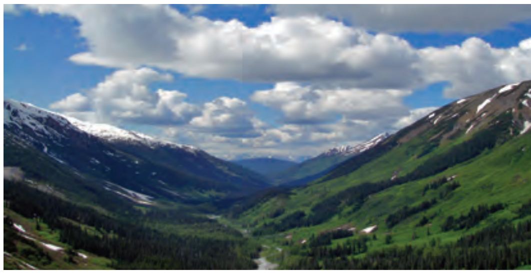
APPENDIX 11-D
HYDROGEOLOGICAL MODELLING REPORT

Seabridge Gold Inc.

KSM PROJECT
Hydrogeological Modelling Report

SEABRIDGE GOLD



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KSM PROJECT
HYDROGEOLOGICAL MODELLING REPORT

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Prepared for:

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Executive Summary

On the basis of a thorough examination and analysis of all the relevant information and test data available for the KSM copper/gold project (the KSM Project), a conceptual hydrogeological model has been developed and a three-dimensional baseline model has been constructed to characterize the current pre-mining conditions of the regional groundwater system and the surface water – groundwater interactions, respectively, in the mