each stress period within the winter season. In general, the model matches mid-winter flows (January to February stress period) well, with 0.080 m^3/s of baseflow predicted versus 0.072 m^3/s of low-flow reported.

Table 9.3-7. Baseflow Calibration - Observed versus Simulated Baseflow at BJL-H1[1]

Month	Reported Low Flows[2] (m^3/s)	Average Observed Flows (m^3/s)	Model Simulated Baseflow[3] (m^3/s)
November	0.24	0.19	0.10
December	0.15		
January	0.08	0.07	0.08
February	0.07		
March	0.08	0.10	0.07
April	0.11		
Average	0.12	0.12	0.08

Notes:
[1]. See Figure 9.3-1 for location of BJL-H1 hydrometric station.
[2]. "Reported low flows" represent estimated, or synthetic data due to under-ice conditions at the BJL-H1 flow gauging station (Rescan 2013). Observed flows averaged over 2-month periods for comparison with transient model stress periods.
[3]. Model simulated baseflow represents the sum of groundwater discharge to boundary conditions (DRN, RIV, GHB) upstream of the BJL-H1 flow gauging station.

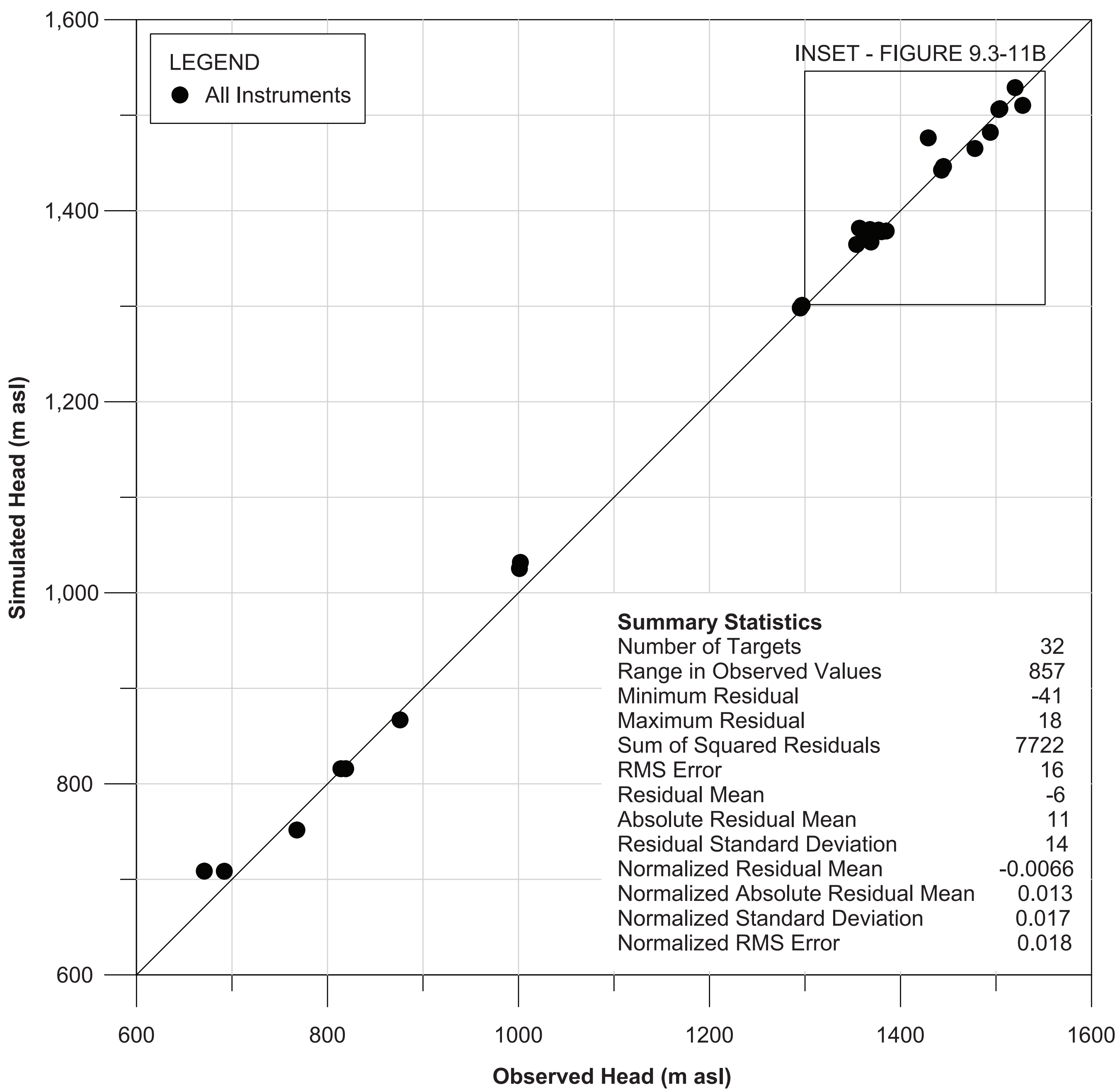
The model was also used to simulate the transient dewatering of the existing underground workings that took place from early November 2011 to early February 2012, and from August 2012 onwards. This final stage of model calibration simulated dewatering by specifying pumping from the subsurface in the vicinity of the underground workings and comparing the observed heads to the simulated results.

Detailed plots of simulated and observed hydraulic heads for head targets with continuous data are presented in Appendix 9-B, BC Input-Output Model Report: Brucejack Mine. Although head offsets are generally present at each location, the plots illustrate that the model captures observed fluctuations reasonably well. That is, the magnitude and timing of changes in head at discrete points are represented by the generalized numerical model. This good representation is despite temporal and spatial complications introduced by irregular drilling activities, variable dewatering rates, and geological uncertainty.

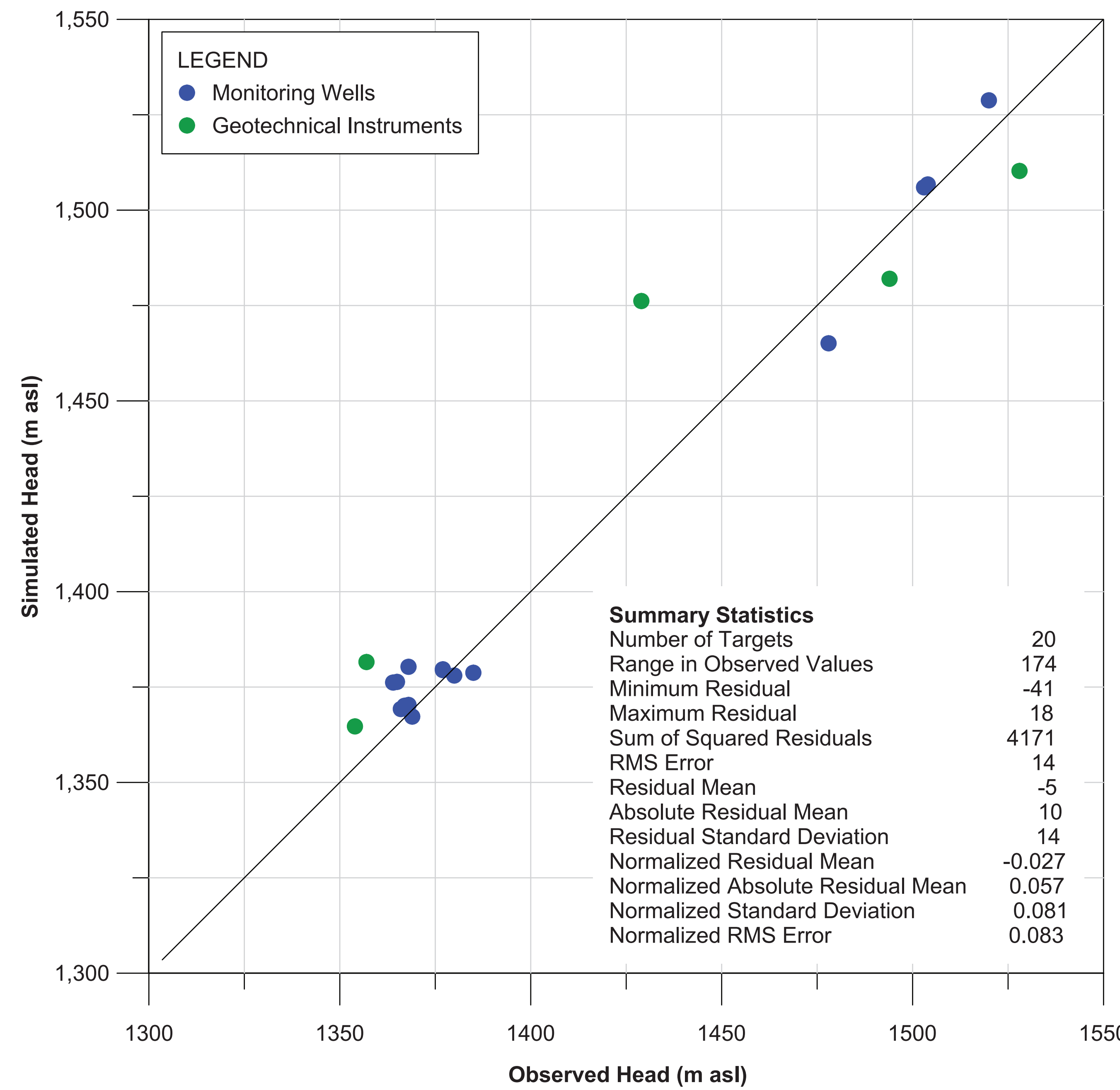
In general, a good match to seasonal variations (i.e., summer versus winter) for the head targets in the transient seasonal simulations was achieved. Similarly, good matches to drawdown in response to dewatering, and to steady-state hydraulic head targets and low-flows at BJL-H1 were achieved. As such, the model was considered to be adequately calibrated for the purpose of the EA.

Figure 9.3-11

Steady State Calibration Results for Hydraulic Head Targets



A] RSA - ALL HYDRAULIC HEAD TARGETS

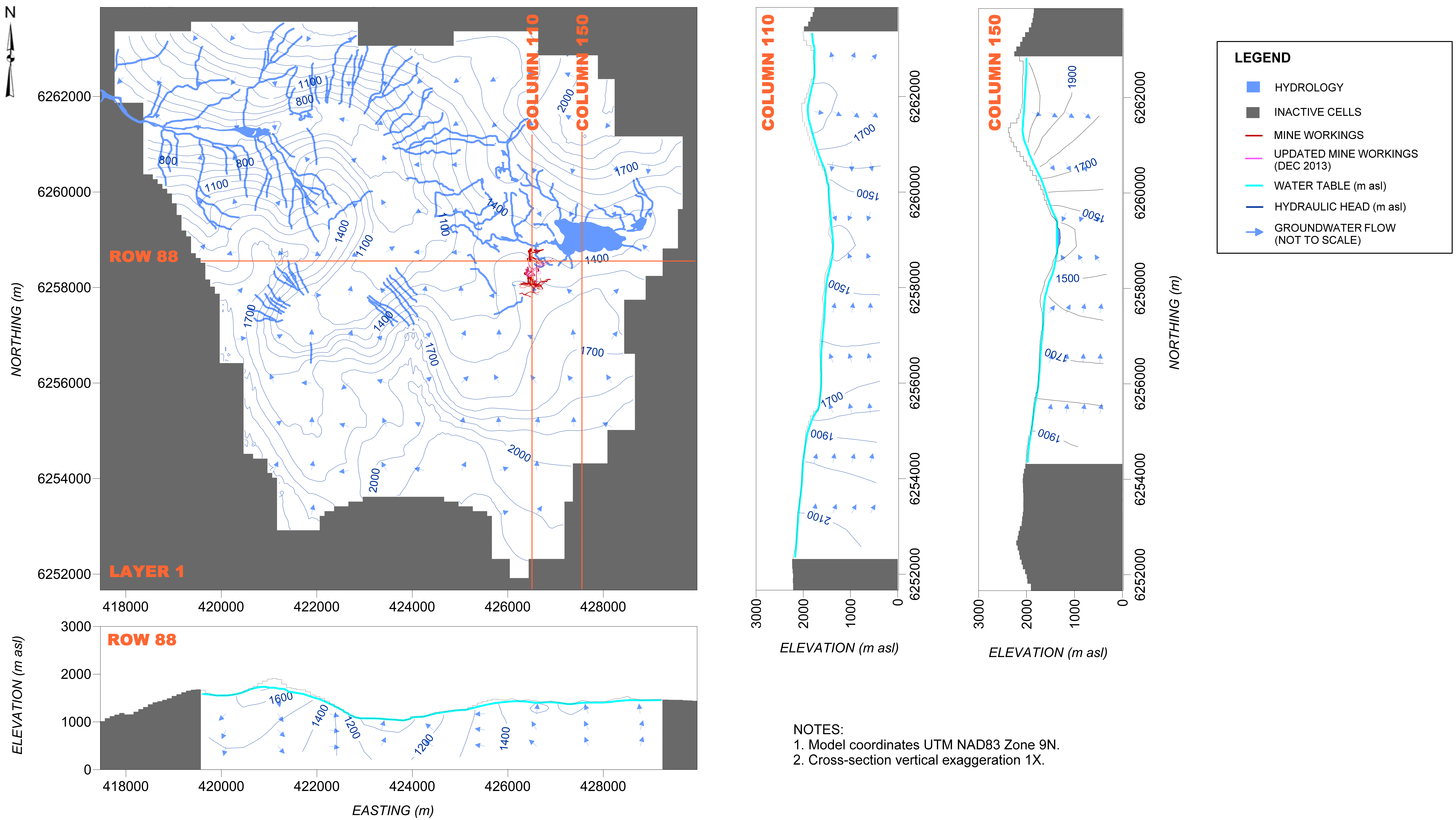


B] LSA - BRUCEJACK PROJECT HYDRAULIC HEAD TARGETS

Source: BGC Engineering Inc. (June 2014).

Figure 9.3-12

Simulated Groundwater Elevation Contours Pre-Disturbance Steady State



NOTES:
1. Model coordinates UTM NAD83 Zone 9N.
2. Cross-section vertical exaggeration 1X.

Source: BGC Engineering Inc. (June 2014).

Benchmarking to Adit Dewatering

Steady-state simulations to represent ongoing dewatering occurring at the site leading up to the start of proposed mining operations were run to benchmark the numerical model against observed dewatering rates and to create initial head conditions for predictive simulations. By simulating yet another set of physical conditions, benchmarking simulations provide an additional measure of how well a numerical model represents the complicated system under consideration.

For these simulations all boundary conditions were the same as for the undisturbed steady-state simulations, above, except drain boundary conditions were added to represent flow from existing underground workings. Elevations for water levels within drain cells were specified according to the existing adit dimensions. The simulated flow rates from the drains were then compared to the measured flow rates from the workings.

Steady-state discharge from the existing underground workings was predicted to be about 2,500 m^3/d in the simulation. This compares favourably to the 2,000 m^3/d of discharge observed in July 2013, at which point one exploration drift was not yet complete. Discharge from the underground workings was expected to increase with completion of the underground drift (i.e., dewatering a greater rock mass should cause an increase in flow); however, it was anticipated that this increase would be offset by the seasonal decrease in groundwater elevations (i.e., lower water levels would result in a lower hydraulic gradient driving flow into the underground workings).

The most recent data from August 2013 through mid-January 2014, saw pumping rates from the underground decline to approximately 900 m^3/d. This decrease indicates that the seasonal reduction in groundwater flow is greater than the anticipated increase in flow to the underground with completion of the bulk sample drift. However, because exploration activities were ongoing during much of the data collection period, it is not possible at this point to resolve inflow to the underground driven by natural processes from anthropogenic (e.g., drilling) activities. In light of this new data, it appears that the predicted steady-state flow to the existing underground workings of 2,500 m^3/d is an overestimate, but the flow should be considered conservative from the perspective of sizing water treatment facilities during the Operation phase.

Sensitivity Analyses

A suite of 16 sensitivity scenarios were performed for the predictive simulations, documented later. A crucial aspect of this exercise was to simulate pre-disturbance scenarios to establish initial conditions. Thus, simulated heads, baseflow rates, and dewatering rates for a range of parameter and boundary conditions were compared to observed conditions (see Table 9.3-8).

The NRMSE for all head targets in the LSA for the base case model was 8.3%. The corresponding statistics for the suite of sensitivity simulations ranged from about 8.4% to over 28% (Table 9.3-8). This indicates that the simulated heads in the numerical model at the target locations are relatively insensitive to certain parameters (e.g., the conductance of GHB and RIV cells) and much more sensitive to other changes (e.g., increasing hydraulic conductivity with no commensurate increase in recharge, or increasing hydraulic conductivity with a decrease in recharge).

The Brucejack Creek stream flow estimated at the stream flow gauging station BJL-H1 and considered reasonable indicators for baseflow, were used as a calibration target for winter stress periods of the transient base case seasonal simulation. The base case simulation matched mid-winter flows (January to February stress period) relatively well, with 0.080 m^3/s of baseflow predicted versus 0.072 m^3/s of low-flow reported. For the sensitivity simulations, predicted baseflow at BJL-H1 for the same time period ranged from 0.075 to 0.19 m^3/s. These results illustrate some changes that might improve the flow target match with further calibration effort (e.g., decreasing hydraulic conductivity or decreasing GHB and RIV Cell conductance). However, the results also demonstrate that certain sensitivity runs result in an excess of water reporting to the surface water system, some more than doubling the reported mid-winter low flows at BJL-H1. Thus, given the uncertainty in the data, the base-case results are thought to be reasonable.

The predicted steady-state mine inflow for the base case scenario simulation was almost 2,500 m^3/d which compares favourably with mine dewatering data from July 2013 (about 2,000 m^3/d), but represents an overestimate of undisturbed winter dewatering data from December 2013 (about 900 m^3/d). Predicted mine inflows for the sensitivity simulations ranged from about 840 m^3/d to 7,500 m^3/d. As with the base-case scenario, most sensitivity scenarios over-predict inflow to the underground mine workings; a more extensive dataset and further calibration effort will be required to match the seasonal fluctuations in mine inflow.

9.4 ESTABLISHING THE SCOPE OF THE ASSESSMENT FOR HYDROGEOLOGY

This section includes a description of the scoping process used to identify potentially affected intermediate components that are a pathway to other receptor VCs, and to select assessment boundaries. Scoping is fundamental to focusing the Application for an Environmental Assessment Certificate/Environmental Impact Statement (Application/EIS) on those issues where there is the greatest potential to cause significant adverse effects. The scoping process for the assessment of groundwater consisted of the following four steps:

- Step 1: scoping process to select intermediate components, sub-components, and indicators based on a consideration of the Project's potential to interact with and/or affect groundwater;
- Step 2: considering feedback on the results of the scoping process;
- Step 3: defining assessment boundaries for groundwater quality and quantity; and
- Step 4: identifying key potential effects on groundwater quality and quantity.

These steps are described in detail below.

9.4.1 Selecting Intermediate Components

Issues scoping is undertaken to focus the Application/EIS on the issues of highest concern. To be considered for assessment, a component must be of recognized importance to society, the local community, or the environmental system, and there must be a perceived likelihood that the component will be affected by the proposed Project. Intermediate components are specific attributes of the biophysical environment that if affected (i.e., there is a positive or negative change in the baseline condition), act as a pathway to pass on those changes to other components of the environment, thereby having the potential to also affect or change the baseline condition of receptor VCs. Intermediate components are scoped during consultation with key stakeholders, including Aboriginal communities and the EA Working Group[1]. Consideration of certain components may also be a legislated requirement, or known to be a concern because of previous project experience.

[1] The EA Working Group is a forum for discussion and resolution of technical issues associated with the proposed Project, as well as providing technical advice to the BC EAO and CEA Agency, who remain ultimately responsible for determining significance. It comprises representatives of provincial, federal, and local government, and Aboriginal groups.

Table 9.3-8. Sensitivity Scenarios for Mining Operation and Post-closure Simulations

Simulation[1]	Description[2]	Calibration Simulations				Predictive Simulations			
						Estimated Flows to Underground Workings[3] (m^3/d)		Estimated Baseflow @ BJL-H1 Gauging Station[4] (m^3/d)	
		Head Target Calibration (%NRMSE)	Jan-Feb Baseflow at BJL-H1 (m^3/s)	Avg. Annual Baseflow at BJL-H1 (m^3/d)	Dewatering Discharge (m^3/d)	Avg Annual	Max Annual[3]	Operation	Post-closure
Base Case	Calibrated numerical model	8.3%	0.08	9,000	2,500	4,900	6,500	7,200	8,800
S.A. Run 1	K of all units increased by a factor of five (x5)	21.2%	0.12	11,900	5,800	11,700	14,400	6,900	11,600
S.A. Run 2	K of all units decreased by a factor of five (/5)	13.8%	0.05	5,800	840	2,300	3,500	5,200	5,600
S.A. Run 3	Ss of all units increased by a factor of five (x5) and Sy of all units increased by a factor of two (x2)[5]	-	0.09	9,000	-	5,100	7,800	7,300	-
S.A. Run 4	Recharge increased by a factor of two (x2)	10.6%	0.12	15,300	3,000	6,700	8,300	13,100	15,000
S.A. Run 5	Recharge under glacier-covered areas increased by a factor of five (x5); other recharge areas unchanged	10.6%	0.09	10,100	2,700	6,200	7,900	8,300	9,800
S.A. Run 6	Conductance of Brucejack Lake bed and model river cells increased by an order of magnitude (x10)	8.4%	0.09	9,900	2,900	6,200	7,900	8,400	9,600
S.A. Run 7	Conductance of Brucejack Lake bed and model river cells decreased by an order of magnitude (/10)	8.4%	0.08	8,200	2,200	4,300	5,800	6,500	8,000
S.A. Run 8	K along Brucejack Fault increased by two orders of magnitude (x100)	9.9%	0.08	8,700	2,300	5,700	7,300	6,900	8,500
S.A. Run 9	Glaciers represented with a constant head boundary set to glacier surface topography	11.3%	0.11	12,200	2,700	8,500	10,300	10,300	12,000
S.A. Run 10	K of underground stope cells backfilled with paste increased by an order of magnitude (x10)[6]	-	-	-	-	5,100	6,600	7,200	8,800
S.A. Run 11	K of underground stope cells and K of mine development cells decreased by an order of magnitude (/10)[6]	-	-	-	-	4,600	6,200	7,300	8,800
S.A. Run 12	K of all units increased by a factor of five (x5) and recharge increased by a factor of two (x2)	14.3%	0.16	19,300	7,500	14,600	17,400	12,300	19,200
S.A. Run 13	K along Brucejack Fault decreased by two orders of magnitude (/100)	8.6%	0.08	9,200	2,400	4,500	6,100	7,500	9,000
S.A. Run 14	K of all units increased by a factor of five (x5), recharge increased by a factor of two (x2), Ss increased by a factor of five (x5) and Sy increased by a factor of two (x2)[5]	-	0.19	19,700	-	14,700	19,100	13,100	-
S.A. Run 15	Brucejack Lake GHB set to an elevation of 1369.4 masl, representing a lake control structure[6]	-	-	-	-	4,900	6,500	6,100	7,500
S.A. Run 16	K of all units increased by a factor of five (x5) and recharge decreased by a factor of two (/2)	28.6%	0.09	7,200	4,300	9,400	12,100	2,900	5,900

Notes:
1. "S.A" indicates "sensitivity analysis" - these runs were modified as described above relative to the base case simulations for mine Operation and Closure.
2. "K" indicates hydraulic conductivity; "S_s" indicates specific storage; "S_y" indicates specific yield.
3. Maximum annual estimated flows to underground workings for all sensitivity scenarios occur in year 8 of mining operations.
4. Estimated baseflow at BJL-H1 gauging station is the average throughout either the mining Operation or the Post-closure simulation, as indicated.

Groundwater quantity and quality were identified as key components of the biophysical environment because of linkages to other ecosystem components, including surface water quantity, surface water quality, human health, aquatic resources, and wetlands (Figure 9.4-1).

Subject areas are classified as either an intermediate component or receptor VC and can be further refined into sub-components and indicators as described in Section 6.4.1. Groundwater quantity and groundwater quality were identified as intermediate components as a result of the scoping process; indicators for these components are defined as follows:

- groundwater quantity: changes to groundwater flow volume and movement assessed on the basis of increases or decreases in hydraulic heads as a result of the project; and
- groundwater quality: changes to concentrations of total and dissolved metals, nutrients, turbidity, total suspended solids, and groundwater temperature.

9.4.1.1 Potential Interactions between the Brucejack Gold Mine Project and Intermediate Components

As described in Section 6.4, a scoping exercise was conducted during the development of a draft AIR to explore potential Project interactions with candidate intermediate components and receptor VCs, and to identify the key potential adverse effects associated with that interaction. The results of the scoping exercise were circulated for review and comment by the EA Working Group, and feedback from that process has been integrated into the Application/EIS.

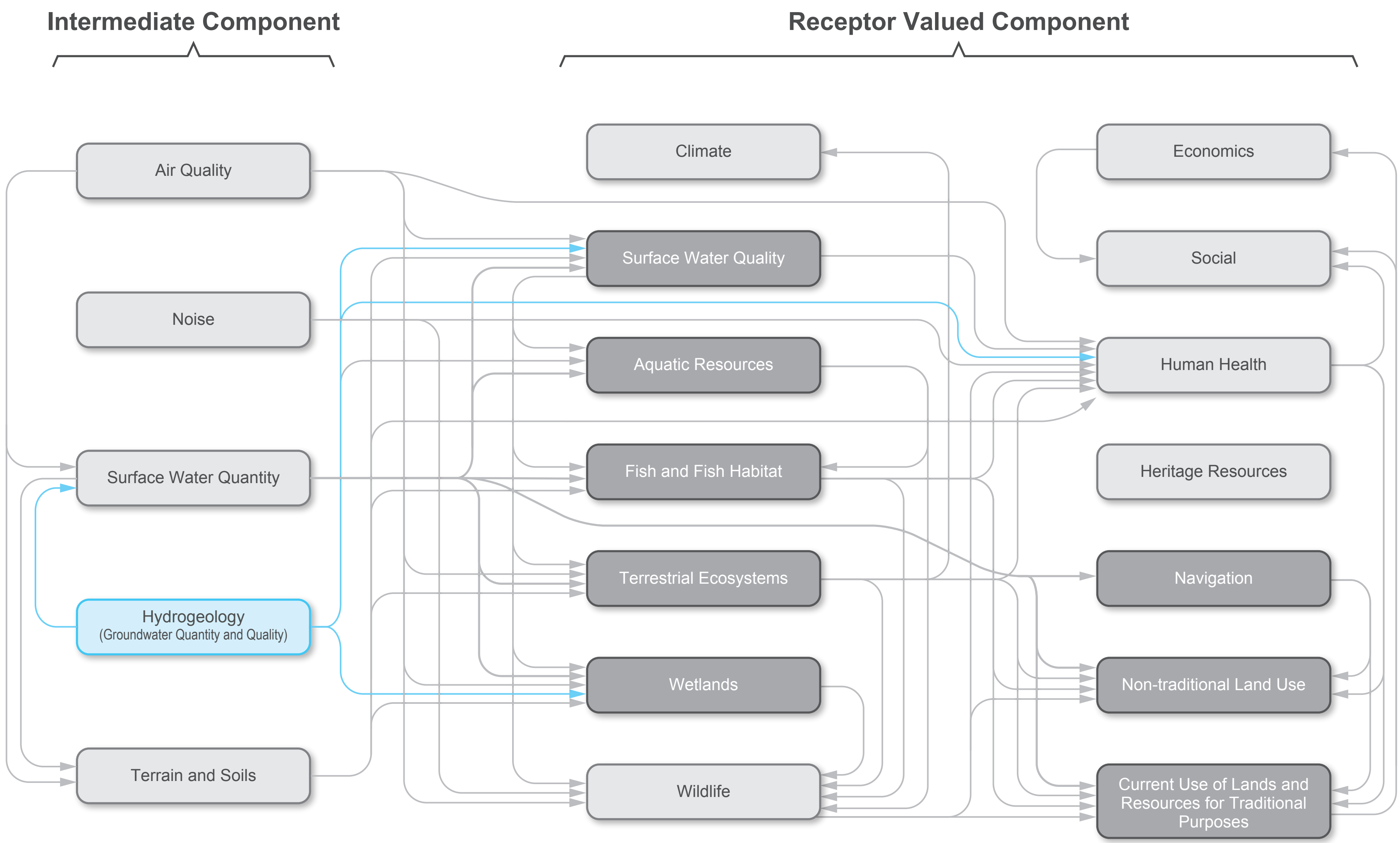
Table 9.4-1 provides an impact scoping matrix of Project components and physical activities that have a possible or likely interaction resulting in a measurable change to groundwater quality and quantity. A full impact scoping matrix for all candidate intermediate and receptor VCs is provided in Table 6.4-1.

Interactions between the Project and groundwater quality and groundwater quantity were assigned a colour code as follows:

- **Not expected (white)**: Interactions coded as not expected are considered to have no potential for adverse effects on a subject area, and are not considered further. These include interactions between the Project and groundwater quantity or quality resulting from, for example, hazardous waste materials use and storage at the site and potential leaks or spills of these materials as these are related to occurrences of low likelihood outside of normal operating conditions. The *Environmental Management Act* (2003) and Contaminated Sites Regulation (BC Reg. 375/96) provide the assessment framework and technical guidance for addressing these low likelihood events. These potential effects are addressed in Chapter 31, Accidents and Malfunctions, as well as the Spill Prevention and Response Plan (Section 29.14).
- **Possible (grey)**: If no mitigation measures are in place, and/or best management practices are not applied, several Project components and activities could potentially affect groundwater quantity and quality. For example, activities resulting in potential increases in surface run off, erosion, and sedimentation, (e.g., site construction and decommissioning) without appropriate ditch, culvert, and attenuation pond designs, or that result in locally decreasing infiltration of precipitation to groundwater (e.g., under constructed lined pads or under building footprints) can locally change groundwater infiltration and discharge patterns. However, the temporal and spatial scales of these effects are localized, and much less than those of the activities with likely (black) interactions.

Figure 9.4-1

Linkages between Hydrogeology and Receptor Valued Components



- **Likely (black)**: These include Project components and activities that involve:
  - significant change in the water table or hydraulic heads; for example, due to dewatering of the underground workings;
  - accompanying changes in groundwater recharge and/or discharge rates to creeks, streams, and lakes in the Project areas; and/or
  - changes to groundwater chemistry from geochemical reactions within the mine or waste materials, or within any zones that are dewatered.

Table 9.4-1. Interaction of Project Components and Physical Activities with Groundwater Quality and Groundwater Quantity

Project Components and Physical Activities by Phase	Groundwater Quality	Groundwater Quantity
Construction Phase		
Activities at existing adit		
Air transport of personnel and goods		
Avalanche control		
Chemical and hazardous material storage, management, and handling		
Construction of back-up diesel power plant		
Construction of Bowser Aerodrome		
Construction of detonator storage area		
Construction of electrical substation at mine site		
Construction of equipment laydown areas		
Construction of helicopter pad		
Construction of incinerators		
Construction of Knipple Transfer Area		
Construction of local site roads		
Construction of mill building (electrical induction furnace, backfill paste plant, warehouse, mill/ concentrator)		
Construction of mine portal and ventilation shafts		
Construction of Brucejack Operations Camp		
Construction of ore conveyer		
Construction of tailings pipeline		
Construction and decommissioning of Tide Staging Area construction camp		
Construction of truck shop		
Construction and use of sewage treatment plant and discharge		
Construction and use of surface water diversions		
Construction of water treatment plant		
Development of underground portal and facilities		
Employment and labour		
Equipment maintenance/machinery and vehicle refuelling/fuel storage and handling		
Explosives storage and handling		

(continued)

Table 9.4-1. Interaction of Project Components and Physical Activities with Groundwater Quality and Groundwater Quantity (continued)

Project Components and Physical Activities by Phase	Groundwater Quality	Groundwater Quantity
***Construction Phase** (cont'd)*		
Grading of the mine site area		
Helicopter use		
Installation and use of Project lighting		
Installation of surface and underground crushers		
Installation of transmission line and associated towers		
Machinery and vehicle emissions		
Potable water treatment and use		
Pre-production ore stockpile construction		
Procurement of goods and services		
Quarry construction		
Solid waste management		
Transportation of workers and materials		
Underground water management		
Upgrade and use of exploration access road		
Use of Granduc Access Road		
Operation Phase		
Air transport of personnel and goods and use of aerodrome		
Avalanche control		
Backfill paste plant		
Back-up diesel power plant		
Bowser Aerodrome		
Brucejack Access Road use and maintenance		
Brucejack Operations Camp		
Chemical and hazardous material storage, management, and handling		
Concentrate storage and handling		
Contact water management		
Detonator storage		
Discharge from Brucejack Lake		
Electrical induction furnace		
Electrical substation		
Employment and labour		
Equipment laydown areas		
Equipment maintenance/machine and vehicle refuelling/fuel storage and handling		
Explosives storage and handling		
Helicopter pad(s)		

(continued)

Table 9.4-1. Interaction of Project Components and Physical Activities with Groundwater Quality and Groundwater Quantity (continued)

Project Components and Physical Activities by Phase	Groundwater Quality	Groundwater Quantity
***Operation Phase** (cont'd)*		
Helicopter use		
Knipple Transfer Area		
Machine and vehicle emissions		
Mill building/concentrators		
Non-contact water management		
Ore conveyer		
Potable water treatment and use		
Pre-production ore storage		
Procurement of goods and services		
Project lighting		
Quarry operation		
Sewage treatment and discharge		
Solid waste management/incinerators		
Subaqueous tailings disposal		
Subaqueous waste rock disposal		
Surface crushers		
Tailings pipeline		
Truck shop		
Transmission line operation and maintenance		
Underground backfill tailing storage		
Underground backfill waste rock storage		
Underground crushers		
Underground: drilling, blasting, excavation		
Underground explosives storage		
Underground mine ventilation		
Underground water management		
Use of mine site haul roads		
Use of portals		
Ventilation shafts		
Warehouse		
Waste rock transfer pad		
Water treatment plant		
Closure Phase		
Air transport of personnel and goods		
Avalanche control		

(continued)

Table 9.4-1. Interaction of Project Components and Physical Activities with Groundwater Quality and Groundwater Quantity (continued)

Project Components and Physical Activities by Phase	Groundwater Quality	Groundwater Quantity
***Closure Phase** (cont'd)*		
Chemical and hazardous material storage, management, and handling		
Closure of mine portals		
Closure of quarry		
Closure of subaqueous tailing and waste rock storage (Brucejack Lake)		
Decommissioning of Bowser Aerodrome		
Decommissioning of back-up diesel power plant		
Decommissioning of Brucejack Access Road		
Decommissioning of camps		
Decommissioning of diversion channels		
Decommissioning of equipment laydown		
Decommissioning of fuel storage tanks		
Decommissioning of helicopter pad(s)		
Decommissioning of incinerators		
Decommissioning of local site roads		
Decommissioning of mill building		
Decommissioning of ore conveyer		
Decommissioning of Project lighting		
Decommissioning of sewage treatment plant and discharge		
Decommissioning of solid waste incineration		
Decommissioning of surface crushers		
Decommissioning of surface explosives storage		
Decommissioning of tailings pipeline		
Decommissioning of transmission line and ancillary structures		
Decommissioning of underground crushers		
Decommissioning of waste rock transfer pad		
Decommissioning of water treatment plant		
Employment and labour		
Helicopter use		
Machine and vehicle emissions		
Procurement of goods and services		
Removal or treatment of contaminated soils		
Solid waste management		
Transportation of workers and materials (mine site and access roads)		
Post-closure Phase		
Discharge from Brucejack Lake		

(continued)

Table 9.4-1. Interaction of Project Components and Physical Activities with Groundwater Quality and Groundwater Quantity (completed)

Project Components and Physical Activities by Phase	Groundwater Quality	Groundwater Quantity
***Post-closure Phase** (cont'd)*		
Employment and labour		
Environmental monitoring		
Procurement of goods and services		
Subaqueous tailing and waste rock storage		
Underground mine		

Notes:
White = interaction not expected between Project components/physical activities and an intermediate component
Grey = possible interaction between Project components/ physical activities and an intermediate component
Black = likely interaction between Project components/ physical activities and an intermediate component

9.4.1.2 Consultation Feedback on Intermediate Components

Consultation feedback on the intermediate components of groundwater quality and quantity was limited to feedback from the EA Working Group comments during the AIR and EIS guidelines review phase, and to comments received during public comment periods (see Chapter 3, Information Distribution and Consultation). In addition, specific direction for indicators to be considered was provided in Section 8.3.3.1 of the AIR, as follows:

- groundwater quantity: flow volume and movement; and
- groundwater quality: concentrations of total and dissolved metals, nutrients, turbidity, total suspended solids, and temperature.

Public consultation feedback resulted in one request that the number of underground water tables that will be affected by the Project be considered.

9.4.1.3 Summary of Intermediate Components Included/Excluded in the Application/EIS

Groundwater is intrinsically linked with surface water and therefore influences aquatic ecosystem health. Groundwater is also a potable water source when water quality is adequate; it is often used for human consumption directly by municipalities and households. In the context of the remote location of the Project, groundwater may foreseeably be used as a potable resource for work camps. Groundwater is protected under the *Canada Water Act* (1985a), the BC *Water Act* (1996c), and the BC *Water Protection Act* (1996d). In addition, land and resource management plans developed for the area provide management direction and objectives for the protection of groundwater quantity and quality. Groundwater quality and quantity were selected as intermediate components as identified in the AIR (BC EAO 2014; Table 9.4-2).

No intermediate components for hydrogeology that were identified for the Project were excluded.

9.4.2 Assessment Boundaries for Hydrogeology

Assessment boundaries define the maximum limit within which changes to intermediate components will be evaluated. They encompass the areas within and times during which the Project is expected to interact with the intermediate components, as well as the constraints that may be placed on the assessment of those interactions due to political, social, and economic realities (administrative boundaries), and limitations in predicting or measuring changes (technical boundaries). The definition of these assessment boundaries is an integral part of the assessment process for hydrogeology. The definition of assessment boundaries encompasses all possible direct, indirect, and induced effects on the intermediate components groundwater quality and groundwater quantity, as well as the trends in processes that may be relevant.

Table 9.4-2. Hydrogeology Intermediate Components Included in the Application/EIS

Hydrogeology Intermediate Components	Identified by*				Rationale for Inclusion
	AG	G	P/S	IM	
Groundwater quality	X	X		X	The BC MOE (2012) specifies that proposed resource development projects take measures to ensure groundwater quality is maintained for present and future uses. Adit dewatering will result in drawdown of the water table in the vicinity of the underground workings may expose PAG materials to oxic, variably-saturated conditions leading to onset of ML/ARD and the potential for degraded groundwater quality. The CIS LRMP (ILMB 2000) and Nass South SRMP (MFLNRO 2012) for the Project area provide management direction and objectives to protect groundwater quality.
Groundwater quantity	X	X	X	X	The BC MOE (2012) specifies that proposed resource development projects take measures to ensure groundwater quantity is maintained for present and future uses. Adit dewatering will result in drawdown of the water table in the vicinity of the underground workings potentially reducing the quantity of groundwater discharges to Brucejack Creek and Brucejack Lake. The CIS LRMP (ILMB 2000) and Nass South SRMP (MFLNRO 2012) for the Project area provide management direction and objectives to protect groundwater quantity.

**AG = Aboriginal Group; G = Government; P/S = Public/Stakeholder; IM = Impact Matrix*

9.4.2.1 Spatial Boundaries

Spatial boundaries for the assessment of hydrogeological effects remain unchanged from those defined for the baseline studies in Section 9.3 and Figure 9.3-1. The RSA, LSA, and model domain are shown in Figure 9.4-2.

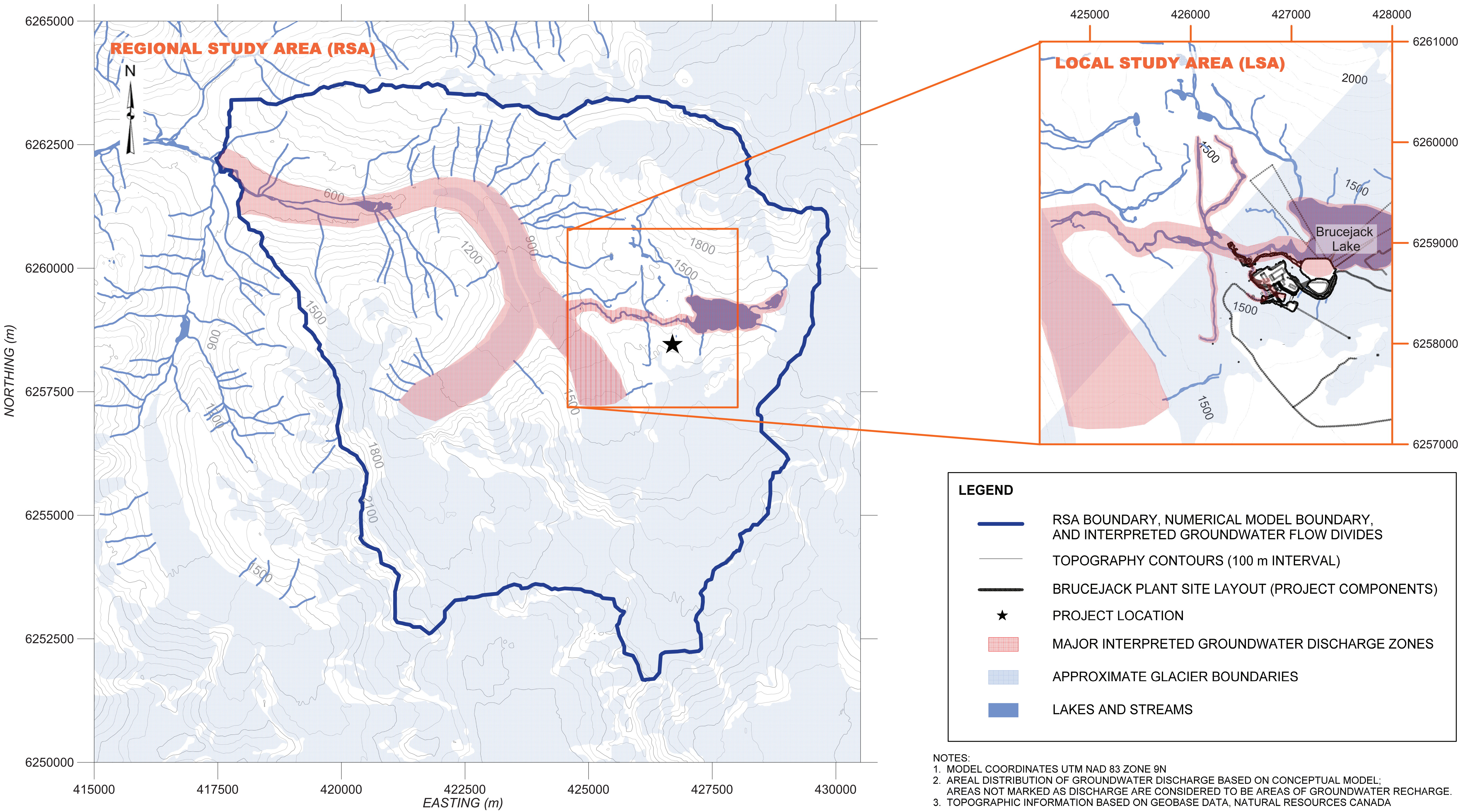
Regional Study Area

The RSA, defined as "the spatial area within which direct and indirect effects are anticipated to occur" (Rescan 2013), in general comprises the Sulphurets Creek watershed area selected for numerical hydrogeologic modelling (discussed in more detail in Appendix 9-B and below).

Local Study Area

The LSA is defined as "the Project footprint (all physical structures and activities that comprise the Project) and surrounding area within which there is a reasonable potential for immediate effects on a specific intermediate component or receptor VC due to an interaction with a Project component(s) or physical activity" (Rescan 2013).

Figure 9.4-2
Brucejack Hydrogeology RSA and LSA, Groundwater Flow Divides and Discharge



Source: BGC Engineering Inc. (June 2014).

NOTES:
1. MODEL COORDINATES UTM NAD 83 ZONE 9N
2. AREAL DISTRIBUTION OF GROUNDWATER DISCHARGE BASED ON CONCEPTUAL MODEL; AREAS NOT MARKED AS DISCHARGE ARE CONSIDERED TO BE AREAS OF GROUNDWATER RECHARGE.
3. TOPOGRAPHIC INFORMATION BASED ON GEOBASE DATA, NATURAL RESOURCES CANADA

In general, the study focused on collecting data to support the assessment of hydrogeologic effects that would result in direct changes to waterbodies within the LSA. For the purposes of the hydrogeologic assessment for the Project, such effects may broadly include: 1) drawdown of the water table or hydraulic heads due to mine dewatering; 2) accompanying changes in groundwater recharge and/or discharge rates; and/or, 3) changes to groundwater chemistry from geochemical reactions within the mine or waste materials, or within any zones that are dewatered. It is anticipated that these stresses to the groundwater system at the Project site will be focused around the underground mine development, and that the LSA from a hydrogeologic perspective will extend over a radial distance of a few km from the proposed mine.

Modelling Domain

The model domain specified for numerical modelling coincides with the RSA (i.e., the Sulphurets watershed), with more detailed discretization in the LSA (i.e., vicinity of the Project area). The rationale for this definition is that hydrology in mountainous areas subject to abundant precipitation is dominated by surface water and topography. Thus, topographic divides are appropriate representations of groundwater divides as no-flow boundaries.

9.4.2.2 Temporal Boundaries

The temporal phases of the Project are:

- **Construction**: 2 years;
- **Operatio**n: 22-years;
- **Closure**: 2 years (includes Project decommissioning, abandonment and reclamation activities), which is consistent with the estimated time for the majority of underground mine workings to flood once dewatering operations cease; and
- **Post-closure:** minimum of 3 years (includes ongoing reclamation activities and Post-closure phase monitoring). Predictive groundwater flow modelling was performed for both a 30-year Post-closure time frame and long-term equilibrium conditions.

9.4.3 Identifying Key Potential Effects on Hydrogeology

The key potential effects that may result from the interaction of the Project's components and activities with hydrogeology are identified in this section, along with the time frames over which they are anticipated to be operative.

The primary and other possible effects are summarized in Table 9.4-3 and discussed in more detail below. Interactions that are marked red or yellow in Table 9.4-3 will be carried forward to support additional discussion and analyses. Those interactions that are marked green (i.e., negligible to minor adverse effects) will not be discussed in detail except to identify that standard operating practises and mitigation measures are generally well known and understood and will be used to address these minor concerns over all necessary phases of the project.

9.4.3.1 Primary Groundwater Quantity Effects

In terms of groundwater quantity (i.e., changes to groundwater flow volume and movement), the primary effect may be drawdown of the water table in the vicinity of the mine workings. Water table drawdown is a direct result of dewatering activities within an underground mine. As water is drained and pumped from the subsurface, the nearby hydraulic head decreases, causing water to flow from greater distances. These decreases in hydraulic head lead to drawdown of the water table. Such water table drawdowns would be centred about the dewatered workings and would be expected to gradually expand over time, for as long as adit dewatering continues. Because of the high precipitation rates in the Project area this drawdown would be expected to be reversible in the short term, following the cessation of water removal.

Table 9.4-3. Ranking Potential Effects on Hydrogeology

Project Components/ Physical Activities	Potential Effects on Hydrogeology	
	Changes to Groundwater Flow Volume and Movement	Changes to Concentrations of Total and Dissolved Metals, Nutrients, Turbidity, Total Suspended Solids, and Groundwater Temperature
Construction Phase		
Construction of back-up diesel power plant	🟢	N/A
Construction of Bowser Aerodrome	🟢	N/A
Construction of detonator storage area	🟢	N/A
Construction of electrical substation at mine site	🟢	N/A
Construction of equipment laydown areas	🟢	N/A
Construction of helicopter pad	🟢	N/A
Construction of incinerators	🟢	N/A
Construction of Knipple Transfer Area	🟢	N/A
Construction of local site roads	🟢	N/A
Construction of mine portal and ventilation shafts	🟡	🟡
Construction of Brucejack Operations Camp	🟢	N/A
Construction and decommissioning of Tide Staging Area construction camp	🟢	N/A
Construction of truck shop	🟢	N/A
Construction and use of sewage treatment plant and discharge	🟢	🟡
Construction and use of surface water diversions	🟢	🟢
Construction of water treatment plant	🟢	N/A
Development of underground portal and facilities	🔴	🔴
Explosives storage and handling	🟢	🟢
Grading of the mine site area	🟢	🟢
Installation of surface and underground crushers	🟢	N/A
Installation of transmission line and associated towers	🟢	N/A
Maintenance and use of exploration access road	🟢	🟢
Potable water treatment and use	🟢	N/A
Pre-production ore stockpile construction	🟢	N/A
Quarry construction	🟡	🟡
Solid waste management	🟢	🟢
Underground water management	🔴	🔴
Upgrade and use of exploration access road	🟢	🟢

(continued)

Table 9.4-3. Ranking Potential Effects on Hydrogeology (continued)

Project Components/ Physical Activities	Potential Effects on Hydrogeology	
	Changes to Groundwater Flow Volume and Movement	Changes to Concentrations of Total and Dissolved Metals, Nutrients, Turbidity, Total Suspended Solids, and Groundwater Temperature
Operation Phase		
Contact water management	● (yellow)	● (yellow)
Discharge from Brucejack Lake	● (green)	● (green)
Non-contact water management	● (green)	N/A
Potable water treatment and use	● (green)	N/A
Pre-production ore storage	● (green)	● (green)
Quarry operation	● (yellow)	● (green)
Sewage treatment and discharge	● (light green)	● (yellow)
Solid waste management/incinerators	● (light green)	● (green)
Subaqueous tailings disposal	● (light green)	N/A
Subaqueous waste rock disposal	● (light green)	N/A
Discharge from Brucejack Lake	● (light green)	● (green)
Underground backfill tailing storage	● (yellow)	● (red)
Underground backfill waste rock storage	● (yellow)	● (red)
Underground: drilling, blasting, excavation	● (red)	● (red)
Underground water management	● (red)	● (red)
Waste rock transfer pad	N/A	● (green)
Closure Phase		
Closure of mine portals	● (red)	● (red)
Closure of quarry	● (yellow)	● (yellow)
Decommissioning of Bowser Aerodrome	● (green)	N/A
Decommissioning of back-up diesel power plant	● (green)	N/A
Decommissioning of Brucejack Access Road	● (green)	N/A
Decommissioning of camps	● (green)	N/A
Decommissioning of diversion channels	● (green)	N/A
Decommissioning of equipment laydown	● (green)	N/A
Decommissioning of fuel storage tanks	● (green)	N/A
Decommissioning of local site roads	● (green)	N/A
Decommissioning of mill building	● (green)	N/A
Decommissioning of mill/concentrators	● (green)	N/A
Decommissioning of sewage treatment plant and discharge	● (green)	● (green)
Decommissioning of waste rock transfer pad	● (green)	● (green)
Decommissioning of water diversion channels	● (green)	● (green)
Decommissioning of water treatment plant	● (green)	● (green)
Removal or treatment of contaminated soils	● (yellow)	● (yellow)
Solid waste management	● (yellow)	● (yellow)

(continued)

Table 9.4-3. Ranking Potential Effects on Hydrogeology (completed)

Project Components/ Physical Activities	Potential Effects on Hydrogeology	
	Changes to Groundwater Flow Volume and Movement	Changes to Concentrations of Total and Dissolved Metals, Nutrients, Turbidity, Total Suspended Solids, and Groundwater Temperature
Post-closure Phase		
Discharge from Brucejack Lake	● (green)	● (green)
Environmental monitoring	● (green)	● (green)
Subaqueous tailing and waste rock storage	● (green)	● (green)
Underground mine	● (red)	● (red)

Notes:

N/A = effect is not applicable to the Project component or physical activity

● (green) = *Negligible to minor adverse effect expected; implementation of best practices, standard mitigation and management measures; no monitoring required, no further consideration warranted.*

● (yellow) = *Potential moderate adverse effect requiring unique active management/monitoring/mitigation; warrants further consideration.*

● (red) = *Key interaction resulting in potential significant major adverse effect or significant concern; warrants further consideration.*

High drawdown of the water table would be expected to lead to decreased baseflow to nearby creeks and to Brucejack Lake. Moderate drawdown of the water table has already occurred during exploration activities, and this drawdown would be expected to increase as development proceeds (i.e., during Construction and Operation). However, this effect on baseflow would be expected to reverse following mining (i.e., during the Closure and Post-closure phases), after underground workings are sealed and pumping ceases.

9.4.3.2 Primary Groundwater Quality Effects

In terms of groundwater quality (i.e., changes to concentrations of total and dissolved metals, nutrients, turbidity, total suspended solids, and groundwater temperature), the primary effects may occur following groundwater contacting mine workings, waste materials placed in the underground workings, and/or blasting residues. Groundwater, originating from the infiltration of precipitation and snowmelt at surface, will flow towards the underground workings as a result of dewatering activities. This groundwater may come into contact with potentially acid generating (PAG) materials (i.e., exposed rock surfaces, backfilled waste rock; see Section 5.6) and, during periods of underground development and dewatering (i.e., Construction and Operation phases), the presence of oxygen may result in ARD reactions and/or metal leaching/mobility. These processes may increase the likelihood of degraded groundwater qualities discharging into the underground mine waters. However, any ML/ARD reactions are expected to terminate during the closure period due to limited oxygen supply following the flooding of the underground and sealing of ventilation shafts and access portals and adits, thereby limiting the supply of oxygen.

Groundwater that flows into the underground workings during the Construction and Operation phases will be collected by subsurface drains and pumps and diverted to the water treatment plant. During the Closure and Post-closure phases, baseflow returns to rates that approach pre-disturbance conditions and this groundwater may discharge to surface waters. The severity of the effects would be largely dependent upon the degree of oxygenation and ML/ARD reactions of the potential source zones and the groundwater pathways to surface.

9.4.3.3 Negligible to Minor Effects

Many Project activities are focused at the mine site or along the access road and transmission line corridors. From a hydrogeological perspective, for both quantity and quality of groundwater, these routine surficial activities are expected to have negligible to minimal adverse effects throughout the life-cycle of the Project (i.e., from Construction through to, and including, the Closure phase). On-site examples include construction of storage and laydown areas, the helicopter pad, the support buildings and facilities, and the mechanical infrastructure (e.g., power plant, electrical substation, crushers, and incinerator). Off-site examples include the Bowser Aerodrome, the Knipple Transfer Area, the Brucejack Access Road, the transmission line and towers, the construction and operations camps, the local roads and staging areas.

Construction of a road, laydown area or similar shallow disturbance of the land surface may interact with localized, shallow perched groundwater or may be in a groundwater discharge area. Such conditions will be addressed with standard construction practices and best management practices for drainage and material use (see Sections 29.10, ML/ARD Management Plan; 29.13, Soil Management Plan; 29.16, Transportation and Access Management Plan; 29.18, Waste Rock Management Plan; and 29.19, Water Management Plan). Similarly construction of a building or pad may result in local changes to infiltration (e.g., mounding at the edge of a pad, or a localized drop in water table) but these are considered to be minor and ultimately reversible and so are not considered. Because these features are small-scale, localized and shallow, their effect on the overall water budget is expected to be small. Later decommissioning and reclamation of these features will be performed according to established and mandated reclamation protocols which will reverse small localized changes to the hydrogeologic system (See Chapter 30, Closure and Reclamation).

Accidents or malfunctions that might occur during operations are assessed in Chapter 31, Accidents and Malfunctions; for groundwater quality, any spills will be addressed by standard operating procedures that will be developed for specific project components (e.g., explosives storage and handling; construction and mine water treatment plants, solid waste management and incinerators, etc.) and in accordance with Section 29.14, Spill Prevention and Response Plan. Similarly, transport, storage and labelling of controlled or potentially hazardous substances will comply with existing federal and provincial regulations (i.e., federal *Transportation of Dangerous Goods Act* [1992]). Furthermore, during the closure and reclamation phase, any spills or leaks that may result in contaminated soils or groundwater will be remediated in accordance with the requirements of the BC Contaminated Sites Regulation (BC Reg. 375/96) and Hazardous Waste Regulation (BC Reg. 63/88) under the BC *Environmental Management Act* (2003). Finally, by their nature, location, size, duration, and materials involved, spills or leaks are largely unpredictable, and thus, from a groundwater quality perspective, such activities cannot be considered in an explicit predictive approach.

The construction, use, and decommissioning of groundwater supply wells for potable water supply are also considered to have negligible to minimal adverse effects with respect to hydrogeology. The installation of wells is regulated by the BC Groundwater Protection Regulation (BC Reg. 299/2004) under the *Water Act* (1996c), and requires use of licensed water-well drillers and pump installers, as well as adherence with minimum well completion and abandonment specifications.

The construction and use of the sewage treatment plant might have a moderate impact on groundwater quality. Such an effect would arise if the sewage treatment plant were to leak. Routine monitoring or inspection for possible system leaks is anticipated; however, effects would most likely be confined to a small shallow area and would be addressed according to the Spill Prevention and Response Plan (Section 29.14). Additionally, specific permit requirements will be established for the sewage treatment plant and any specific inspection, monitoring and sampling requirements established for this system will be followed during the Construction, Operation, and Closure phases of the Project, so the impact is not considered further here.

9.4.3.4 Construction Phase

Quarry construction may have a moderate impact on either groundwater quantity or quality. As the quarry is developed, groundwater in the cut slopes may drain towards the quarry floor. It is anticipated that the quarry floor might behave as a groundwater discharge area, such that there would be little to no infiltration of water or dissolved constituents. Groundwater levels in the quarry walls may become locally depressed. Horizontal drains may be needed to manage pore pressures in the quarry walls, contributing to both groundwater discharge flows and localized lowering of the water table. The quarry was sited specifically to exploit non-PAG rock for plant site construction fill materials, and thus the potential for ARD is considered low; however, metal leaching under neutral pH conditions, neutral rock drainage (NRD) may occur (Section 29.10, ML/ARD Management Plan). Groundwater drainage will be collected together with surface runoff and directed, with appropriate sediment control, to Brucejack Lake. A geochemical source term was developed for the quarry drainage (Appendix 13-C, Predictive Water Quality Report) to support the assessment of project effects on surface water quality in Chapter 13, Assessment of Potential Surface Water Quality Effects. Specific inspection, monitoring and sampling requirements for the quarry are outlined in the ML/ARD Management Plan (Section 29.10).

Development of the underground portal and facilities requires that dewatering of the subsurface be initiated. This activity may have a major effect because removal of water leads to drawdown of the water table. As described above, from a water quantity perspective this will likely lead to a decrease in baseflow to Brucejack Creek, its tributary streams and Brucejack Lake. From a water quality perspective this drawdown may enhance ML/ARD processes by allowing the migration of oxygen into the subsurface. The pumping and removal of water necessitates the underground water management system. This system has the potential for major hydrogeological effects because the groundwater brought to the surface must be treated prior to discharge to Brucejack Lake during the Construction and Operation phases.

Construction of mine portal and ventilation shafts may have a moderate effect on groundwater quantity and quality because it also requires some dewatering, water management and waste rock management activities. Potential effects related to these activities will largely be addressed by specific management and mitigation plans developed for the project (Sections 29.10, ML/ARD Management Plan; 29.13, Soil Management Plan; 29.18, Waste Rock Management Plan; and 29.19, Water Management Plan) and these effects are specifically considered as part of the predictive assessment.

9.4.3.5 Operation Phase

The potential for the quarry to have a moderate effect on groundwater quantity and quality may continue into the Operation phase, for the same reasons outlined for the Construction phase.

Contact water from the surface developments (e.g., plant site cuts, portal development, etc.) will be collected and drained to the contact water collection pond. This water will be piped to the mine water treatment plants during Construction and Operation and thus the only potential effects to groundwater might include interception and localized changes to infiltration. The captured water will be treated and discharged to Brucejack Lake, the predevelopment discharge location for this water, and only small effects to groundwater quantity are anticipated. There is a small possibility of leakage from any lined collection pond. Any leaks would be dealt with using standard operating procedures in accordance with the Spill Prevention and Response Plan (Section 29.14).

The major effects for groundwater quantity during the Operation phase will likely be dominated by underground water management and by drilling, blasting, and excavation. Additional dewatering will lead to further drawdown as the mine workings increase in spatial extent. Drilling, blasting, and excavation may be expected to use variable amounts of water and to change the hydraulic conductivity of the subsurface. Enhanced hydraulic conductivity and increased dewatering activities will lead to increased drawdown and decreased baseflow, as discussed above. Similarly, placement of waste rock and paste tailings in the underground as backfill may result in locally increased or decreased hydraulic conductivity of the subsurface compared to pre-mining conditions.

For groundwater quality, the major potential effects are associated with the chemistry and permeability of backfill material, underground blasting and underground water management. Pumping of water will lead to enhanced drawdown of the water table and possible ingress of oxygen into the subsurface, as discussed above. Backfill materials and their hydraulic conductivity may affect the source term for PAG materials (see Appendix 13-C, Predictive Water Quality Report). Blasting residue may impact groundwater quality by contributing nitrates and other dissolved constituents. Note, however, that the underground water management system will capture poor quality water for treatment such that the groundwater quality will be controlled during the Construction and Operation phases.

9.4.3.6 Closure Phase

Minor potential hydrogeological effects at Closure were discussed above in the context of surface works. Surface infrastructure will be removed under existing protocols, guidelines, and regulations and the disturbed land reclaimed (Chapter 30, Closure and Reclamation). Similarly, removal or treatment of contaminated soils and any solid waste management are generally routine activities with established procedures and regulations. Decommissioning of the quarry may be expected to have only moderate effects for groundwater as the former quarry will continue to be a groundwater discharge area.

The only major potential effect at Closure may be associated with closure of the mine portals; ventilation shafts, adits, and portals will be sealed at Closure, limiting the potential for direct mine water discharge to surface waters, and limiting the ingress of oxygen. With the workings backfilled and the dewatering pumps turned off, the water table should rise over the time span of a few years. Consequently, baseflow should start to increase in streams near the Project and should approach pre-development conditions by the end of the Closure phase.

From a water quality perspective, flooding of the underground mine during closure will limit oxygen ingress to exposure surfaces and/or PAG material. A decrease in oxygen to suboxic and (possibly) anoxic conditions will significantly limit sulphide oxidation and the potential for ML/ARD conditions. Flushing of wall rock surfaces may mobilize precipitates and/or particulates, which have been identified as a potential concern during the closure period. However, ML/ARD management plans recommend several contingency options to mitigate this potential effect, which includes hydrologic containment and maintaining water treatment for as long as needed. As well, the short time associated with this rise in water table at closure and reclamation may limit the extent of oxygen ingress into the subsurface and the time frame may be too short for significant amounts of ML/ARD water to discharge to surface water. Affected groundwater may, however, have the potential to migrate through, and be attenuated in, the subsurface for a number of years following Closure.

9.4.3.7 Post-closure Phase

After Closure, most possible hydrogeological effects are considered to be negligible because the site will have been reclaimed. Targeted monitoring is envisioned to ensure that any outstanding groundwater issues are managed. The only anticipated major effect involves the remnants of the underground mine. Within a few years following Closure, most induced drawdown should be reversed and there may only be a small zone of residual drawdown remaining. Consequently, groundwater contributions to baseflow may be generally restored to creeks in the vicinity of the former mine. Backfill of the underground workings with low permeability material may be an important mitigation requirement for this to occur and is planned as part of mine operations (Sections 29.10, ML/ARD Management Plan; 29.18, Waste Rock Management Plan). As the zone of residual drawdown is decreased it is anticipated that a smaller volume of the subsurface would be accessible to oxygen, so the degree to which ML/ARD processes could occur should decrease. Monitoring of groundwater discharging to surface water should be considered, with a contingency for ongoing management and/or treatment if necessary (Section 29.10, ML/ARD Management Plan).

9.5 PREDICTIVE STUDY METHODS FOR HYDROGEOLOGY

9.5.1 Groundwater Quantity

The predictive operations (transient) simulation covers a 2-year mine Construction phase and a 22-year mining Operation phase. The most recent feasibility study report from June 2014 (Appendix 5-A) describes an 18 year Operation phase, while an earlier feasibility study (Tetra Tech 2013) had identified a 22 year Operation phase. For the purposes of this environmental assessment, an Operation phase of 22 years has been used as this is expected to provide, overall, a more conservative effects assessment associated with greater waste rock and tailings production and longer period of active disturbance prior to reclamation activities. The predictive Closure and Post-closure phase was simulated with both steady-state and 30-year transient simulations. The steady-state simulation represents average annual conditions Post-closure, after the groundwater system has fully recovered following mine dewatering. The transient simulation incorporates seasonality, and simulates the recovery of the groundwater system over time from closure through to equilibrium conditions.

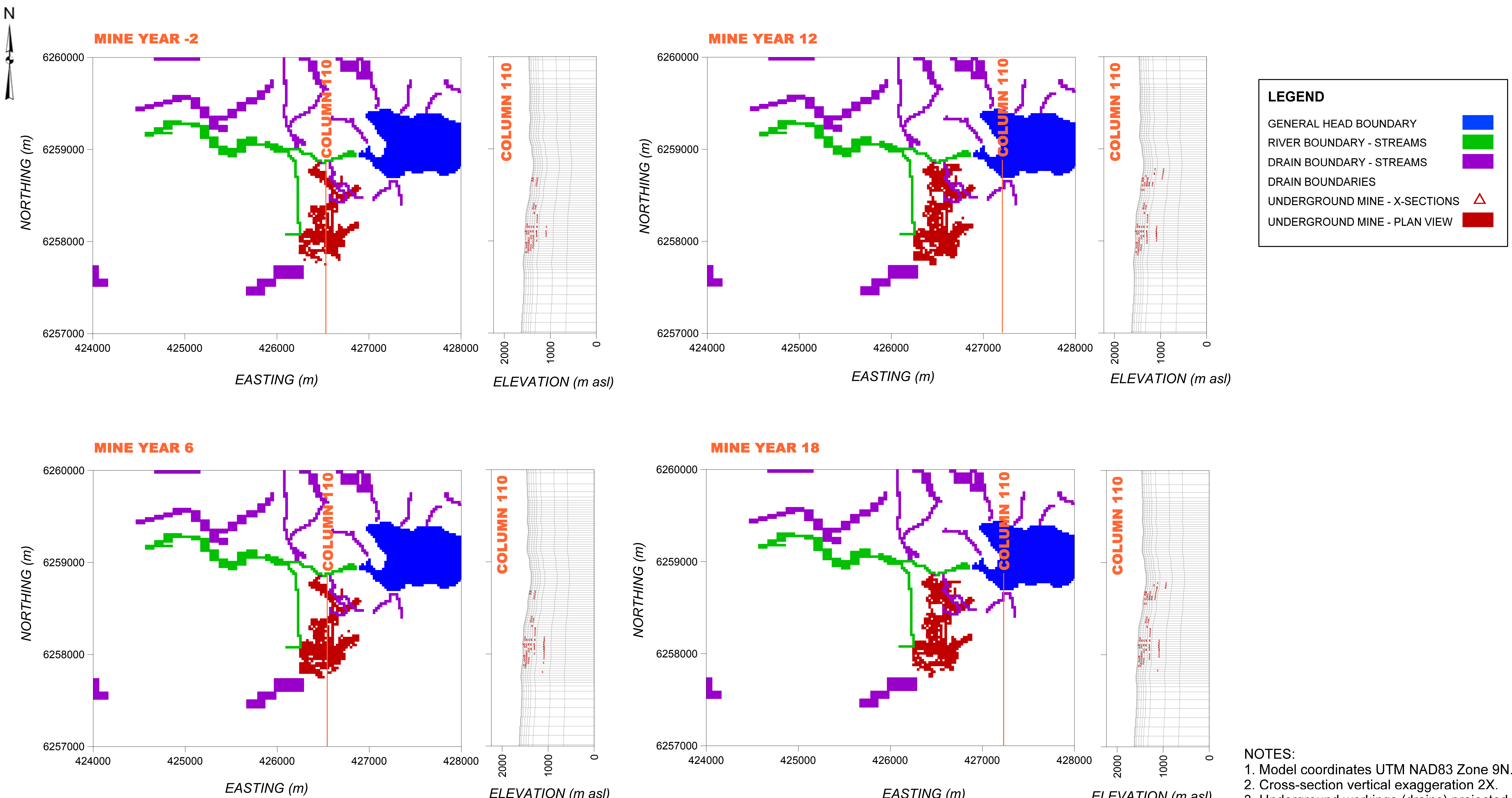
For all simulations the basic model conceptualization, configuration, calibrated hydraulic parameters, boundary conditions, and execution were identical to those outlined for the baseline characterization simulations (Section 9.3.4.5). Thus, only changes to the model setup are highlighted here.

9.5.1.1 Mine Construction and Operation

Initial heads for the model simulation were imported from the pre-operations steady-state (i.e., average, baseline conditions) simulation. The base case transient predictive simulation was developed using two-month stress periods with seasonal recharge and evapotranspiration, as discussed previously. The mining operations simulation, discussed next, was set up to correspond with the calendar year (i.e., with the first stress period corresponding to the months of January and February).

The underground mine plan was used to simulate advancement of development workings and the mining of stopes. Underground mining stopes and associated development tunnels were simulated using drains. Water levels within the drain cells were specified at the depth of mining. Drains representing the development (i.e., underground workings, access and egress ramps, and declines) became active according to the annual schedule derived from the mine development plan and remained active throughout the remainder of mining operations. Drains representing stopes were turned on according to the phased mine plan and were turned off when the stopes were assumed to be backfilled with paste tailings or waste rock, one year after mining of a stope level. This backfilling was represented in the model via deactivation of the drains representing the stope cells and alteration of the hydraulic conductivity in the appropriate cells to one order of magnitude greater than the surrounding bedrock fabric. The arrangement of drains representing the underground workings is illustrated on Figure 9.5-1 for years -2, 6, 12, and 18 of mining operations.

Figure 9.5-1
Underground Workings for Selected Years showing Arrangement of Drains



NOTES:
1. Model coordinates UTM NAD83 Zone 9N.
2. Cross-section vertical exaggeration 2X.
3. Underground workings (drains) projected to surface on plan view drawings.

Source: BGC Engineering Inc. (June 2014).

The conductance and areal extent of the general head boundary at Brucejack Lake was adjusted throughout mining operations to reflect tailings deposition. The thickness of the tailings deposit in Brucejack Lake was calculated using the provided waste schedule, an assumed density of 1.6 tonnes/m^3, and an assumed settlement of 100% in the year of deposition. Deposition of waste rock will occur along with tailings deposition in Brucejack Lake, but the tailings are considered to be the limiting factor with regards to bed conductance because of their fine-grained nature.

9.5.1.2 Closure and Reclamation and Post-closure

The transient Closure to Post-closure simulation directly followed the predictive mining operations simulation. Thus, initial heads for the Post-closure simulation were imported from the final stress period of the mining operations simulation. Seasonal recharge and evapotranspiration were applied to the transient simulations, as discussed previously.

During the simulations for the predictive mining operations, described above, drain boundaries were used to represent development workings and stopes. Stopes were simulated to be backfilled one year after mining; however, the underground development workings were assumed to remain open until the end of mining. For the Closure and Post-closure simulations, these drains were deactivated at Closure and the hydraulic conductivity of the associated grid blocks was specified to be two orders of magnitude greater than the surrounding bedrock fabric.

The proposed mine site layout includes facilities that will be constructed on a platform that will primarily be developed from a cut made in bedrock. The mill site was simulated using drains to represent the bedrock cut. The proposed site layout also includes a section of fill extending into Brucejack Lake. The fill was represented in the model by deactivating the GHB cells covered by fill material.

9.5.2 Groundwater Quality

The primary effect of the Project on groundwater quality is related to the potential for ML/ARD reactions to occur when groundwater and oxygen are in contact with exposed or disturbed rock. Areas of identified PAG material that may contact groundwater include plant-site cuts at the surface and underground exposures related to excavated areas and stored waste rock. Seepage from the non-PAG quarry site also has the potential to affect groundwater quality due to neutral rock drainage conditions. In these scenarios, the mobilization of certain elements may be increased at circumneutral pH conditions (e.g., As, Mo, Se).

For groundwater quality to become affected, one of two pathways must occur, as follows:

- infiltrating rainwater and/or snow melt must infiltrate to oxic, or suboxic regions of the subsurface and come into contact with PAG or non-PAG materials; or
- ML/ARD affected water must infiltrate into the groundwater flow system.

To assess the potential for groundwater quality to be affected by ML/ARD reactions, the results of the numerical flow modelling described above were reviewed to understand groundwater recharge areas, groundwater flow directions, and groundwater discharge areas in the context of the locations of disturbed (PAG or non-PAG) materials. Where the potential for groundwater quality to become degraded by ML/ARD reactions was determined to exist, chemical source terms to represent the affected groundwater were developed for use in evaluating effects on the receiving environment.

The direction of affected groundwater flow is an important component in the Project effects assessment. Groundwater flow to the mine site area during the Construction, Operation, and initial Closure and reclamation stages of the Project is primarily directed towards the underground, under the influence of the dewatering system. As such, this water is collected and directed to the mine water treatment plant prior to discharge to Brucejack Lake (i.e., the flow of groundwater is a discharge flow and is mainly of concern to surface water quality). During the Post closure phase, following water table recovery in the subsurface, there is potential for ML/ARD-affected groundwater to flow towards and into Brucejack Lake, Brucejack Creek and small tributaries, and the plant site.

Source-term water compositions were developed for base and conservative cases using average and 95th percentile concentrations (respectively) from compiled datasets (Appendix 13-C, Predictive Water Quality Report) for each of the following:

- background water quality;
- quarry runoff;
- plant-site runoff;
- underground mine discharge;
- water treatment plant;
- tailings slurry; and
- waste rock in Brucejack Lake.

Of these possible scenarios, the source water terms with the potential to affect groundwater quality by one or both of the pathways identified above include: quarry runoff (Table 4-5 from Lorax 2014), plant-site runoff (Table 4-7 from Lorax 2014) and underground mine discharge (Tables 4-9 [pre-lag], 4-10 [post-lag] and 4-14 [nutrients] from Lorax 2014). Values derived for these source terms are shown as dissolved concentrations only; however, water quality modelling applied the assumption that total metal concentrations are equivalent to dissolved metal concentrations.

It is worth noting that the sewage treatment plant source term (not listed above) was based on background water quality concentrations and vendor-specific nutrient concentrations scaled to reflect anticipated camp sizes. Further details can be found in Lorax (2014).

9.5.2.1 Quarry Runoff

Runoff from the quarry will flow into Brucejack Lake during all phases of the Project. The quarry material is predominantly volcanic (plagioclase-hornblende) porphyry (P1), with no observed major discontinuities and negligible sulphide mineralization (Pretivm, pers. comm.). Based on its ML/ARD characterization (BGC 2014), quarry material is classified as non-PAG. Results from three humidity cells with complementary P1 materials (HC 27 - Office P1; HC 28 and 35 - Bridge P1; BGC 2014) were used to generate the water quality source term for quarry runoff. Mean concentrations from the last 10 weeks of leachate results were compiled for each of the three humidity cells. The base case and conservative source water terms for the quarry runoff are presented in Table 9.5-1.

9.5.2.2 Plant-Site Runoff

Groundwater flow from or to the plant-site area was considered for all time periods (see Section 9.6.1.2, below). No groundwater is expected to discharge to the plant-site area during Construction or Operation due to mine dewatering (i.e., the water table is drawn down sufficiently that no groundwater discharge occurs to the plant site). Following Closure, small amounts of groundwater may seasonally discharge to surface. The majority of the material in the plant site area consists of intermediate volcanic assemblages. Results from humidity cells bearing similar intermediate volcanic assemblages (HC 17, 26 and 29) were used to derive source terms for the plant site during the Operation and Post closure phases. Operation phase source terms were developed from an average of the entire humidity cell dataset, whereas Post-closure source terms were derived from the average of data from the last 10 weeks of sample measurements. Base case and conservative source water terms for the plant site runoff are summarized in Table 9.5-2.

Table 9.5-1. Quarry Source Term Values for Base Case and Conservative Case Scenarios (as Dissolved Concentrations in mg/L)

Parameter	Base Case (BC)	Conservative Case (CC)
pH	7.54	7.47
Alkalinity	29.1	28.1
Nitrate N(5)	n/a	n/a
Nitrite N(3)	n/a	n/a
P	5.0E-03	5.5E-03
Cl	3.00	4.90
S(6)	10.7	17.6
Ag	5.0E-06	5.0E-06
Al	0.089	0.10
As	0.0056	0.0094
Ca	6.94	8.91
Cd	2.6E-05	3.9E-05
Co	9.7E-05	1.2E-04
Cr	2.5E-04	2.5E-04
Cu	0.0037	0.0094
Fe	0.0067	0.0075
Hg	6.5E-06	7.4E-06
K	2.38	3.34
Mg	1.06	1.42
Mn	0.034	0.056
Mo	9.1E-04	0.0010
Na	2.07	2.78
Pb	2.4E-04	4.8E-04
Se	3.4E-04	7.5E-04
Tl	2.0E-05	3.4E-05
Zn	0.0030	0.0058

Note: Based on Table 4-5 of Lorax (2014).

Table 9.5-2. Plant Site Source Term Values for Operation and Post-closure Phases (as Dissolved Concentrations in mg/L)

Parameter	Operation		Post-closure	
	Base Case (BC)	Conservative Case (CC)	Base Case (BC)	Conservative Case (CC)
pH	7.41	6.41	7.43	5.17
Alkalinity	21.2	25.6	16.7	15.0
Nitrate N(5)	n/a	n/a	n/a	n/a
Nitrite N(3)	n/a	n/a	n/a	n/a
Diss-P	4.9E-03	5.3E-03	4.5E-03	4.7E-03
Cl	n/a	n/a	n/a	n/a
Sulphate S(6)	29.7	59.8	12.2	43.7
Ag	1.5E-05	1.7E-05	1.3E-05	1.2E-05
Al	0.077	0.12	0.13	0.12
As	0.016	0.017	0.016	0.015
Ca	4.41	11.1	3.77	11.7
Cd	2.3E-05	0.0017	2.8E-05	0.0033
Co	1.5E-04	0.0049	1.4E-04	0.0079
Cr	2.5E-04	2.5E-04	2.5E-04	2.5E-04
Cu	6.9E-04	0.011	6.4E-04	0.024
Fe	0.0062	0.12	0.0061	0.25
Hg	6.3E-06	6.9E-06	5.0E-06	6.3E-06
K	2.01	2.86	1.87	2.01
Mg	1.30	1.29	1.02	1.27
Mn	0.026	0.0030	0.027	0.42
Mo	0.0033	0.0031	0.0017	0.0015
Na	9.90	16.6	1.83	6.05
Pb	1.9E-04	0.0027	1.4E-04	0.0041
Se	0.0015	0.0012	0.0010	8.2E-04
Tl	2.7E-05	5.0E-05	2.1E-05	3.7E-05
Zn	0.0021	0.10	0.0018	0.22

Note: Based on Table 4-7 of Lorax (2014).

9.5.2.3 Underground Mine Discharge

Mine water collected underground is conceptualized as the summation of groundwater infiltration through exposed materials in the underground workings and bleedwater from the paste backfilling process (i.e., excess water exuded from the paste, if any). Based on water balance models of the underground workings, bleedwater is predicted to contribute at most 5% to the overall underground flow term, such that the year-to-year development of underground workings is the primary control on adit water quality.

Base case and conservative case source terms were developed for each of the seven geological model units for both pre-lag (i.e., prior to onset of ARD) and post-lag (i.e., after the onset of ARD) conditions and for possible nutrient loading scenarios. These cases are presented in Table 9.5-3, Table 9.5-4, and Table 9.5-5, respectively.

Table 9.5-3. Underground Water Pre-lag Source Terms (in mg/L) for Seven Brucejack-designated Geological Model Units

Unit	Fragmental		VSF		Conglomerate		P2		Bridge P1		Silicified Cap	Office P1
Scenario	**BC**	**CC**	**BC**	**CC**	**BC**	**CC**	**BC**	**CC**	**BC**	**CC**	**BC/CC**	**BC/CC**
pH	7.29	6.89	7.26	6.95	7.38	7.26	7.5	7.41	7.76	7.68	7.54	7.52
Ag	5.2E-06	8.9E-06	6.3E-06	1.7E-05	3.8E-06	4.2E-06	3.8E-06	4.2E-06	4.3E-06	5.0E-06	3.9E-06	3.5E-06
Al	9.7E-03	1.9E-02	1.1E-02	2.1E-02	4.2E-03	5.7E-03	6.8E-03	8.3E-03	2.1E-02	2.2E-02	7.4E-03	2.2E-02
Alkalinity	12.2	6.18	11.1	3.64	13.2	6.17	12.8	11.5	15.8	14.6	9.84	17.8
As	4.3E-03	1.1E-02	1.7E-02	6.4E-02	1.3E-03	1.5E-03	9.0E-03	1.5E-02	4.2E-03	7.4E-03	1.7E-03	8.6E-03
Ca	41.2	94.4	34.1	67.0	54.5	76.7	79.0	87.4	22.4	25.6	22.1	19.0
Cd	8.0E-05	2.1E-04	1.7E-04	7.0E-04	4.6E-04	8.9E-04	1.7E-04	3.5E-04	3.1E-05	5.0E-05	8.2E-04	9.2E-05
Cl	44.8	69.1	52.4	116	4.85	1.00	46.8	50.4	87.2	118	48.2	142
Co	5.0E-05	1.0E-04	4.4E-04	2.2E-03	1.2E-03	2.9E-03	5.2E-05	8.5E-05	1.7E-05	1.8E-05	2.9E-05	4.6E-05
Cr	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04	1.5E-04
Cu	4.7E-04	9.2E-04	8.6E-04	2.4E-03	3.2E-03	8.0E-03	3.8E-03	9.3E-03	1.9E-03	3.0E-03	9.6E-04	5.6E-04
Fe	5.7E-03	1.2E-02	1.6E-02	6.2E-02	2.4E-03	3.2E-03	6.9E-03	1.3E-02	8.8E-03	9.1E-03	3.8E-03	1.5E-02
Hg	4.4E-06	6.7E-06	3.6E-06	4.9E-06	3.3E-06	3.3E-06	3.3E-06	3.3E-06	3.3E-06	3.3E-06	3.3E-06	3.3E-06
K	1.53	2.70	1.97	3.63	1.55	2.51	1.74	2.03	3.40	3.94	0.57	1.76
Mg	14.6	26.9	19.6	52.8	3.53	5.19	16.2	19.6	22.8	33.3	12.2	43.5
Mn	0.11	0.31	0.12	0.45	0.20	0.35	0.20	0.33	0.04	0.05	0.07	0.02
Mo	2.1E-03	5.9E-03	4.4E-03	1.5E-02	2.3E-03	4.1E-03	6.7E-04	1.2E-03	1.3E-03	1.4E-03	7.9E-04	1.1E-03
Na	2.39	4.13	3.13	7.81	2.26	7.44	3.84	4.27	5.12	5.83	1.80	3.72
Pb	1.6E-04	5.9E-04	7.3E-05	1.5E-04	5.8E-04	9.1E-04	3.3E-05	7.7E-05	9.5E-05	1.4E-04	4.8E-05	3.3E-05
S(6)	93.3	247	88.7	231	135	217	190	222	28.2	38.5	32.5	20.6
Se	5.0E-04	1.0E-03	5.6E-04	2.1E-03	6.6E-04	1.3E-03	2.0E-03	3.6E-03	1.5E-04	2.5E-04	9.5E-04	1.2E-05
Tl	1.5E-05	3.5E-05	1.9E-05	4.5E-05	5.5E-05	8.3E-05	1.2E-05	1.2E-05	1.1E-05	1.2E-05	1.0E-05	1.0E-05
Zn	1.9E-03	4.1E-03	5.0E-03	2.3E-02	2.6E-02	6.5E-02	2.4E-03	4.5E-03	1.4E-03	2.1E-03	8.6E-03	1.7E-03

Note: Table 4-9 of Lorax (2014)

Table 9.5-4. Underground Water Post-lag Source Terms (in mg/L) for Seven Brucejack-designated Geological Model Units

Unit	Fragmental		VSF		Conglomerate		P2		Bridge P1		Silicified Cap		Office P1
Scenario	BC	CC	BC	CC	BC	CC	BC	CC	BC	CC	BC	CC	BC
pH	3.21	3.03	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.82	3.50	3.50
Ag	8.4E-05	1.4E-04	9.5E-05	2.6E-04	5.7E-05	6.4E-05	5.7E-05	6.4E-05	6.5E-05	7.6E-05	5.9E-05	1.1E-04	5.3E-05
Al	4.58	9.70	4.06	7.60	1.53	2.09	2.49	3.04	7.85	8.22	0.38	2.73	7.88
Alkalinity	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
As	3.9E-02	5.9E-02	3.9E-02	1.5E-01	3.1E-03	3.5E-03	2.1E-02	3.6E-02	9.8E-03	1.7E-02	3.0E-03	4.1E-03	2.0E-02
Ca	426	978	353	694	564	794	818	906	231	264	14.9	229	197
Cd	2.1E-02	5.5E-02	4.5E-02	1.8E-01	1.2E-01	2.3E-01	4.5E-02	9.2E-02	8.1E-03	1.3E-02	2.0E-01	2.2E-01	2.4E-02
Cl	470	918	356	593	521	653	752	834	384	424	1.00	1.00	387
Co	2.5E-02	5.2E-02	2.2E-01	1.1E+00	5.8E-01	1.5E+00	2.6E-02	4.2E-02	8.6E-03	8.7E-03	2.0E-03	1.5E-02	2.3E-02
Cr	1.3E-03	2.0E-03	1.3E-03	1.3E-03	1.3E-03	1.3E-03	1.3E-03	1.3E-03	1.3E-03	1.3E-03	1.3E-03	2.6E-03	1.3E-03
Cu	0.20	0.25	0.22	0.60	0.80	2.05	0.96	2.35	0.49	0.75	0.24	0.49	0.14
Fe	26.0	35.2	11.0	43.4	1.71	2.23	4.80	9.17	6.13	6.36	2.68	2.93	10.6
Hg	1.1E-05	1.9E-05	7.1E-06	9.6E-06	6.4E-06	6.4E-06	6.4E-06	6.4E-06	6.4E-06	6.4E-06	5.0E-06	6.4E-06	6.4E-06
K	1.42	2.5	1.83	3.37	1.44	2.33	1.61	1.89	3.15	3.65	0.13	0.53	1.63
Mg	8.15	15.0	10.9	29.5	1.97	2.90	9.04	11.0	12.7	18.6	0.45	6.78	24.2
Mn	30.2	88.9	34.9	128	56.5	99.9	58	94.7	9.97	13.9	0.51	20.6	6.13
Mo	4.2E-04	1.2E-03	8.9E-04	3.1E-03	4.7E-04	8.2E-04	1.4E-04	2.3E-04	2.6E-04	2.8E-04	8.3E-05	1.6E-04	2.3E-04
Na	1.20	2.07	1.57	3.91	1.13	2.17	1.92	2.14	2.56	2.92	67.7	297	1.86
Pb	2.7E-02	9.8E-02	1.2E-02	2.4E-02	9.6E-02	1.5E-01	5.5E-03	1.3E-02	1.6E-02	2.3E-02	2.0E-03	8.0E-03	5.5E-03
S(6)	543	1437	516	1.34E+03	784	1.27E+03	1.11E+03	1.29E+03	164	224	189	1.26E+03	120
Se	1.3E-03	2.7E-03	1.5E-03	5.5E-03	1.8E-03	3.4E-03	5.2E-03	9.6E-03	3.9E-04	6.7E-04	2.5E-03	1.1E-02	3.1E-05
Tl	9.0E-05	1.4E-04	1.9E-05	4.5E-05	5.5E-05	8.3E-05	1.2E-05	1.2E-05	1.1E-05	1.2E-05	1.0E-05	3.5E-05	1.0E-05
Zn	0.70	1.34	1.62	7.44	8.62	21.2	0.77	1.47	0.45	0.68	2.79	6.48	0.56

Note: Table 4-10 of Lorax (2014)

Table 9.5-5. Estimated Adit Water Source Terms (mg/L) for Elements Associated with Blasting during Operation

	Base Case						Conservative Case					
	NH_4^+	NO_3^-	NO_2^-	Tot-N	Cl^-	Tot-P	NH_4^+	NO_3^-	NO_2^-	Tot-N	Cl^-	Tot-P
Year	0.80*	1.79	0.30	2.92	2.10	0.76	1.17	2.39	0.49	3.86	2.50	1.01
-2	1.24	2.79	0.47	4.57	3.28	1.19	1.82	3.73	0.77	6.03	3.91	1.57
-1	1.51	3.40	0.57	5.55	3.99	1.45	2.22	4.53	0.93	7.33	4.75	1.91
1	1.32	2.96	0.50	4.84	3.47	1.26	1.93	3.95	0.81	6.39	4.14	1.67
2	1.19	2.68	0.45	4.38	3.14	1.14	1.75	3.57	0.74	5.78	3.74	1.51
3	1.13	2.53	0.42	4.14	2.98	1.08	1.65	3.38	0.70	5.47	3.54	1.43
4	1.21	2.72	0.45	4.44	3.19	1.16	1.77	3.63	0.75	5.87	3.80	1.53
5	1.11	2.49	0.42	4.07	2.93	1.06	1.63	3.33	0.68	5.38	3.48	1.40
6	1.03	2.31	0.39	3.78	2.71	0.99	1.51	3.08	0.63	4.99	3.23	1.30
7	0.53	1.20	0.20	1.95	1.40	0.51	0.78	1.6	0.33	2.58	1.67	0.67
8	0.94	2.12	0.36	3.47	2.49	0.91	1.38	2.83	0.58	4.58	2.97	1.20
9	0.78	1.75	0.29	2.85	2.05	0.74	1.14	2.33	0.48	3.77	2.44	0.98
10	0.65	1.46	0.24	2.39	1.72	0.62	0.96	1.95	0.40	3.16	2.04	0.82
11	0.60	1.34	0.22	2.19	1.58	0.57	0.88	1.79	0.37	2.90	1.88	0.76
12	0.65	1.46	0.24	2.38	1.71	0.62	0.95	1.94	0.40	3.15	2.04	0.82
13	0.57	1.29	0.22	2.11	1.52	0.55	0.84	1.72	0.35	2.79	1.80	0.73
14	0.53	1.19	0.20	1.94	1.40	0.51	0.78	1.59	0.33	2.57	1.66	0.67
15	0.35	0.78	0.13	1.28	0.92	0.33	0.51	1.04	0.22	1.69	1.09	0.44
16	0.26	0.59	0.10	0.96	0.69	0.25	0.38	0.79	0.16	1.27	0.82	0.33
17	0.30	0.67	0.11	1.09	0.79	0.29	0.44	0.89	0.18	1.45	0.94	0.38
18	0.25	0.56	0.09	0.91	0.66	0.24	0.37	0.75	0.15	1.21	0.78	0.32
19	0.16	0.35	0.06	0.57	0.41	0.15	0.23	0.46	0.10	0.75	0.49	0.20
20	0.19	0.43	0.07	0.70	0.51	0.18	0.28	0.57	0.12	0.93	0.60	0.24
21	0.05	0.12	0.02	0.20	0.14	0.05	0.08	0.16	0.03	0.26	0.17	0.07
22	0.04	0.08	0.01	0.14	0.10	0.04	0.05	0.11	0.02	0.18	0.12	0.05

Note: Table 4-14 of Lorax (2014).
Blue text represents base values from adit waters during the Bulk Sample program (refer to Table 4-12 of Lorax (2014).

Based on the underground mine discharge source terms, two underground water quality scenarios were developed to represent temporal end-members during flooding of the underground workings:

- Before Underground Flooding – This water chemistry was derived from a PHREEQC (Parkhurst and Appelo 2013) mixing-model simulation that used material-specific source terms and each term was weighted according to the proportion of exposed or extracted material from the underground (as described by the Project underground mine plan). The base case scenario was developed using base case source terms and base case estimated lag-times (i.e., median estimated lag-times), while the conservative scenario was developed using base case source terms and conservative case estimated lag times (i.e., minimum estimated lag-times). The PHREEQC model allowed for the precipitation of common secondary oxides (Fe and Al) and carbonates in a fully oxygenated environment. The "before underground flooding" chemistry represents a worst-case water quality scenario and a possible expected water quality at the start of the closure period. This source water will migrate predominantly along groundwater flow paths to Brucejack Lake and Brucejack Creek, and represents the water quality that may be expected to discharge to surface water in the years following mine closure.

- Flooded Underground Workings – This water chemistry was derived from historical water quality data from the existing adit (from Newhawk operations). This data was collected during the post-Newhawk period when the underground workings were allowed to flood and adit waters passively drained to Brucejack Creek. The base case scenario represents average concentrations measured during this period, while the conservative scenario represents 95th percentile concentrations. The “flooded underground workings” chemistry represents an expected water quality scenario for flooded workings in the Post-closure phase.

9.6 PREDICTIVE STUDY RESULTS FOR HYDROGEOLOGY

9.6.1 Predictive Study for Groundwater Quantity

9.6.1.1 Mine Construction and Operation

Following model calibration and benchmarking to current baseline conditions, predictive simulations for mining Construction (2 years), Operation (22-year mine life), Closure (a few years, assessed as the time required for groundwater to flood the underground mine workings and return to a new steady-state condition) and Post-closure were developed.

The objectives of the predictive mining Construction and Operation simulations were:

- to estimate the rate of groundwater inflow to the proposed underground workings;
- to predict changes to the groundwater flow system throughout mining operations; and
- to estimate groundwater discharge to surface water receptors throughout mining operations.

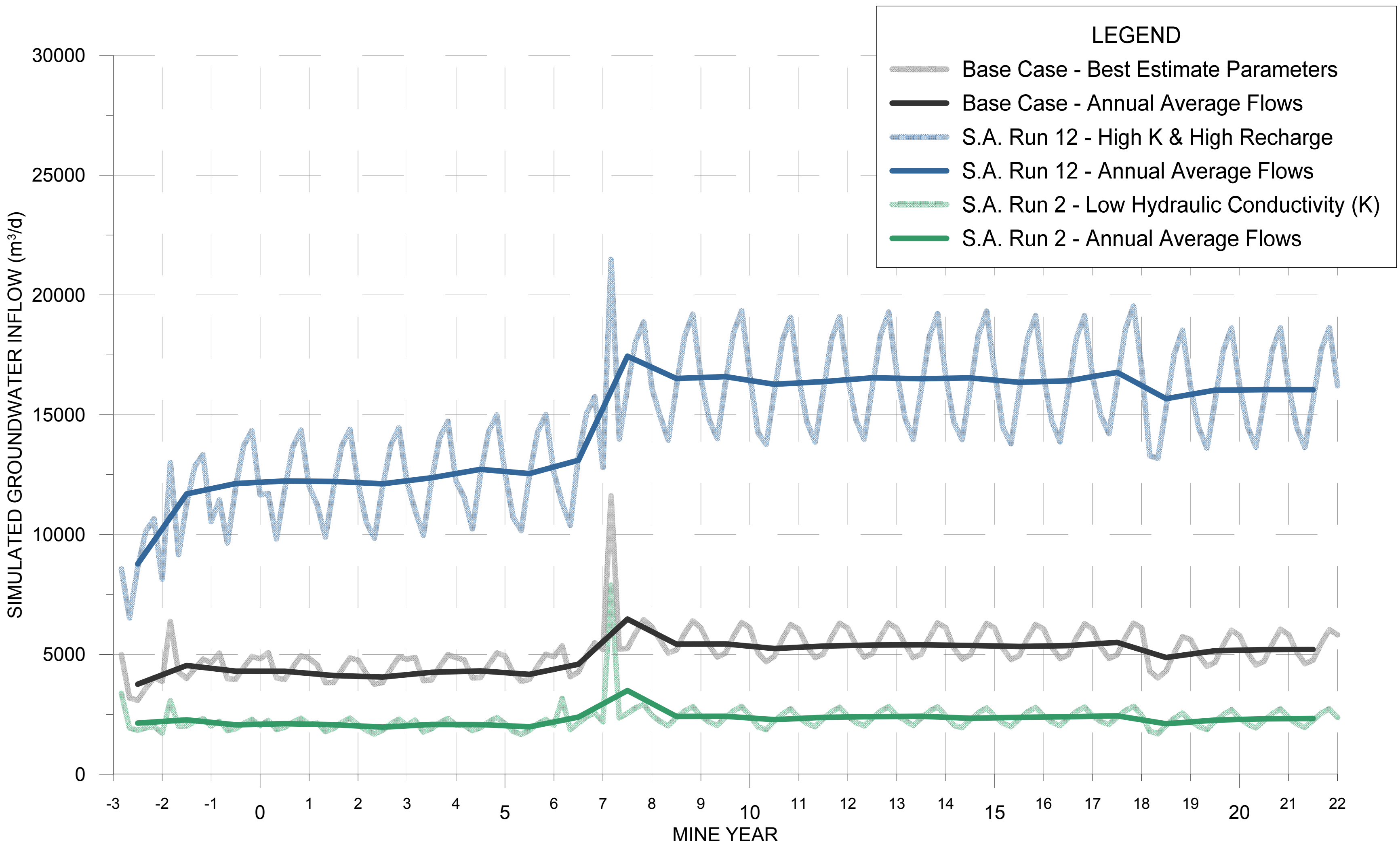
The estimated inflows for each stress period of the numerical model, along with annual average estimated inflows, are shown graphically on Figure 9.6-1. Note that the inflow peaks arise because the model boundary conditions are set to advance the mine and backfill stopes on an annual basis. A more detailed mine plan would yield a smoother hydrograph.

The average annual rate of groundwater inflow to the underground workings is predicted to gradually increase during Construction and then to remain relatively stable throughout the development of the Valley of the Kings resource during years 1 to 7 of mine life, ranging between 4,100 and 4,600 m^3/d. The rate of inflow to the underground workings is predicted to increase to an annual average peak of approximately 6,500 m^3/d in year 8, with the initiation of development of the WZ resource. During years 9 to 18 of mine life, predicted annual average inflows range between 5,200 and 5,500 m^3/d, before decreasing slightly and ranging between 4,900 and 5,200 m^3/d for the final four years of mine life. The overall average flow for the entire simulated period is 4,900 m^3/d.

With the advent of mining operations, groundwater flow within the LSA becomes largely directed towards the dewatered mine workings. The elevation of the water table is drawn down substantially, up to approximately 400 m, within the footprint of the underground workings. At the height of dewatering, (year 12) drawdown contours propagate over an area two to three times the size of the mine footprint (Figure 9.6-2). The cone of depression associated with 10 m or more of drawdown due to mine dewatering has an approximate areal extent of 2 by 3 km. Plots of predicted groundwater elevation contours and drawdown at the end of mine life (year 22) are provided on Figure 9.6-3 and Figure 9.6-4, respectively. During this period, groundwater flow direction is oriented into the underground such that groundwater potentially affected by ML/ARD processes in the underground is collected by the dewatering system, and routed to treatment at the mine water treatment plant.

Figure 9.6-1

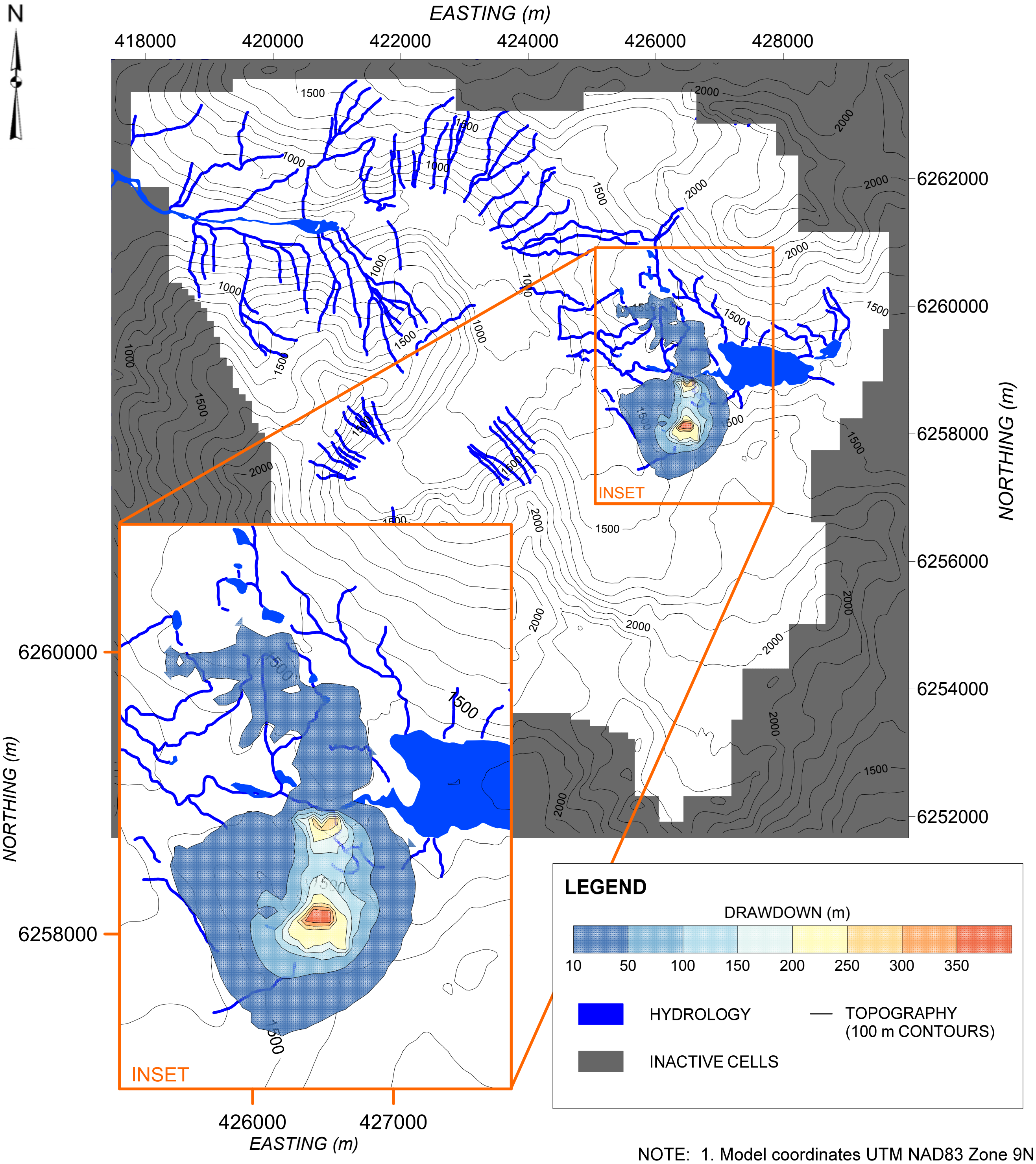
Simulated Inflow to Underground Workings



Source: BGC Engineering Inc. (June 2014).

Figure 9.6-2

Maximum Simulated Drawdown Year 12 of Mining Operations

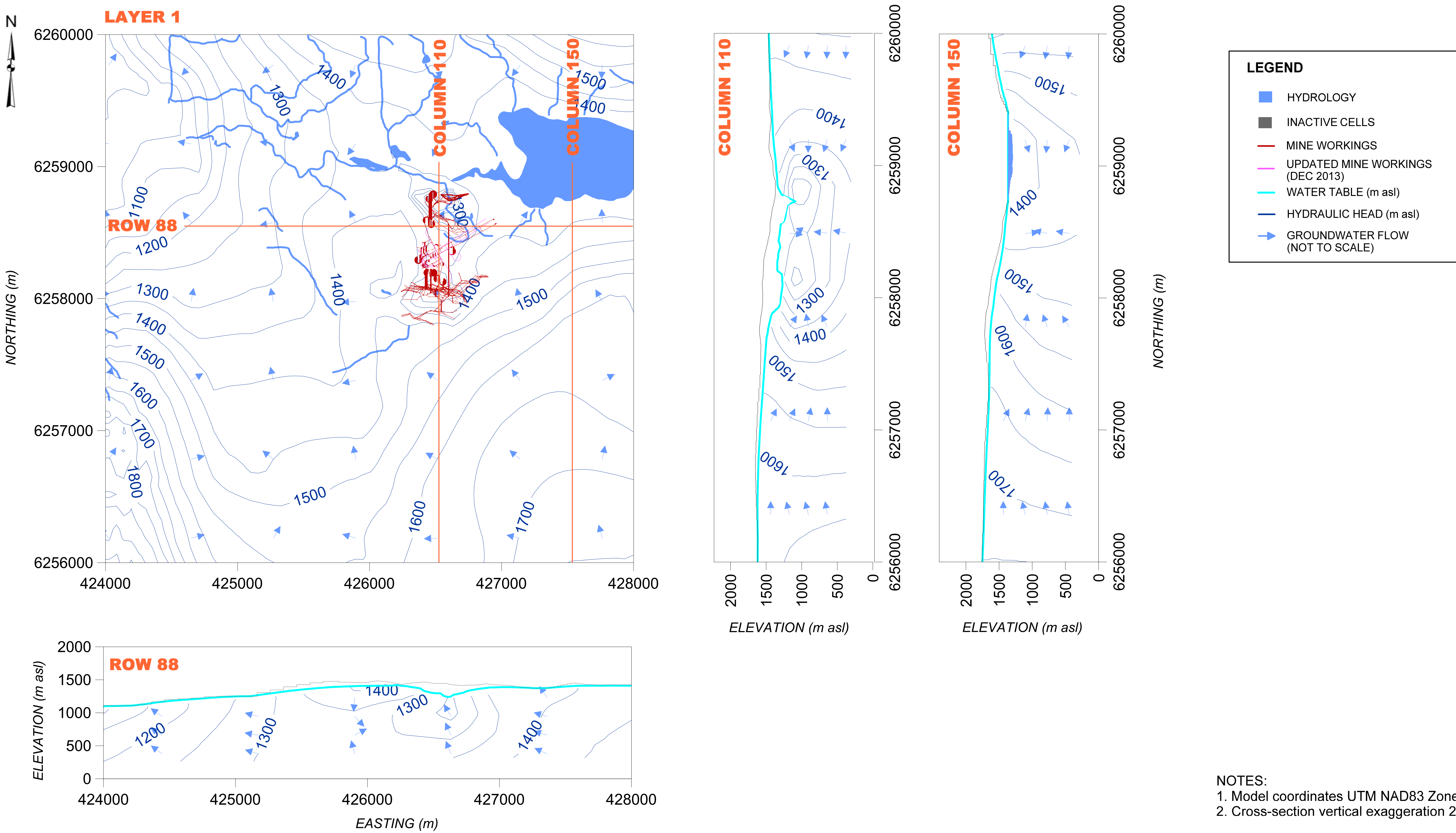


NOTE: 1. Model coordinates UTM NAD83 Zone 9N.

Source: BGC Engineering Inc. (June 2014).

Figure 9.6-3

Simulated Groundwater Elevation Contours - End of Mine Life

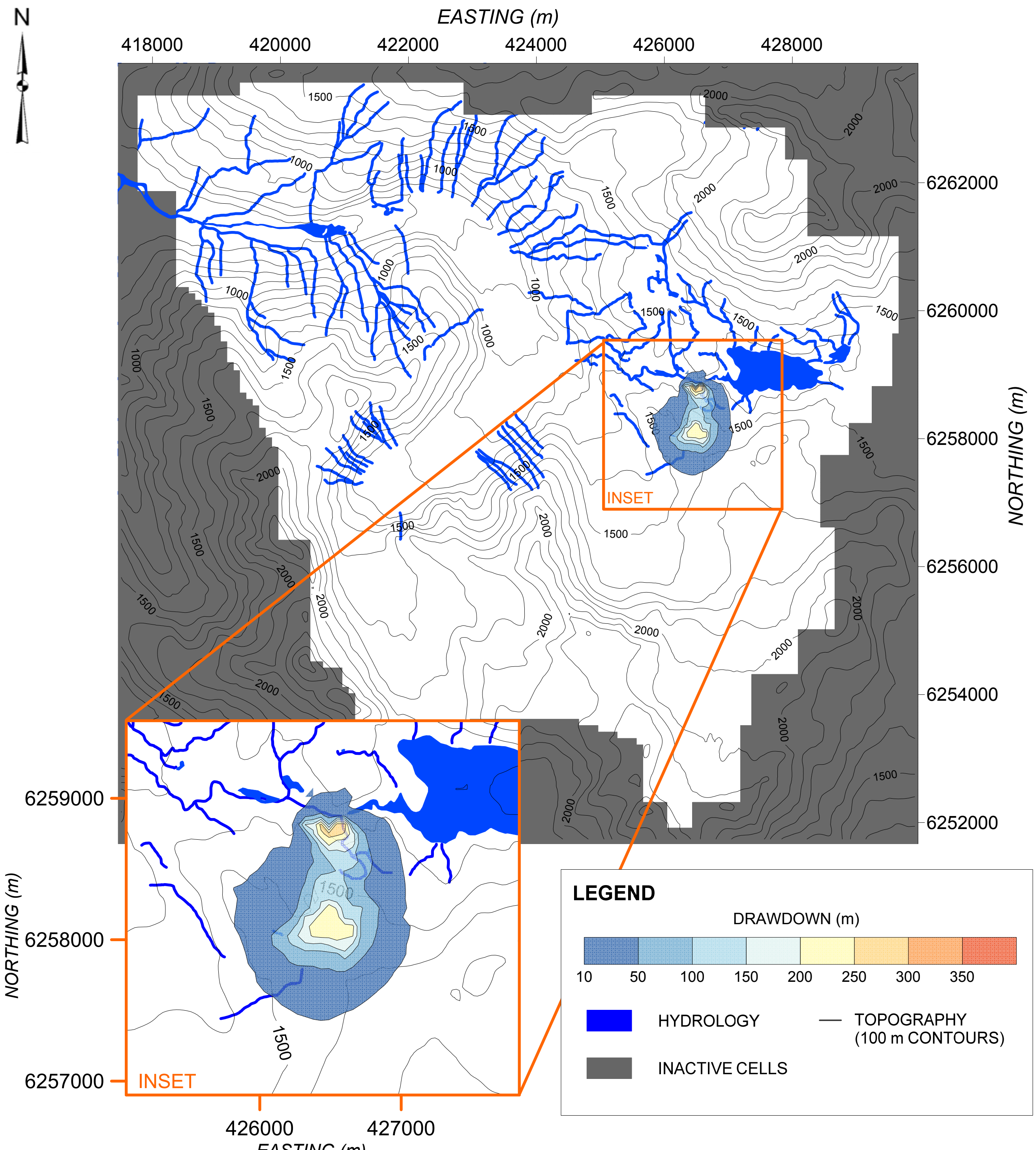


NOTES:
1. Model coordinates UTM NAD83 Zone 9N.
2. Cross-section vertical exaggeration 2X.

Source: BGC Engineering Inc. (June 2014).

Figure 9.6-4

Simulated Drawdown - End of Mine Life



NOTE: 1. Model coordinates UTM NAD83 Zone 9N.

Source: BGC Engineering Inc. (June 2014).

In general, the surface water features closest to the proposed underground mine are expected to be most impacted by mine dewatering (i.e., Camp Creek, Valley of the Kings Creek, and Brucejack Creek). Changes in groundwater discharge to surface water receptors can be measured through changes to predicted groundwater baseflow at the BJ 200 m D/S monitoring point and BJL-H1 gauging stations, as groundwater baseflow consists of the sum of groundwater discharge to boundary conditions upstream of these points (i.e., groundwater discharge to general head boundaries, drain and river boundaries, and groundwater seepage at the defined boundaries). The average baseflow at BJ 200 m D/S throughout mining operations is a predicted 6,100 m^3/d, which represents a 20% reduction of the estimated pre-disturbance baseflow of 7,600 m^3/d. The average baseflow at the downstream point BJL-H1 throughout mining operations is predicted to be 7,200 m^3/d, versus the estimated pre-disturbance baseflow of 9,000 m^3/d, or 20%. Simulated discharges to surface-water receptors during the Project life, including changes from pre-disturbance conditions, are summarized on Table 9.6-1.

Table 9.6-1. Summary of Predicted Groundwater Discharge to Surface Water Receptors in the Local Study Area

Surface Water Receptor[1]	Pre-Disturbance / Baseline (m^3/d)		Construction[3] (m^3/d)		Operation (Year 8) (m^3/d)		Operation (Year 22) (m^3/d)		Post-closure (m^3/d)	
	Summer[2]	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
Tributaries to Brucejack Lake	5,400 (-)	3,400 (-)	5,300 (-1%)	3,300 (-1%)	5,300 (-2%)	3,300 (-3%)	5,200 (-3%)	3,200 (-4%)	5,500 (+2%)	3,300 (-3%)
Brucejack Lake	2,200 (-)	2,000 (-)	2,100 (-4%)	1,900 (-4%)	1,800 (-17%)	1,600 (-19%)	2,000 (-11%)	1,800 (-11%)	2,100 (-5%)	1,800 (-7%)
Camp Creek	130 (-)	50 (-)	0 (-100%)	0 (-100%)	0 (-100%)	0 (-100%)	0 (-100%)	0 (-100%)	160 (+22%)	100 (+91%)
Brucejack Creek between Brucejack Lake and BJ 200 m D/S	1,300 (-)	820 (-)	320 (-75%)	150 (-82%)	40 (-97%)	10 (-99%)	30 (-97%)	4 (-100%)	1,100 (-11%)	820 (-1%)
Valley of the Kings Creek	250 (-)	120 (-)	80 (-70%)	40 (-67%)	40 (-86%)	20 (-85%)	30 (-87%)	20 (-88%)	200 (-17%)	90 (-23%)
Unnamed Creek	1,000 (-)	600 (-)	970 (-5%)	540 (-10%)	860 (-17%)	450 (-26%)	820 (-20%)	410 (-32%)	1,000 (+2%)	580 (-4%)
Brucejack Creek between BJ 200 m D/S and BJL-H1	420 (-)	320 (-)	390 (-7%)	280 (-12%)	330 (-23%)	220 (-32%)	320 (-25%)	200 (-38%)	430 (+1%)	310 (-1%)

Notes:
1. Predicted groundwater discharge to surface water receptors comprises flux to the boundary conditions that represent those receptors (i.e., DRN, RIV, and GHB cells). Total flow rates are presented along with percentage change from pre-disturbance or baseline conditions.
2. Summer flows represent the average of three 2-month summer stress periods, while winter flows represent the average of three 2-month winter stress periods.
3. Construction flows are averaged over mining operations model years -3 through -1. Operation flows are presented for years 8 and 22 (i.e., end of mine life).

9.6.1.2 Closure and Reclamation and Post-closure

The objectives of the predictive Closure and Post-closure simulations were:

- to predict changes to groundwater flow system (i.e., groundwater elevation and flow) following mining operations, including an assessment of how long it will take for the underground workings to flood; and
- to estimate groundwater discharge to surface water receptors and surface cuts in the Post-closure phase.

The transient simulation indicates that the majority of water table recovery happens in the one to three years following the end of the Operation phase (i.e., during the Closure phase), with the groundwater flow system approaching steady-state (i.e., Post-closure) conditions within five years of turning off the dewatering system.

Post-closure, the general arrangement of groundwater elevation contours is consistent with pre-disturbance conditions: the water table is predicted to mimic the surface topography and within the LSA the predicted direction of groundwater flow is from areas of higher elevation towards Brucejack Lake and Brucejack Creek. There is also a component of deeper groundwater flow within the LSA that occurs westwards, towards the Sulphurets Glacier (additional discussion is provided in Section 9.6.2). A plot of simulated water table contours is provided as Figure 9.6-5 for the steady-state Post-closure simulation.

Within the footprint of the mine workings, the Post-closure water table is lower than it was under pre-disturbance conditions; this is a result of the specified hydraulic conductivities of the backfill materials, which are a higher K than the surrounding bedrock. The areal extent impacted in Post-closure with drawdown greater than 10 m relative to pre-disturbance conditions is approximately 0.5 by 1 km. The difference between the pre-mining and Post-closure phase groundwater elevation contours is highlighted on Figure 9.6-6, which shows the difference between the pre-mining water table and the steady-state Post-closure water table; note the change in scale for contours in the inset figure.

No groundwater discharge reports to the proposed plant-site cut during mining operations due to the mine dewatering; after dewatering stops, groundwater discharge to the cut is predicted to start within about two years. The groundwater discharge is predicted to stabilize within five years with an estimated 12 m^3/d of groundwater discharge occurring on average in the summer months. No groundwater discharge is predicted to occur during the winter months when the water table experiences seasonal declines.

Groundwater discharge to surface water receptors is predicted to return to levels approaching pre-disturbance within approximately 5 years following mine closure. The Post-closure baseflow estimates at BJ 200 m D/S and BJL-H1 (7,400 m^3/d and 8,800 m^3/d, respectively) both represent 98% of the predicted pre-disturbance flows for these locations (7,600 and 9,000 m^3/d, respectively). This suggests that mining operations associated with the Project do not result in any significant long-term impact to the quantity of baseflow in the Sulphurets Creek watershed. Simulated discharges to surface-water receptors during the Project life, including changes from pre-disturbance conditions, are summarized in Table 9.6-1.

Only those surface water features that show large baseflow rate impacts during mining (i.e., Camp Creek, Valley of the Kings Creek, and Brucejack Creek) receive appreciable quantities of discharge water that may have come into contact with the underground workings or backfilled stopes.

9.6.1.3 Sensitivity Analyses

In addition to predictive mining operations and Post-closure modelling, sensitivity simulations were performed to evaluate changes to model-predicted groundwater elevations and flows for a range of input parameters. For each sensitivity simulation, hydraulic parameters and/or boundary conditions were modified to investigate the variation in hydrogeologic response (e.g., water table elevation, predicted mine inflow, discharge to surface water receptors, etc.) relative to the base case model simulation results. Table 9.3-8 summarizes the sensitivity scenarios considered. Of the 16 sensitivity scenarios considered for the groundwater flow model (Appendix 9-B, Brucejack Project Environmental Assessment - Numerical Hydrogeologic Model), two were provided for input to the water balance model and illustrate the extreme expected cases:

- Sensitivity Analysis Run 2 (hydraulic conductivity decreased by a factor of five everywhere) yielded the smallest groundwater contribution to surface water receptors, with a decrease of 30 to 40% relative to the calibrated model; and
- Sensitivity Analysis Run 12 (hydraulic conductivity increased by a factor of five and recharge increased by a factor of two) yielded the highest peak groundwater flows to surface water receptors, with an increase of 70 to 120% relative to the calibrated model.

As noted earlier, none of the sensitivity scenarios were able to better reproduce the observed heads used for baseline calibration; however there is some uncertainty in the available data.

9.6.2 Predictive Study for Groundwater Quality

9.6.2.1 Construction

Results of the predictive groundwater flow modelling for base case and sensitivity simulation runs predict that, during Construction, the groundwater flow direction is oriented into the underground workings such that it will be collected by the mine dewatering system and pumped to the mine water treatment plant prior to discharge to Brucejack Lake. Therefore, no effect on groundwater quality during the Construction phase is anticipated. The effect of mine dewatering on surface water quality is assessed in Chapter 13, Assessment of Potential Surface Water Effects.

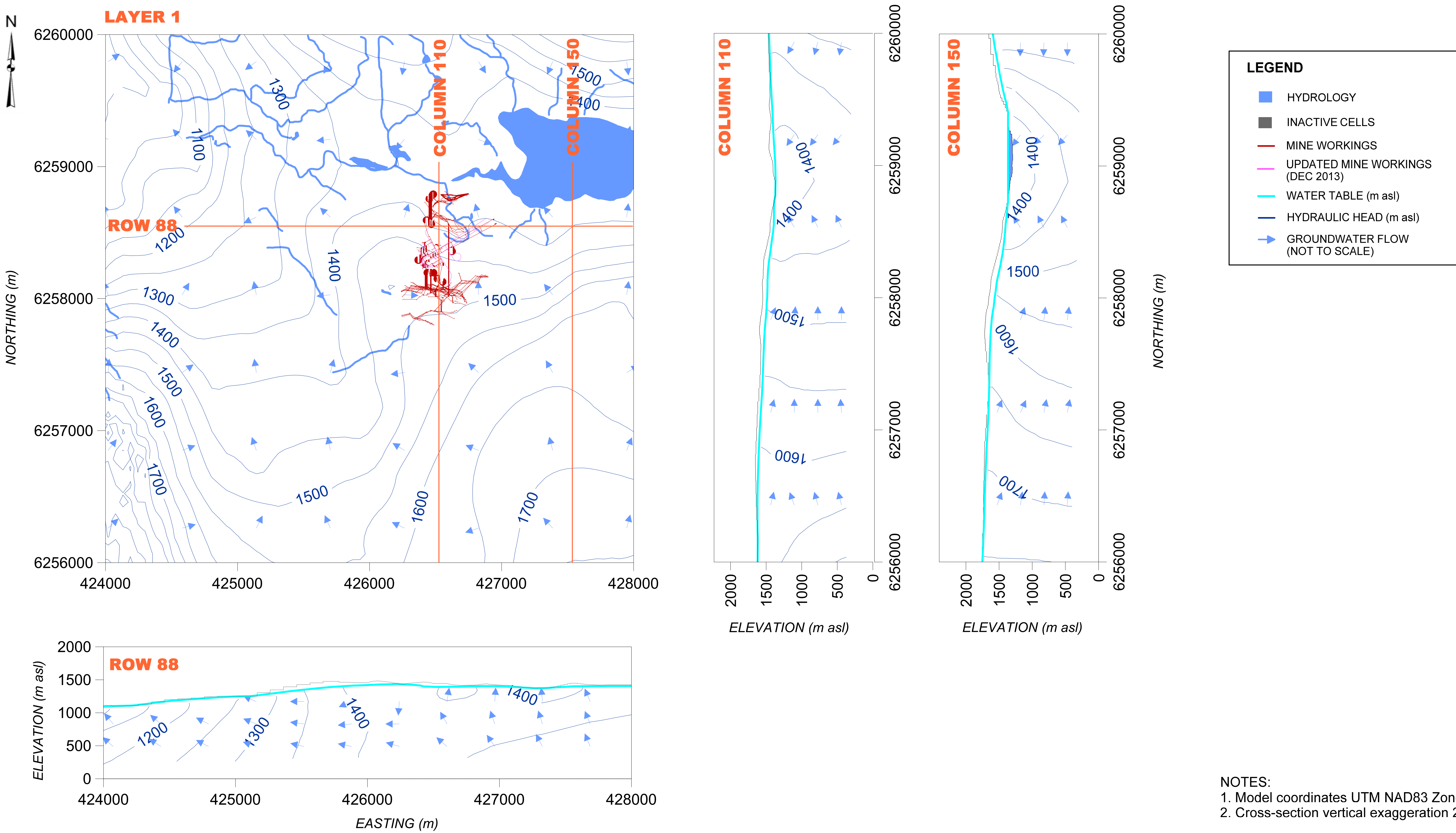
9.6.2.2 Operation

Results of the predictive groundwater flow modelling for base case and sensitivity simulation runs predict that, during Operation, the groundwater flow direction is oriented into the underground workings such that it will be collected by the mine dewatering system and pumped to the mine water treatment plant prior to discharge to Brucejack Lake. Therefore, no effect on groundwater quality during the Operation phase is anticipated. The effect of mine dewatering on surface water quality is assessed in Chapter 13, Assessment of Potential Surface Water Effects.

9.6.2.3 Closure

During the Closure phase, groundwater flow conditions are predicted to transition, over a period of three to five years, from groundwater flowing towards the underground mine workings to groundwater resuming pre-disturbance flow patterns. The influence of these flow patterns on groundwater quality in the Post-closure phase is discussed in the following section.

Figure 9.6-5
Simulated Groundwater Elevation Contours - Post-Closure

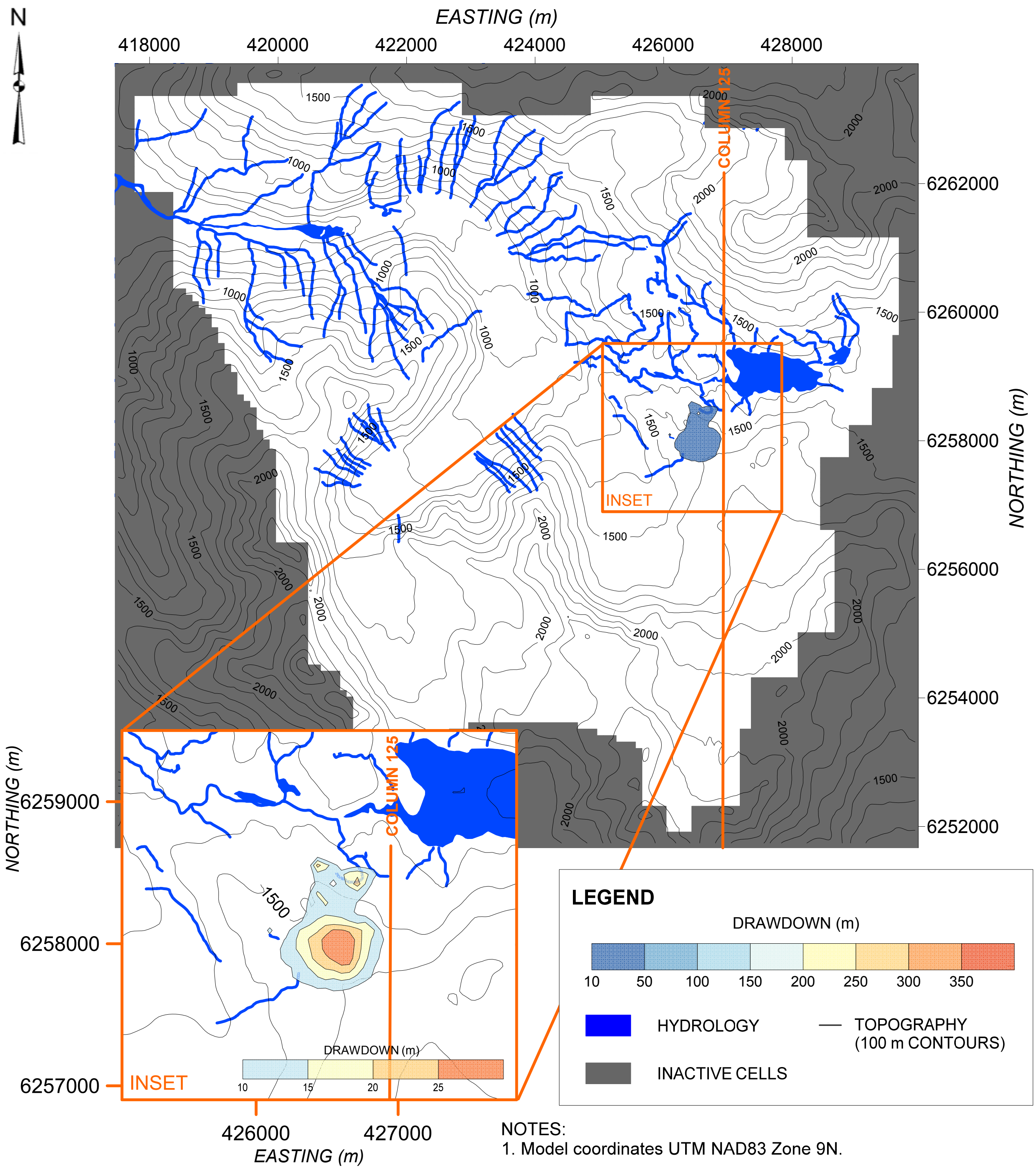


NOTES:
1. Model coordinates UTM NAD83 Zone 9N.
2. Cross-section vertical exaggeration 2X.

Source: BGC Engineering Inc. (June 2014).

Figure 9.6-6

Simulated Drawdown - Post-Closure



NOTES:
1. Model coordinates UTM NAD83 Zone 9N.

Source: BGC Engineering Inc. (June 2014).

9.6.2.4 Post-closure

Once the mine workings have flooded, groundwater flow is predicted to return to pre-development conditions. Groundwater is predicted to flow from the underground workings primarily towards Brucejack Creek and Brucejack Lake, with a smaller component of flow simulated to occur along a longer and slower flow path towards the Sulphurets drainage. Groundwater is also simulated to discharge from the plant site cut during summer months, but not during the winter months. Project effects on groundwater flow in the quarry area were not explicitly simulated with the groundwater flow model; however, groundwater quality beneath the non-PAG Quarry is anticipated to reflect baseline pre-development groundwater conditions provided it remains a discharge area, and PAG materials are not exposed during excavation. However, if the quarry floor is not a discharge area, infiltration of quarry runoff to the groundwater table may result in potential effects related to neutral rock drainage. This possibility will be discussed in the following section on the quarry site.

Groundwater quality along each of these flow paths is considered in the sections below. In regards to those source terms without estimated hardness values, those values typical of background water qualities were used for the purpose of calculating potential exceedances from these leachates. For the purpose of identifying the potential for residual contamination of the area, concentrations that are greater than two times those values from the relative baseline groundwater quality are highlighted. However, it should be mentioned that elements within the range of two to four times higher source term values (or similar proxy) may still be within the natural variability of baseline water quality. Further groundwater sampling into the Construction phase will likely refine the magnitude boundary between “residual contamination” and “no effect to groundwater quality.”

The effects of groundwater discharge to Brucejack Creek, and its small tributaries, and to Brucejack Lake are assessed in Chapter 13, Assessment of Potential Surface Water Quality Effects.

<u>Groundwater Quality on the Flow Path from the Quarry to Brucejack Lake</u>

The quarry rock type is identified as predominantly non-PAG and Office P1 material, and therefore the groundwater quality along the flow path from the quarry to Brucejack Lake is considered to be represented by the Office P1 groundwater type. The Office P1 groundwater type is the low end-member of metal enriched groundwater (Section 9.3.4.3).

Median concentrations of selected chemical constituents are presented in Table 9.6-2 for the Office P1 baseline groundwater type, and are compared with relevant water quality guidelines. Based on the results of the baseline study, groundwater from the Office P1 material type is likely to have concentrations exceeding guidelines for the following parameters: total Al, Ag, As, Cr, Cu, and Fe. Note that although total Ag is not highlighted in Table 9.6-2, Ag concentrations from several Office P1 groundwater samples showed significantly high values that surpassed the BC MOE one-time maximum guidelines.

In the Post-closure phase, the quarry source term is used to characterize water quality from the quarry reporting to Brucejack Lake (Section 9.5.2). Concentrations of chemical constituents for this source term are presented in Table 9.6-2, for comparison with the Office P1 groundwater type and relevant water quality guidelines.

For the base case Quarry source term, the total metal exceedances are comparable to baseline water quality of the Office P1 material type, with exceedances of total As and Cu in regards to BC MOE aquatic life and/or CCME guidelines. For the conservative case, exceedances of total Al, As, Cu, and dissolved Al may be observed.

Table 9.6-2. Comparison of Office P1 Groundwater Type and Quarry Source Term (in mg/L)

Parameter[1]	BC MOE				CCME FW Long-term Max.	Office P1 (n=11) Median	Quarry Source Term[2]	
	Drinking Water (DW)		Aquatic Life (AW)					
	30-day Avg.	Max	30-day Avg.	Max.			Base Case	Conservative Case
Physical Tests								
pH	6.5 - 8.5		6.5 - 9.0		6.5 - 9.0	8.14	7.54	7.47
Anions and Nutrients								
Ammonia (as N)	-	-	0.380-2.08	1.99-23.2	0.502 – 23.1	0.0025	-	-
Chloride (Cl)	250	250	150	600	120	0.25	3.00	4.90
Nitrate (as N)	-	10	3	32.8	13	0.018	-	-
Nitrite (as N)	-	1	0.02-0.20	0.06	0.06	-	-	-
Sulphate (SO_4)	500	500	128-429	-	-	33.9	10.8	17.6
Total Metals								
Aluminum (Al)-Total	-	-	-	-	0.005 - 0.1	*2.43*	0.089	*0.10*
Arsenic (As)-Total	0.025		0.005		0.005	<u>*0.0089*</u>	<u>*0.0056*</u>	<u>*0.0094*</u>
Cadmium (Cd)-Total	-	-	-	-	0.00009	0.000032	2.6E-05	4.0E-05
Chromium (Cr)-Total	-	-	-	-	0.001	*0.0012*	2.5E-04	2.5E-04
Cobalt (Co)-Total	-	-	0.004	0.11	-	0.00056	1.0E-04	1.2E-04
Copper (Cu)-Total	-	0.5	0.002-0.01	0.002-0.026	0.002-0.004	<u>*0.0047*</u>	<u>*0.0037*</u>	<u>*0.0094*</u>
Iron (Fe)-Total	-	-	1	1	0.3	*1.30*	0.0070	0.0075
Lead (Pb)-Total	None proposed	0.05	0.004-0.016	0.003-0.33	0.001-0.007	0.0017	2.4E-04	4.8E-04
Manganese (Mn)-Total	-	-	0.605-1.9	0.54-3.8	-	0.061	0.034	0.055
Mercury (Hg)-Total	-	0.001	0.00000125-0.0002	-	0.000026	0.000005	6.0E-06	7.4E-06
Molybdenum (Mo)-Total	-	0.25	1	2	0.073	0.0017	9.1E-04	0.0010
Nickel (Ni)-Total	-	-	-	-	0.025-0.150	0.0010	1.6E-04	2.1E-04
Selenium (Se)-Total	-	0.01	0.002	-	0.001	0.00022	3.4E-04	7.5E-04

(continued)

Table 9.6-2. Comparison of Office P1 Groundwater Type and Quarry Source Term (in mg/L; completed)

Parameter[1]	BC MOE				CCME FW Long-term Max.	Office P1 (n=11) Median	Quarry Source Term[2]	
	Drinking Water (DW)		Aquatic Life (AW)					
	30-day Avg.	Max	30-day Avg.	Max.			Base Case	Conservative Case
Total Metals *(cont'd)*								
Silver (Ag)-Total	-	-	0.00005-0.0015	0.0001-0.003	0.0001	0.000075	5.0E-06	5.0E-06
Thallium (Tl)-Total	-	-	0.0003		0.0008	0.000059	2.0E-05	3.4E-05
Zinc (Zn)-Total	5	5	0.0075-0.240	0.033-2.65	0.03	0.014	0.0030	0.0058
Dissolved Metals								
Aluminum (Al)-Dissolved	-	0.2	0.005-0.05	0.02-0.1	-	0.016	0.089	0.10
Iron (Fe)-Dissolved	-	-	-	0.35	-	0.015	0.0067	0.0075

[1]. A number of guidelines are dependent on background concentrations of the parameter (colour, total suspended solids, turbidity, and organic carbon), pH of the sample (ammonia and aluminum), hardness of the sample (fluoride, sulphate, cadmium, copper, lead, manganese, nickel, silver, and zinc) or chloride concentration of the sample (nitrite). These relationships are outlined in the footnotes associated with Table 9.3-2. Herein, the full range of upper concentration limits which could occur depending on the above parameters are shown.
[2]. For guidelines which are hardness dependent, the Quarry base case and conservative case values are compared with the maximum concentration. This includes the BC MOE guidelines for total sulphate, copper, lead, manganese, silver and zinc and dissolved aluminum, as well as the CCME guidelines for total copper, lead and nickel.
Note: The following formatting conventions have been applied to indicate when a parameter exceeds a guideline:
Concentration exceeds CCME Guideline
Concentration exceeds BC MOE AW 30-day avg. standard
Concentration exceeds BC MOE AW one-time maximum standard
Concentration exceeds BC MOE DW standard

In general, parameter concentrations of Office P1 groundwater are greater than or similar to the estimated quarry source terms for base case and conservative case scenarios. Two exceptions to this observation are total Se and dissolved Al. Total Se concentrations are 3.5 times higher in conservative case quarry source terms (relative to Office P1 groundwater), and dissolved Al exceeds background water quality by approximately six times in both scenarios. At circumneutral pH conditions, dissolved Al will likely be controlled by mineral precipitation and thus Se is the only element where enrichment above background is highlighted; however, the concentration of Se is likely to remain below guidelines.

As the quarry source term is a surface runoff term, it incorporates significant dilution from precipitation and snowmelt (Appendix 13-C, Water Quality Predictions for Construction, Operation, and Post-closure Mine Phases). The relative length of the flow path for seasonal groundwater recharge and discharge at the quarry location is much shorter and faster than groundwater discharging along a longer flow path with greater residence time. It is therefore expected that the representative groundwater quality at the quarry location would have higher concentrations of chemical constituents than the associated source term. These results indicate that no change to groundwater quality due to infiltration of quarry runoff water is expected.

Groundwater Quality on the Flow Path from the Plant Site to Brucejack Lake

Groundwater quality beneath the plant site will be a combination of infiltration from snowmelt and rainwater and groundwater. The area of potential residual groundwater quality effect for the plant site is shown on Figure 9.6-7, and comprises the area where seasonal (i.e., summer) groundwater discharge is predicted by the transient Post-closure groundwater model. During the winter, groundwater levels are predicted to decline below the ground surface and the possibility of cyclical wetting and drying of the PAG rocks in this area exists, potentially leading to locally degraded groundwater quality. End member chemistries for this groundwater quality are considered to be the baseline groundwater quality from the VSF rock type and the source terms developed for plant site runoff (Table 9.6-3).

Median concentrations of selected chemical constituents are presented in Table 9.6-3 for the VSF groundwater type, and are compared with relevant water quality guidelines (see Table 9.3-2; Section 9.2, Section 9.3.4.3). The majority of F and total Al, Ag, As, Cd, Co, Cr, Cu, Fe, Pb, and Zn concentrations surpass CCME and/or BC MOE AQ guidelines in collected VSF groundwater samples. Notably, although total concentrations of Ag, Cd, Co, Cu, Pb, and Zn are not highlighted in Table 9.6-3, these are included as material-specific enrichments as they frequently present samples with values significantly above guidelines and/or show spatially significant enrichments in select monitoring wells.

The plant site base case runoff terms show similar exceedances of total Al and As, when compared with VSF groundwater. Specifically, the plant site shows lower total As and Al values than those noted in background VSF waters, but still show concentrations exceeding the BC MOE aquatic life and/or CCME guidelines. For both base case and conservative case scenarios, dissolved Al exceeds the BC MOE aquatic life 30-day average and one-time max value of 0.02 to 0.1 mg/L and is approximately 6.5 times higher than background groundwater. As well, total Zn exceeds BC MOE aquatic life 30-day average and one-time maximum values in the conservative case only.

Conservative case plant site values do show marked increases in estimated total Cd, Co, Cu, Pb, Mn, Ni, and Zn and dissolved Fe, by factors of 2.5 to 61 over those of background VSF groundwater. Note that although Cl concentrations exceed CCME, BC MOE AW, and DW guidelines, these are not highlighted as true exceedances. Specifically, Cl (and sometimes Na) is used for charge balancing in model simulations to estimate source term values and so model simulated concentrations should not be considered real. Of these, and in addition to total Al, As and Zn, and dissolved Al discussed above, total Cd, Co and Cu may exceed CCME FW and/or BC MOE AW guidelines. These large increases in metal concentrations are likely related to a decrease in pH by two to three pH units relative to the base case scenario and to background conditions. Therefore monitoring of groundwater quality on this flow path is warranted during Closure and Post closure.

Table 9.6-3. Comparison of Volcanic Sedimentary Facies Groundwater Type and Plant Site Source Term (in mg/L)

Parameter[1]	BC MOE				CCME FW Long-term Max	VSF (n=18) Median	Plant Site Source Term [2] Post-closure	
	Drinking Water (DW)		Aquatic Life (AW)					
	30-day Avg.	Max.	30-day Avg.	Max.			Base Case	Conservative Case
Physical Tests								
pH	6.5 - 8.5		6.5 - 9.0		6.5 - 9.0	8.13	7.43	***5.17***
Anions and Nutrients								
Ammonia (as N)	-	-	0.380-2.08	1.99-23.2	0.502 - 23.1	0.12	-	-
Chloride (Cl)	250	250	150	600	120	0.61	4.88	4.26
Nitrate (as N)	-	10	40	200	13	0.0041	-	-
Nitrite (as N)	-	1	0.02-0.20	0.06	0.06	0.0011	-	-
Sulphate (SO_4)	500	500	128-429	-	-	97.3	12.2	43.7
Total Metals [3]								
Aluminum (Al)-Total	-	-	-	-	0.005 - 0.1	*0.792*	*0.13*	*0.12*
Arsenic (As)-Total	0.025		0.005		0.005	*0.023*	*0.016*	*0.016*
Cadmium (Cd)-Total	-	-	-	-	0.00009	0.000054	0.000028	*0.0033*
Chromium (Cr)-Total	-	-	-	-	0.001	*0.0020*	0.00014	0.00025
Cobalt (Co)-Total	-	-	0.004	0.11	-	0.0012	0.00025	0.0078
Copper (Cu)-Total	-	0.5	0.002-0.01	0.002-0.026	0.002-0.004	0.0018	0.0006	*0.024*
Iron (Fe)-Total	-	-	1	1	0.3	*0.82*	0.006	0.25
Lead (Pb)-Total	None proposed	0.05	0.004-0.016	0.003-0.33	0.001-0.007	0.0012	0.00014	0.0041
Manganese (Mn)-Total	-	-	0.605-1.9	0.54-3.8	-	0.17	0.027	0.42
Mercury (Hg)-Total	-	0.001	0.00000125-0.0002	-	0.000026	0.000014	5.0E-06	0.0000063
Molybdenum (Mo)-Total	-	0.25	1	2	0.073	0.0021	0.0017	0.0015
Nickel (Ni) - Total	-	-	-	-	0.025-0.150	0.0011	0.00015	0.0050
Selenium (Se)-Total	-	0.01	0.002	-	0.001	<0.0010	0.0010	0.00082
Silver (Ag)-Total	-	-	0.00005-0.0015	0.0001-0.003	0.0001	0.000074	0.000013	0.000013

(continued)

Table 9.6-3. Comparison of Volcanic Sedimentary Facies Groundwater Type and Plant Site Source Term (in mg/L; completed)

Parameter[1]	BC MOE Drinking Water (DW) 30-day Avg.	BC MOE Drinking Water (DW) Max.	BC MOE Aquatic Life (AW) 30-day Avg.	BC MOE Aquatic Life (AW) Max.	CCME FW Long-term Max	VSF (n=18) Median	Plant Site Source Term [2] Post-closure Base Case	Plant Site Source Term [2] Post-closure Conservative Case
Total Metals [3] *(cont'd)*								
Thallium (Tl)-Total	-	-	0.0003		0.0008	0.00010	0.00003	0.00002
Zinc (Zn)-Total	5	5	0.0075-0.240	0.033-2.65	0.03	0.026	0.0018	*0.22*
Dissolved Metals								
Aluminum (Al)-Dissolved	-	0.2	0.005-0.05	0.02-0.1	-	0.020	0.13	0.12
Iron (Fe)-Dissolved	-	-	-	0.35	-	0.015	0.01	0.25

[1]. *A number of guidelines are dependent on background concentrations of the parameter (colour, total suspended solids, turbidity, and organic carbon), pH of the sample (ammonia and aluminum), hardness of the sample (fluoride, sulphate, cadmium, copper, lead, manganese, nickel, silver, and zinc) or chloride concentration of the sample (nitrite). These relationships are outlined in the footnotes associated with Table 9.3-2. Herein, the full range of upper concentration limits which could occur depending on the above parameters are shown.*

[2]. *For guidelines which are hardness dependent, the Plant Site base case and conservative case values are compared with the maximum concentration. This includes the BC MOE guidelines for total sulphate, copper, lead, manganese, silver and zinc and dissolved aluminum, as well as the CCME guidelines for total copper, lead and nickel.*

[3]. *For plant site runoff terms, only dissolved metal concentrations were developed. It is assumed that the total metals are equal to the dissolved metals.*

Note: The following formatting conventions have been applied to indicate when a parameter exceeds a guideline:

Concentration exceeds CCME Guideline

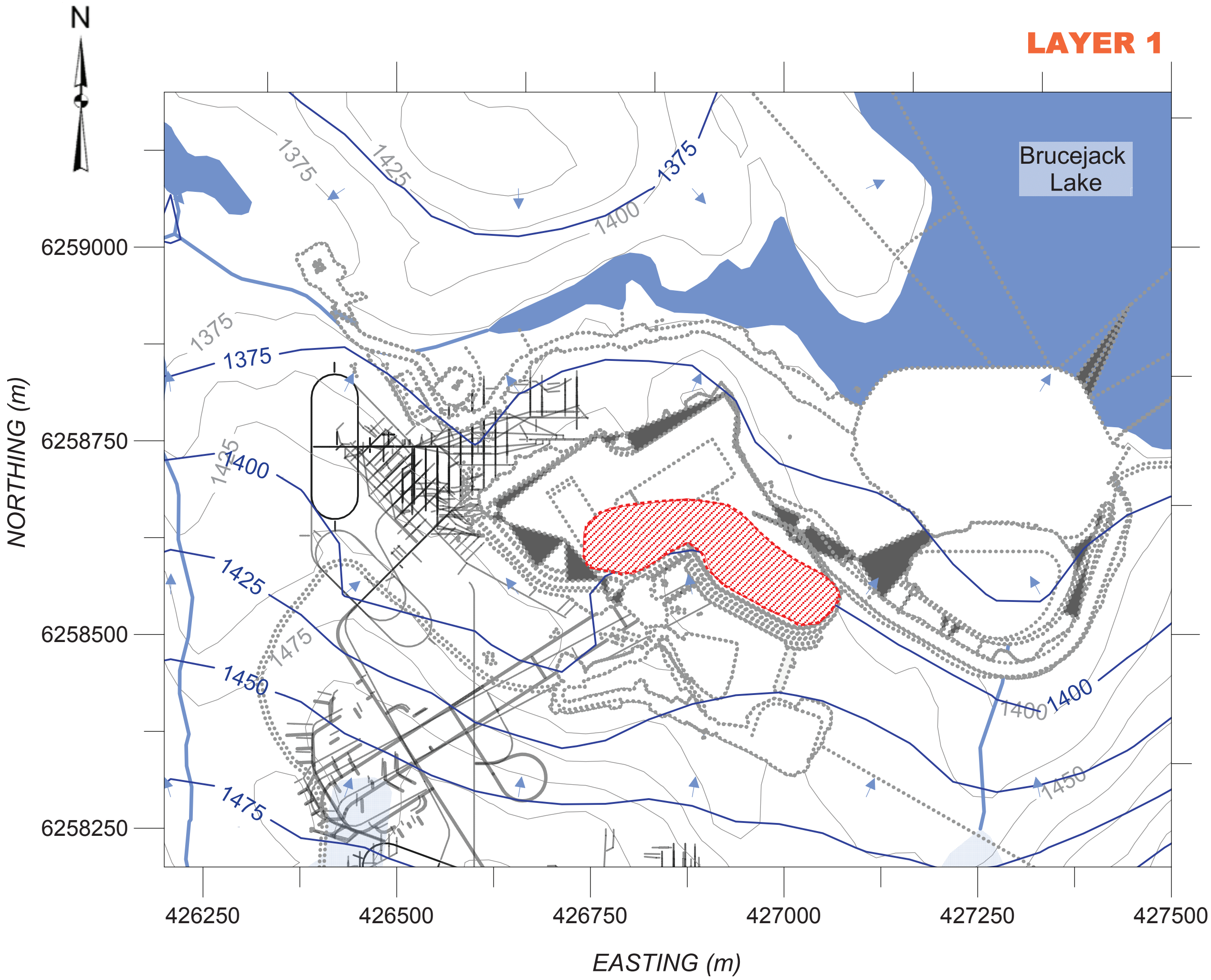
Concentration exceeds BC MOE AW 30-day avg. standard

Concentration exceeds BC MOE AW one-time maximum standard

Concentration exceeds BC MOE DW standard

Figure 9.6-7

Predicted Residual Groundwater Quality Effect - Plant Site Area



LEGEND

- TOPOGRAPHIC CONTOUR (m asl) 25 m CONTOUR INTERVAL
- BRUCEJACK DECOMMISSIONED PLANT SITE
- HYDRAULIC HEAD (m asl)
- GROUNDWATER FLOW (NOT TO SCALE)
- GLACIERS
- PROPOSED UNDERGROUND WORKINGS
- LAKES AND STREAMS
- PREDICTED ZONE OF RESIDUAL GROUNDWATER QUALITY EFFECT

NOTES:
1. Model coordinates UTM NAD83 Zone 9N.
2. Underground workings projected to ground surface.

Source: BGC Engineering Inc. (June 2014).

Groundwater Quality on the Flow Path from the Underground Mine to Brucejack Lake, Brucejack Creek and Local Tributaries

Baseline groundwater quality along the flow path from the underground mine workings to Brucejack Lake and Brucejack Creek is considered to be representative of the VSF groundwater type (Section 9.3.4.3). This geologic unit encompasses the largest proportion of the underground exposure, and reflects median concentrations of chemical constituents in groundwater based on analysis of Piper diagrams.

The general characteristics of the VSF groundwater type are discussed above in Section 9.6.2.4. Median concentrations of selected chemical constituents are presented in Table 9.6-4 for the VSF groundwater type, and are compared with relevant water quality guidelines (Section 9.2, Section 9.3.4.3). In summary, bulk groundwater chemistry from the VSF material is likely to exceed (i.e., median concentration is greater than) one or more guideline(s) for total Al, Ag, As, Cd, Co, Cu, Cr, Fe, Pb, and Zn (Table 9.6-4).

As discussed in Section 9.5.2.3, two underground water quality scenarios were developed to represent temporal end-members during flooding of the underground workings. These end-members comprise a “before underground flooding scenario” and a “flooded underground workings scenario,” and are presented in Table 9.6-4 together with the VSF groundwater type. Briefly, the “before underground flooding scenario” is a compilation of material-specific source terms that were weighted to proportion of material exposure at the start of closure. The “flooded underground workings scenario” is based on historical flooded adit data, following Newhawk operations, whereby adit waters passively flowed to Brucejack Creek.

For the “Before Underground Flooding” end member water chemistry, guideline exceedances are observed for total As, Cd, Cr, Cu, and Zn (base case scenario) and additionally pH, sulphate, total Al, Co, Pb, Mn, and Se and dissolved Al (conservative scenario). For the “Flooded Underground Workings” end member water chemistry, guideline exceedances are observed for total Cd and Zn (base case scenario) and additionally total As, Hg, Mn, and Ag (conservative scenario).

At Closure (represented by the “Before Underground Flooding” water chemistry end-member), the majority of risk for contamination occurs with conservative case scenarios values. Specifically, at the start of the Closure period, there is a possibility for sulphate, total Al, Cd, Cr, Co, Cu, Pb, Mn, Mo, Tl, Zn, and dissolved Al to present significantly higher concentrations relative to background groundwater (i.e., more than a factor of two times greater than background). In terms of CCME and BC MOE guidelines, all of the above will exceed guidelines with the exception of total Mo and Tl.

At the end of flooding, this list is significantly smaller as total Cd, Pb, Hg, Ag, Zn, and dissolved Fe show higher concentrations in conservative case scenarios relative to background conditions. Dissolved Fe will likely be controlled by secondary mineral precipitation and, of the above list, only total Cd, Hg and Zn present values that exceed guideline concentrations at closure.

The spatial area over which this residual groundwater quality effect may occur is illustrated in Figure 9.6-8, which shows groundwater flow paths from potentially unsaturated portions of the underground mine (i.e., model layers 1 to 4) towards Brucejack Lake and Brucejack Creek.

Table 9.6-4. Comparison of Volcanic Sedimentary Facies Groundwater Type and Underground Mine Water Quality End-members (in mg/L)

	BC MOE									
	Drinking Water DW		Aquatic Life AW			VSF	Before Underground Flooding[2]		Flooded Underground Workings	
Parameter[1]	**30-day Avg.**	**Max**	**30-day Avg.**	**Max**	**CCME FW Long-term Max**	**(n=18) Median**	**Base Case**	**Cons Case**	**Base Case**	**Cons Case**
Physical Tests										
pH	6.5 - 8.5		6.5 - 9.0		6.5 - 9.0	8.13	6.56	*4.08*	7.52	7.00
Anions and Nutrients										
Ammonia (as N)	-	-	0.380-2.08	1.99-23.2	0.502 – 23.1	0.12	-	-	0.037	0.086
Chloride (Cl)	250	250	150	600	120	0.61	40.6	353	0.51	1
Nitrate (as N)	-	10	40	200	13	0.0041	-	-	0.088	0.15
Nitrite (as N)	-	1	0.02-0.20	0.06	0.06	0.0011	-	-	0.0030	0.0060
Sulphate (SO_4)	500	500	128-429	-	-	97.3	122	459	116	166
Total Metals										
Aluminum (Al)-Total	-	-	-	-	0.005 - 0.1	*0.79*	0.00015	*2.00*	0.020	0.020
Arsenic (As)-Total	0.025		0.005		0.005	*0.0225*	*0.0079*	*0.023*	0.0049	*0.011*
Cadmium (Cd)-Total	-	-	-	-	0.00009	0.000054	*0.027*	*0.03*	*0.00028*	*0.0005*
Chromium (Cr)-Total	-	-	-	-	0.001	*0.0020*	*0.0034*	*0.0042*	0.00034	0.0005
Cobalt (Co)-Total	-	-	0.004	0.11	-	0.0012	0.0031	0.096	0.00029	0.00072
Copper (Cu)-Total	-	0.5	0.002-0.01	0.002-0.026	0.002-0.004	0.0018	*0.038*	*0.18*	0.00064	0.0005
Iron (Fe)-Total	-	-	1	1	0.3	*0.82*	0.00000031	0.000056	0.079	0.056
Lead (Pb)-Total	None proposed	0.05	0.004-0.016	0.003-0.33	0.001-0.007	0.0012	0.00066	0.017	0.0013	0.0052
Manganese (Mn)-Total	-	-	0.605-1.9	0.54-3.8	-	0.17	0.00042	27	0.18	*0.27*
Mercury (Hg)-Total	-	0.001	0.00000125-0.0002	-	0.000026	0.000014	0.0000040	0.0000080	0.000013	*0.000086*
Molybdenum (Mo)-Total	-	0.25	1	2	0.073	0.0021	0.01	0.0094	0.0017	0.0023

(continued)

Table 9.6-4. Comparison of Volcanic Sedimentary Facies Groundwater Type and Underground Mine Water Quality End-members (in mg/L; completed)

Parameter[1]	BC MOE				CCME FW	VSF (n=18)	Before Underground Flooding[2]		Flooded Underground Workings	
	Drinking Water DW		Aquatic Life AW							
	30-day Avg.	Max	30-day Avg.	Max	Long-term Max	Median	Base Case	Cons Case	Base Case	Cons Case
Total Metals *(cont'd)*										
Nickel (Ni)-Total	-	-	-	-	0.025-0.150	0.0011	-	-	0.00043	0.0005
Selenium (Se)-Total	-	0.01	0.002	-	0.001	<0.0010	0.00079	*0.0012*	0.00034	0.0005
Silver (Ag)-Total	-	-	0.00005-0.0015	0.0001-0.003	0.0001	0.000074	0.000015	0.000077	0.000084	*0.00033*
Thallium (Tl)-Total	-	-	0.0003		0.0008	0.000028	0.00010	0.00005	0.000019	0.000019
Zinc (Zn)-Total	5	5	0.0075-0.240	0.033-2.65	0.03	0.026	*0.41*	*1.00*	*0.032*	*0.067*
Dissolved Metals										
Aluminum (Al)-Dissolved	-	0.2	0.005-0.05	0.02-0.1	-	0.020	0.00015	2.00	0.020	0.020
Iron (Fe)-Dissolved	-	-	-	0.35	-	0.015	0.0000003	0.000056	0.079	0.056

[1]. A number of guidelines are dependent on background concentrations of the parameter (colour, total suspended solids, turbidity, and organic carbon), pH of the sample (ammonia and aluminum), hardness of the sample (fluoride, sulphate, cadmium, copper, lead, manganese, nickel, silver, and zinc) or chloride concentration of the sample (nitrite). These relationships are outlined in the footnotes associated with Table 9.3-2. Herein, the full range of upper concentration limits which could occur depending on the above parameters are shown.

[2]. For guidelines which are hardness dependent, the before flooding and flooded underground working cases, values are compared with the maximum concentration. This includes the BC MOE guidelines for total sulphate, copper, lead, manganese, silver and zinc and dissolved aluminum, as well as the CCME guidelines for total copper, lead, and nickel.

Note: The following formatting conventions have been applied to indicate when a parameter exceeds a guideline:

Concentration exceeds CCME Guideline

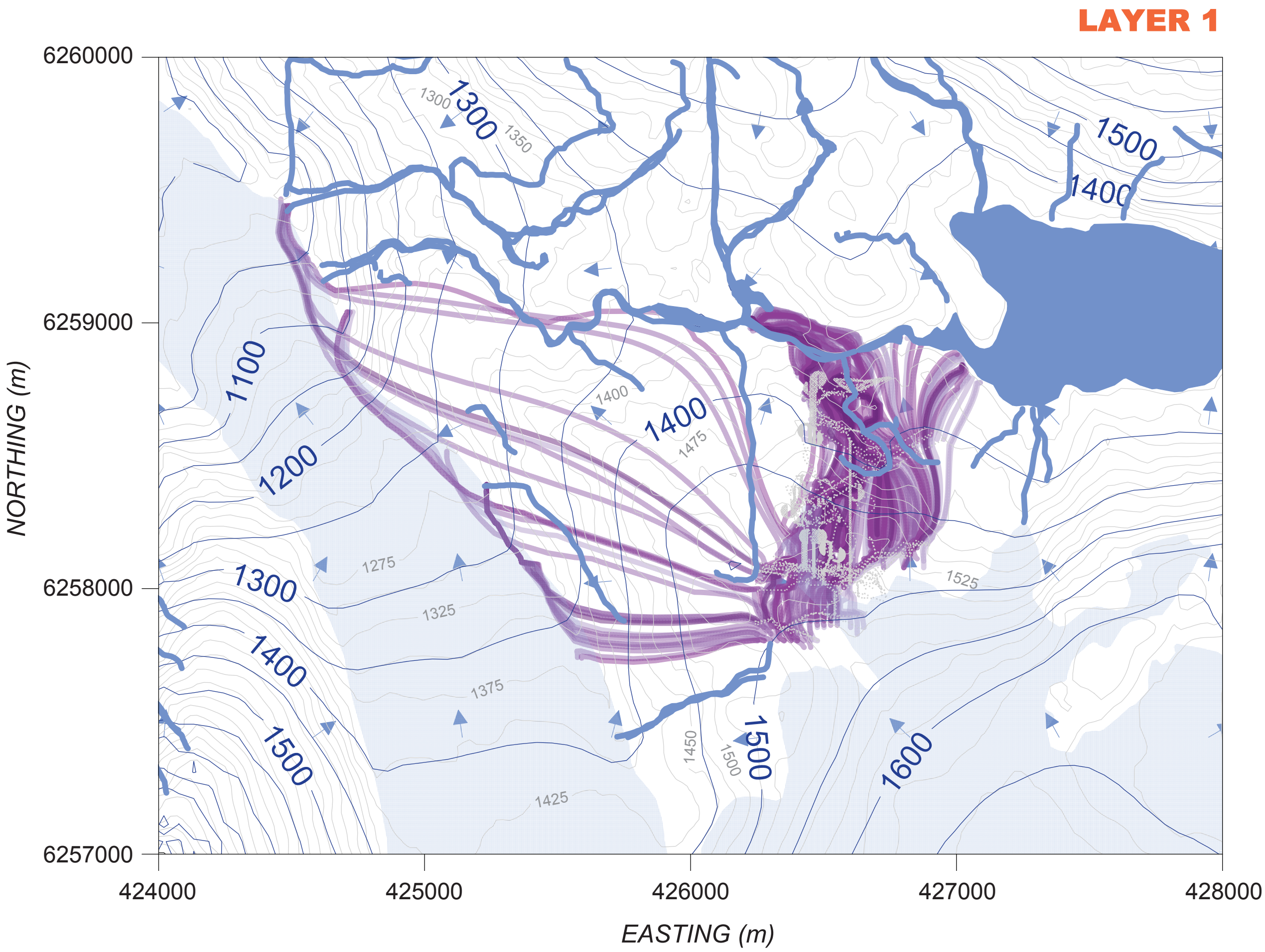
Concentration exceeds BC MOE AW 30-day avg. standard

Concentration exceeds BC MOE AW one-time maximum standard

Concentration exceeds BC MOE DW standard

Figure 9.6-8

Post-Closure Groundwater Flow Paths from Underground Working Cells in Model Layers 1-4



LEGEND

HYDRAULIC HEAD (m asl)	LAKES AND STREAMS
GROUNDWATER FLOW (NOT TO SCALE)	GLACIERS
PROPOSED UNDERGROUND WORKINGS	LAYER 1 FLOW PATHS
TOPOGRAPHIC CONTOUR (m asl) 25 m CONTOUR INTERVAL	LAYER 2 FLOW PATHS
	LAYER 3 FLOW PATHS
	LAYER 4 FLOW PATHS

NOTES:
1. Model coordinates UTM NAD83 Zone 9N.
2. Groundwater flow paths determined using MODPATH particle tracking for the steady-state post-closure simulation; Underground workings in model layers 1-4 represent potentially unsaturated mine workings (i.e., above the water table).
3. Underground workings and groundwater flow paths projected to ground surface.

Source: BGC Engineering Inc. (June 2014).

Groundwater Quality on the Flow Path to Sulphurets Glacier / Sulphurets Creek

Predictive modelling of groundwater flow pathways originating from the underground workings indicated the existence of a minor groundwater flow path towards the Sulphurets drainage; as shown in Figure 9.6-8. The flow paths are indicated as flow lines for particles released from individual cells containing underground workings in the top four layers of the numerical groundwater flow model (Sections 9.5.1 and 9.6.1). These cells represent portions of the underground workings that may be subjected to seasonal rise and fall of the water table in post closure, which could lead to ML/ARD impacts to groundwater quality. One particle was released from each grid block; as shown in Figure 9.6-8, about 95% of the particles follow flow paths that discharge to Brucejack Creek or Brucejack Lake (and were considered above); the remaining particles follow deeper, longer and slower flow paths (i.e., time scales range from several decades to centuries before discharge to surface water).

Baseline groundwater quality along these westwards flow paths from the underground mine workings to Sulphurets Glacier and Sulphurets Creek is considered to be represented by the Office P1 groundwater type (Section 9.3.4.3). This geologic unit extends to the western perimeter of the block model, and is assumed to comprise the majority of material that groundwater may pass through along this flow path.

As was discussed previously in Section 9.6.2.4, groundwater from the Office P1 material type is likely to have concentrations exceeding guidelines for the following parameters: total Al, Ag, As, Cr, Cu, and Fe. The Office P1 groundwater type is compared with the two underground water quality scenarios discussed previously in 9.6.2.4. The two scenarios, which represent temporal end-members during the flooding of the underground workings, are summarized and compared to relevant guidelines along with Office P1 water chemistry data in Table 9.6-5.

At early stage flooding, represented by “before underground flooding” end member mine water chemistry, concentrations of sulphate, total Cd, Cr, Co, Cu, Mo, Se, and Zn (base case) and additionally pH, As, Pb, Mn and dissolved Al (conservative case) are predicted to be greater than median background groundwater concentrations by a factor of 2 or more. Of these, concentrations of total Cd, Cr, Cu, and Zn (base case) and sulphate, total As, Co, Pb, Mn, Se and dissolved Al (conservative case) are predicted to be greater than the CCME or BC MOE water quality guidelines and could lead to residual groundwater quality effects for groundwater migrating towards the Sulphurets drainage.

In the longer term, after flooding (represented by the “flooded underground workings” end member mine water chemistry) concentrations of sulphate, total Cd, Mn, Hg, Zn and dissolved Fe (base case) and additionally, total Pb, Se and Ag (conservative case) are predicted to be greater than median background groundwater concentrations by a factor of 2 or more (i.e., are potentially enriched above the range of natural variation). Of these, total Cd and Zn (base case) and sulphate, total Ag, Cd, Hg, and Zn (conservative case) are predicted to be greater than CCME FW and/or BC MOE AW guidelines and so could contribute to a residual effect to groundwater quality on the Sulphurets flow path.

9.7 MITIGATION MEASURES FOR HYDROGEOLOGY

Most potential effects identified in Section 9.4 are local in extent; low magnitude; short-term to moderate-term in direction; and can be mitigated through standard operating procedures, best management practices, adherence to existing environmental regulations, and utilizing appropriate design criteria (Section 9.4). The primary effects that will arise revolve around changes to baseflow for groundwater quantity and ML/ARD issues for groundwater quality (see Sections 9.6 and 9.8). The mitigation measures incorporated into the Project design are outlined in the following subsections.

Table 9.6-5. Comparison of Office P1 Groundwater Type and Underground Mine Water Quality End-Members

Parameter[1]	BC MOE				CCME FW Long-term Max	Office P1 (n=11) Median	Before Underground Flooding[2]		Flooded Underground Workings	
	Drinking Water DW		Aquatic Life AW							
	30-day Avg.	Max.	30-day Avg.	Max.			Base Case	Cons Case	Base Case	Cons Case
Physical Tests										
pH	6.5 - 8.5		6.5 - 9.0		6.5 - 9.0	8.14	6.56	*4.08*	7.52	7.00
Anions and Nutrients										
Ammonia (as N)	-	-	0.380-2.08	1.99-23.2	0.502 - 23.1	0.0025			0.037	0.086
Chloride (Cl)	250	250	150	600	120	0.018	40.6	***353***	0.51	1.00
Nitrate (as N)	-	10	40	200	13	-			0.088	0.15
Nitrite (as N)	-	1	0.02-0.20	0.06	0.06	-			0.0030	0.0060
Sulphate (SO_4)	500	500	128-429	-	-	33.9	122	459	116	166
Total Metals										
Aluminum (Al)-Total	-	-	-	-	0.005 - 0.1	*2.43*	0.00015	*2.00*	0.020	0.020
Arsenic (As)-Total	0.025	0.005	0.005			*0.0089*	*0.0079*	*0.023*	0.0049	*0.011*
Cadmium (Cd)-Total	-	-	-	-	0.00009	0.000032	*0.027*	*0.03*	*0.00028*	*0.0005*
Chromium (Cr)-Total	-	-	-	-	0.001	*0.0012*	*0.0034*	*0.0042*	0.00034	0.0005
Cobalt (Co)-Total	-	-	0.004	0.11	-	0.00056	0.0031	0.096	0.00029	0.00072
Copper (Cu)-Total	-	0.5	0.002-0.01	0.002-0.026	0.002-0.004	*0.0047*	*0.038*	*0.18*	0.00064	0.0005
Iron (Fe)-Total	-	-	1	1	0.3	*1.3*	0.00000031	0.000056	0.079	0.056
Lead (Pb)-Total	None proposed	0.05	0.004-0.016	0.003-0.33	0.001-0.007	0.0017	0.00066	0.017	0.0013	0.0052
Manganese (Mn)-Total	-	-	0.605-1.9	0.54-3.8	-	0.061	0.00042	27	0.18	0.27
Mercury (Hg)-Total	-	0.001	0.00000125-0.0002	-	0.000026	0.000005	0.000004	0.000008	0.000013	*0.000086*
Molybdenum (Mo)-Total	-	0.25	1	2	0.073	0.0017	0.01	0.0094	0.0017	0.0023

(continued)

Table 9.6-5. Comparison of Office P1 Groundwater Type and Underground Mine Water Quality End-Members (completed)

Parameter[1]	BC MOE				CCME FW Long-term Max	Office P1 (n=11) Median	Before Underground Flooding[2]		Flooded Underground Workings	
	Drinking Water DW		Aquatic Life AW							
	30-day Avg.	Max.	30-day Avg.	Max.			Base Case	Cons Case	Base Case	Cons Case
Total Metals *(cont'd)*										
Nickel (Ni)-Total	-	-	-	-	0.025-0.150	0.0010	-	-	0.00043	0.0005
Selenium (Se)-Total	-	0.01	0.002	-	0.001	0.00022	0.00079	*0.0012*	0.00034	0.0005
Silver (Ag)-Total	-	-	0.00005-0.0015	0.0001-0.003	0.0001	0.000075	0.000015	0.000077	0.000084	*0.00033*
Thallium (Tl)-Total	-	-	0.0003		0.0008	6.0E-05	0.0001	0.00005	0.000019	0.000019
Zinc (Zn)-Total	5	5	0.0075-0.240	0.033-2.65	0.03	0.014	*0.41*	*1.00*	*0.032*	*0.067*
Dissolved Metals										
Aluminum (Al)-Dissolved	-	0.2	0.005-0.05	0.02-0.1	-	0.016	0.00015	2	0.020	0.020
Iron (Fe)-Dissolved	-	-	-	0.35	-	0.015	0.0000003	0.000056	0.079	0.056

1. A number of guidelines are dependent on background concentrations of the parameter (colour, total suspended solids, turbidity, and organic carbon), pH of the sample (ammonia and aluminum), hardness of the sample (fluoride, sulphate, cadmium, copper, lead, manganese, nickel, silver, and zinc) or chloride concentration of the sample (nitrite). These relationships are outlined in the footnotes associated with Table 9.3-2. Herein, the full range of upper concentration limits which could occur depending on the above parameters are shown.
2. For guidelines which are hardness dependent, the before flooding and flooded underground working cases, values are compared with the maximum concentration. This includes the BC MOE guidelines for total sulphate, copper, lead, manganese, silver and zinc and dissolved aluminum, as well as the CCME guidelines for total copper, lead, and nickel.
Note: The following formatting conventions have been applied to indicate when a parameter exceeds a guideline:
Concentration exceeds CCME Guideline
Concentration exceeds BC MOE AW 30-day avg. standard
Concentration exceeds BC MOE AW one-time maximum standard
Concentration exceeds BC MOE DW standard

9.7.1 Mitigation Methods for Groundwater Quantity

The primary groundwater quantity effect is a decrease in baseflow to small creeks near the Brucejack Mine Site due to groundwater pumping. This effect can be partially mitigated by decreasing the amount of water diverted to the underground water management (i.e., collection) system. Thus, the primary mitigation measure to be implemented is early backfilling of stopes and underground workings with low permeability material. Material with low hydraulic conductivity will reduce the flow of water away from the ground surface and through former mine tunnels and stopes.

To the degree practical, underground workings will be backfilled as soon as possible after abandonment. This will decrease the amount of water that must be pumped and will mitigate, somewhat, the overall drawdown. Ultimately, for Post-closure conditions, as much of the underground workings as possible will be backfilled so that baseflow will return to pre-disturbance conditions. The predictive modelling performed for the Project assumed backfill material will have a hydraulic conductivity within two orders of magnitude of the surrounding country rock.

Seepage of water from the quarry was also identified as a moderate, or secondary, potential effect on groundwater. As described in Section 9.4.3, the effect of groundwater seepage into the quarry will be mitigated by collecting groundwater drainage and surface runoff and directing the water, with appropriate sediment control, to Brucejack Lake. If necessary, horizontal drains could be used to relieve the associated potential problem of excess groundwater pressures within quarry walls.

During Closure and reclamation, the disturbed surface footprint of the mine site will be reclaimed, contoured for drainage and re-vegetated (Chapter 30, Closure and Reclamation). These activities will limit the potential for infiltration of precipitation and minimizing opportunities for pooling and ponding of water, except as needed to minimize sediment loading to Brucejack Lake.

9.7.2 Mitigation Methods for Groundwater Quality

During the Construction and Operation phases, groundwater will necessarily be extracted from the mine, treated and discharged to Brucejack Lake. As discussed above, backfilling of underground workings will reduce the volume of water that must be pumped and treated.

Following Closure and reclamation, the primary groundwater quality effects revolve around the generation, migration and attenuation of constituents originating from ML/ARD reactions. In general terms, such processes require (a) the movement of groundwater, (b) contact with PAG materials, and (c) an oxic to suboxic environment. Consequently, mitigation measures are designed to minimize groundwater movement past PAG materials in the presence of oxygen.

The methods for reducing groundwater movement to mitigate most groundwater quantity effects are equally effective for mitigating groundwater quality effects. That is, backfilling of stopes and underground workings during operations with low permeability material will reduce groundwater flow rates past PAG material in the underground mine. This design choice will decrease both generation and migration of ML/ARD affected groundwater. Thus, to the degree practical, underground workings will be backfilled as soon as possible with waste rock and paste tailings (Sections 29.10, ML/ARD Management Plan; 29.15, Tailings Management Plan; 29.17, Waste Rock Management Plan). Furthermore, turning the dewatering pumps off will decrease the hydraulic head gradient in the subsurface, slowing the movement of water even more than when the pumps were operational.

Oxygen ingress into the subsurface will be limited in a number of ways. The same backfilling discussed above, for limiting water movement will also be beneficial for mine workings, portals and ventilation shafts located above the water table. Flooding of the mine will also limit migration of oxygen into the deep subsurface where much of the PAG materials are located. Re-grading, contouring for drainage and re-vegetating the disturbed surface areas of the mine (Chapter 30, Closure and Reclamation) will also limit infiltration of precipitation to the subsurface.

There are also opportunities for adaptive management: the deepest part of the mine will be completed during the operating mine life and allowed to flood. This affords the opportunity to monitor the pooling water quality to evaluate whether additional measures might be needed as mining continues: such contingencies might include the application of shotcrete to seal exposures of materials with short lag time ARD reactions or the construction of plugs and seals internal to the underground workings (i.e., engineered plugs or seals, or reactive barriers) to limit the movement of groundwater (i.e., effectively decreasing the hydraulic conductivity of the underground) (Section 29.10, ML/ARD Management Plan).

Contact with exposed PAG rock may occur at surface exposures in plant-site cuts and the quarry, and underground in excavations, waste rock or paste tailings. A design decision was to quarry rock from an area with non-PAG material. This use helps mitigate groundwater quality effects in both the quarry and in filled areas (e.g., plant-site fills). Prior to closure, drainage and collection systems will contain any affected near-surface water. Many of the underground workings are located within ore zones that contain PAG material. Thus, the primary mitigation measures for these areas are to limit water movement and oxygen ingress, as discussed above.

Contingencies to the design and planned mitigation management strategies included in the Project may include, for example:

- risk assessment to re-evaluate site specific standards for groundwater quality flowing from the mine to discharge in Brucejack Creek and Lake;
- installation of passive treatment methods to deal with shallow path groundwater flows (e.g., PRB trench);
- active interception and treatment (e.g., seepage interception wells); and
- contingency to allow for the water treatment plant to remain on site and operational during mine flooding to treat water in the flooded workings

9.8 PREDICTED CHANGES ON HYDROGEOLOGY

A summary of predicted changes on hydrogeology, for groundwater quantity and quality, is presented in Table 9.8-1. Predicted changes or expected effects of the Project on groundwater quantity and quality identified as possible in Section 9.4 and quantified in Section 9.6 are further characterized and assessed in this section. Predicted changes are characterized using standard criteria (i.e., the magnitude, geographic extent, duration, frequency, reversibility, resiliency, and ecological context). Standard ratings (e.g., major, moderate, minor/low, medium, and high) for these characterization criteria are provided in Section 6.6.2 of the Methodology chapter; however, Table 9.8-2 provides a summary of definitions for each characterization criterion, specific to groundwater quantity and quality.

9.8.1 Characterization of Predicted Changes in Groundwater Quantity

The primary changes to groundwater quantity will involve changes to baseflow (i.e., groundwater discharge) to small creeks within the Project footprint. These predicted changes are summarized on Table 9.8-1. From the Construction phase through the Operation phase, local baseflow decreases as water is extracted from the mine to lower the water table. Baseflow may cease in the smallest streams closest to the mine and groundwater discharge to Brucejack Lake will decrease slightly. The general characterization of these changes to groundwater quantity is that they are: major in magnitude, medium-term in duration, continuous in nature, local in scale and reversible over the medium term. The surface water receptors are likely to have neutral resiliency and low ecological context.

By the end of the closure and reclamation phase the predicted changes to groundwater quantity (i.e., baseflow and discharge to Brucejack Lake) are negligible. That is, the changes are predicted to be reversible over the short term of a few years and the residual effect on groundwater quantity will be similar to natural variability.

The predicted changes to surface water quantity as a result of changes to baseflow quantity are assessed in Chapter 10, Surface Water Hydrology Predictive Study.

9.8.2 Characterization of Predicted Changes in Groundwater Quality

The primary changes to groundwater quality will involve ML/ARD processes in backfilled underground mine workings following closure. These predicted changes are summarized on Table 9.8-1. Water of affected quality will move through the subsurface and eventually discharge in surface-water streams. The predicted changes to surface water quality as a result of the changes to groundwater quality are assessed in Chapter 13, Assessment of Potential Surface Water Quality Effects. The general characterization of these changes to groundwater quality is that they are: major in magnitude, long-term in duration, continuous in nature, local in scale and reversible over the long term. The surface water receptors are likely to have low resiliency and low ecological context.

Smaller changes in groundwater quality may involve ML/ARD processes where surficial rocks have been disturbed; however, these effects are predicted to be minimized because most disturbances will be of non-PAG material and the areas affected are smaller. During the Construction and Operation phases these effects will be managed with drainage systems. The general characterization of these changes is that they are: minor in magnitude, medium-term in duration, continuous in nature, local in scale and reversible over the long term. The surface water receptors are likely to have low resiliency and low ecological context.

Quantitative comparisons of baseline concentrations and possible source terms to applicable groundwater quality guidelines are presented in Table 9.6-2 (groundwater from the quarry source), Table 9.6-3 (groundwater in contact with disturbed rock at the plant site), Table 9.6-4 (groundwater baseflow from the underground mine discharging to Brucejack Lake and Brucejack Creek), and Table 9.6-5 (groundwater from the underground mine discharging to the Sulphurets Glacier). The notes at the end of the table summarize the formatting used to indicate whether a given value in these tables exceeds a particular water quality guideline.

9.9 HYDROGEOLOGY AS A PATHWAY TO RECEPTOR VALUED COMPONENTS

Groundwater quantity and quality were identified as key components of the biophysical environment because of linkages to other ecosystem components, including surface water quantity, surface water quality, human health, aquatic resources and wetlands (Figure 9.4-1). The primary effect through groundwater quantity is expected to manifest prior to Closure, when baseflow is reduced to some surface-water receptors in the LSA. The primary effect through groundwater quality will be during Post-closure, as water affected by ML/ARD processes migrates through the subsurface towards surface-water receptors. These effects are discussed further in the surface water assessments, Chapters 10 and 13.

Table 9.8-1. Summary of Predicted Changes after Mitigation for Hydrogeology

Sub-component	Project Phase (Timing of Effect)	Project Component / Physical Activity	Description of Cause-Effect[1]	Description of Mitigation Measure(s)	Description of Predicted Change(s)
Change in groundwater quantity flowing to small creeks in LSA and Brucejack Lake	Construction, Operation	Construction of mine portal and ventilation shafts, Development of underground portal and facilities, Underground water management, Underground: drilling, blasting, excavation	Dewatering of underground workings lowers water table, causing groundwater to be diverted to Underground Water Management System instead of baseflow.	Backfill underground workings with waste rock, paste tailings or other low-permeability material.	Groundwater discharge will decrease or cease, resulting in decreased baseflow and discharge.
Change in groundwater quantity flowing to small creeks in LSA and Brucejack Lake	Closure, Post-closure	Closure of mine portals, Underground mine.	Cessation of pumping for dewatering leads to groundwater flow reverting to pre-disturbance conditions.	Backfill underground workings with waste rock, paste tailings or other low-permeability material; cease dewatering activities.	Groundwater discharge and baseflow will return to pre-disturbance rates.
Change in groundwater quality emanating from underground mine	Closure, Post-closure	Closure of mine portals, Underground mine.	Cessation of pumping for dewatering leads to groundwater flow reverting to pre-disturbance conditions. Oxic or suboxic water in contact with PAG materials leads to ML/ARD reactions.	Backfill underground workings with waste rock, paste tailings or other low-permeability material; seal portals and ventilation shafts; cease dewatering activities.	Groundwater affected by ML/ARD reactions will migrate through the subsurface, discharging to creeks in the vicinity of the LSA.
Change in groundwater quality in mine-site cuts and fills or quarry	Construction, Operation, Closure and Reclamation, Post-closure	Construction, use and decommissioning of surface workings involving rock disturbance.	Possible contact of oxygenated water with PAG materials	Quarry site chosen to be non-PAG to minimize ML/ARD processes within quarry and mine-site fill areas. Drainage during Construction and Operation.	Limited amounts of groundwater affected by localized ML/ARD reactions.

[1] *"Cause-effect" refers to the relationship between the Project component/physical activity that is causing the change or effect in the condition of the receptor VC.*

Table 9.8-2. Definitions of Characterization Criteria for Predicted Changes on Hydrogeology

Magnitude	Duration	Frequency	Geographic Extent	Reversibility	Resiliency	Ecological Context
Minor: The magnitude of effect is within the range of natural variation and/or is well below a guideline or threshold value.	**Short term:** Effect lasts less than about five years	**Once:** The effect that occurs once or infrequently during any phase of the Project	**Local:** The effect is limited to the Project footprint in off-site areas and the LSA for the mine site	**Reversible short term:** The effect can be reversed relatively quickly	**Low:** The receptor is considered to be of low resiliency following disturbances	**Low:** The receptor is considered to have little to no unique attributes in the geographic area
Moderate: The magnitude of effect approaches the limits of natural variation and/or is below or equal to a guideline or threshold value.	**Medium term:** Effect lasts more than five years but less than about twenty years	**Sporadic:** The effect that occurs at sporadic or intermittent intervals during any phase of the Project	**Landscape:** The effect extends beyond the Project footprint to a broader area (limited to portions of RSA	**Reversible medium term:** The effect can be reversed after a few years	**Neutral:** The receptor is considered to be moderately resilient following disturbances	**Neutral:** The receptor is considered to have some unique attributes in the geographic area
Major: The magnitude of effect is predicted to differ from baseline conditions and exceed guideline or threshold values so that there will be a detectable change beyond the range of natural variation (i.e., change of state from baseline conditions)	**Long term:** Effect lasts more than twenty years but less than about one hundred years **Far future:** Effect lasts more than one hundred years	**Regular:** The effect that occurs on a periodic basis during any phase of the Project **Continuous:** The effect that occurs regularly during any phase of the Project and beyond	**Regional:** The effect extends across the RSA. **Beyond regional:** The effect extends beyond the RSA possibly across or beyond the province (i.e., transboundary effects)	**Reversible long term:** The effect can be reversed after many years **Permanent:** The effect cannot be reversed	**High:** The receptor is considered to be highly resilient following disturbances	**High:** The receptor is considered to be unique in the geographic area

9.10 CUMULATIVE EFFECT ASSESSMENT FOR HYDROGEOLOGY

Cumulative changes relate to changes "*which are likely to result from the designated project in combination with other projects and activities that have been or will be carried out.*" This definition follows the cumulative effects in section 19(1) of the *Canadian Environmental Assessment Act, 2012* (2012) and is consistent with the IFC Good Practice Note on Cumulative Impact Assessment which refers to consideration of other existing, planned, and/or reasonably foreseeable future projects and developments. This cumulative effect assessment provides information to supplement the cumulative effects sssessment (CEA) for the receptor VCs, which is a requirement of the AIR and the EIS Guidelines and is necessary for the proponent to comply with the *Canadian Environmental Assessment Act, 2012* (2012) and the BC *Environmental Assessment Act* (2002a).

The assessment method adopted here complies with CEA Agency Operational Policy Statement *Assessing Cumulative Environmental Effects under the Canadian Environmental Assessment Act 2012* (CEA Agency 2013a) and the *Guideline for the Selection of Valued Components and the Assessment of Potential Effects* (BC EAO 2013). The method involves the following key steps which are further discussed in the proceeding sub-sections:

- scoping;
- analysis;
- identification of mitigation measures;
- identification of residual cumulative changes; and
- characterization of residual cumulative changes.

9.10.1 Establishing the Scope of the Cumulative Effects Assessment

The scoping process involves identification of the intermediate components for which residual changes are predicted, definition of the spatio-temporal boundaries of the assessment, and an examination of the relationship between the residual effects of the Project and those of other projects and activities.

9.10.1.1 Identifying Intermediate Components for the Cumulative Effects Assessment

Intermediate components included in the hydrogeology CEA were selected using four criteria following BC EAO (2013):

1. There must be a residual environmental effect of the project being proposed.
2. Environmental effect must be demonstrated to interact cumulatively with the environmental effects from other projects or activities.
3. Other projects or activities must be known to have been or will be carried out and are not hypothetical.
4. The cumulative environmental effect must be likely to occur.

The intermediate components for hydrogeology that are included in this CEA are:

- groundwater quantity: changes to groundwater flow volume and movement assessed on the basis of increases or decreases in hydraulic heads as a result of the project ; and
- groundwater quality: changes to concentrations of total and dissolved metals, nutrients, turbidity, total suspended solids, and groundwater temperature.

Section 9.8, above, provides an assessment summary for changes and residual effects related to hydrogeology and associated with the Project. Residual effects related to groundwater quantity are predicted to be negligible post-closure of the Project. Residual effects for groundwater quality are predicted to include local discharge of low levels of ML/ARD affected groundwater (Figure 9.6-8) for an extended period. Project-related residual effects for hydrogeology are not anticipated in areas extending more than two km down gradient from the Project footprint.

9.10.1.2 Potential Interaction of Projects and Activities with the Brucejack Gold Mine Project for Hydrogeology

A review of the potential interaction between predicted changes on intermediate components from the Project and potential effects of other projects and activities on hydrogeology was undertaken. The review assessed the projects and activities identified in Section 6.8.2 of the Assessment Methodology, including:

- regional projects and activities that are likely to affect the intermediate component, even if they are located outside the direct zone of influence of the Project;
- effects of past and present projects and activities that are expected to continue into the future (i.e., beyond the effects reflected in the existing conditions of groundwater quantity and quality, Section 9.6); and
- activities not limited to other reviewable projects, if those activities are likely to affect the intermediate component cumulatively (e.g., mineral exploration, mining activities).

A matrix identifying the potential cumulative effect interactions for hydrogeology is provided in Table 9.10-1 below.

Table 9.10-1. Potential Interaction of Projects and Activities with the Brucejack Gold Mine Project for Hydrogeology

Projects and Activities	Groundwater Quantity	Groundwater Quality
Historical		
Eskay Creek Mine		
Galore Creek Project - Access Road Only		
Goldwedge Mine		
Granduc Mine		
Johnny Mountain Mine		
Kitsault Mine		
Silbak Premier Mine		
Snip Mine		
Snowfield Exploration Project		
Sulphurets Advanced Exploration Project		
Swamp Point Aggregate Mine		
Present		
Brucejack Exploration and Bulk Sample Program		
Forrest Kerr Hydroelectric Power Facility		
Long Lake Hydroelectric Power Facility		
McLymont Creek Hydroelectric Project		

(continued)

Table 9.10-1. Potential Interaction of Projects and Activities with the Brucejack Gold Mine Project for Hydrogeology (completed)

Projects and Activities	Groundwater Quantity	Groundwater Quality
Present *(cont'd)*		
Northwest Transmission Line		
Red Chris Project		
Reasonably Foreseeable Future		
Arctos Anthracite Coal Project		
Bear River Gravel Project		
Bronson Slope Project		
Coastal GasLink Pipeline Project		
Galore Creek Project		
Granduc Copper Mine		
KSM Project		
Kinskuch Hydroelectric Project		
Kitsault Mine		
Kutcho Project		
LNG Canada Export Terminal Project		
Northern Gateway Pipeline Project		
Prince Rupert Gas Transmission Project		
Prince Rupert LNG Project		
Schaft Creek Project		
Spectra Energy Gas Pipeline		
Storie Moly Project		
Treaty Creek Hydroelectric Project		
Turnagain Project		
Volcano Hydroelectric Project		

Black = likely interaction between Brucejack Gold Mine Project and other project or activity
Grey = possible interaction between Brucejack Gold Mine Project and other project or activity
White = unlikely interaction between Brucejack Gold Mine Project and other project or activity

9.10.1.3 Spatio-temporal Boundaries of the Cumulative Effects Assessment

The CEA boundaries define the maximum limit within which the assessment is conducted. They encompass the areas within, and times during which, the Project is expected to interact with the intermediate component and with other projects and activities, as well as the constraints that may be placed on the assessment of those interactions due to political, social, and economic realities (administrative boundaries), and limitations in predicting or measuring changes (technical boundaries). The definition of these assessment boundaries is an integral part of the hydrogeology cumulative effects assessment, and encompasses possible direct, indirect, and induced changes of the Project on groundwater quantity and quality.

<u>Spatial Boundaries</u>

The maximum spatial boundaries for the CEA are limited to the RSA for the Project; however, the changes and residual effects of the Project are localized to the headwaters of the watershed, within 2 km of the Project footprint (Figure 9.6-8).

Temporal Boundaries

The time frame for possible groundwater interaction includes all historical intrusive activities within the headwaters of the RSA watershed.

9.10.1.4 Potential for Cumulative Changes

The former Goldwedge Mine, located 2 km northwest of Brucejack Lake on Catear Creek, a tributary of Brucejack Lake, is thought to have no groundwater interactions that overlap with the Project. This is because the Goldwedge Mine site is located within a different topographic sub-basin than the Project.

The Snowfield Exploration Project, located 7 km north of the Project, is within the Sulphurets Creek watershed but downstream of the Project and beyond the extent of residual groundwater quality effects.

The proposed KSM Project, located 4 km northeast of the Brucejack Gold Mine Project, is within the Sulphurets Creek watershed but downstream of the Project and beyond the extent of residual groundwater quality effects.

The only past project that may affect groundwater quality and quantity and might spatially overlap potential effects from the Project is the Sulphurets Advanced Exploration Project.

Advanced exploration and bulk sample mining occurred at the Sulphurets Project between 1986 and 1990. No additional cumulative effects related to this project would be expected with development of the Brucejack Gold Mine Project beyond what was already considered in baseline and predictive studies, as well as within geochemical source terms used to inform predictive water quality models for the Project (Appendix 13-C, Predictive Water Quality Report). Therefore, activities associated with the Sulphurets Project will not be considered further in the CEA for hydrogeology.

The only present or future project that may affect groundwater quantity and quality and might spatially overlap potential effects from the Project is the Brucejack Exploration and Bulk Sample Program.

Brucejack exploration activities commenced in 2011 and have included a drilling program and bulk sampling program. Further details on the effect of past activities on the groundwater quantity and quality baseline are provided in Sections 9.3 and 9.5. No additional cumulative effects related to exploration activities would be expected with development of the Brucejack Gold Mine Project beyond what was already considered in baseline studies; therefore, the Brucejack exploration program will not be considered further in the CEA for hydrogeology.

The locations of both the Sulphurets Advanced Exploration Project and the Brucejack Exploration Bulk Sample Program are coincident with the Project.

9.10.2 Analysis of Cumulative Changes

The current Project is essentially an expansion of both the Sulphurets Advanced Exploration Project and the Brucejack Exploration Bulk Sample Program. Changes in hydrogeology from the current Project will be superimposed on the small changes that might remain from the previous projects. Legacy effects from the prior projects have been accounted for in the baseline and predictive studies. Thus, there are no additional changes to consider and the cumulative changes to groundwater quantity and quality correspond to those of the Project itself.

9.10.3 Mitigation Measures to Address Cumulative Predicted Changes

The cumulative changes attributed to the Project correspond to those of the Project itself. Consequently, mitigation measures for the Project are the same as those for cumulative changes. Mitigation measures for the Project are discussed in Section 9.7.

9.10.4 Predicted Cumulative Changes for Hydrogeology

The cumulative changes attributed to the Project correspond to those of the Project itself. Consequently, the predicted changes for groundwater quantity and quality are the same as those for the Project. These predicted changes are fully evaluated in Section 9.6.

9.10.5 Characterizing Predicted Cumulative Changes for Hydrogeology

The cumulative changes attributed to the Project correspond to those of the Project itself. The characterization of the predicted changes for hydrogeology of the Project are discussed in Section 9.8 and summarized in Table 9.8-1.

9.10.6 Hydrogeology as a Pathway for Interaction with Receptor Valued Components

The primary receptor VC for hydrogeology is surface water quality.

9.11 SUMMARY AND CONCLUSIONS FOR HYDROGEOLOGY

Table 9.11-1 presents a summary of the assessment of potential environmental effects on hydrogeology.

Table 9.11-1. Summary of Predicted Changes to Hydrogeology

Predicted Effects	Project Phase(s)	Mitigation Measures	Cumulative Residual Effects	Receptor VCs Affected
Groundwater Quantity				
Decreased baseflow to Brucejack Creek and small tributaries and Brucejack Lake	Construction, Operation	Backfill underground workings with waste rock, paste tailings or other low-permeability material; cease dewatering activities.	Negligible Post-closure	Surface water quantity
Groundwater Quality				
Migration of ML/ARD affected water from underground mine	Closure and Reclamation, Post-closure	Implement ML/ARD Management Plan (Section 29.10); Implement Waste Rock Management Plan (Section 29.18); Implement Water Management Plan (Section 29.19); Implement Tailings Management Plan (Section 29.15)	Groundwater affected by ML/ARD reactions will migrate through the subsurface, discharging to creeks in the vicinity of the LSA.	Surface water quality
Change in groundwater quality in mine-site cuts and fills or quarry	Construction, Operation, Closure and Reclamation, Post-closure	Quarry site chosen to be non-PAG to minimize ML/ARD processes within quarry and mine-site fill areas. Implement ML/ARD Management Plan (Section 29.10); Implement Waste Rock Management Plan (Section 29.18); Implement Water Management Plan (Section 29.19); Implement Tailings Management Plan (Section 29.15)	Limited amounts of groundwater affected by ML/ARD reactions	Surface water quality

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1996c. *Water Act*, RSBC. C. 483.

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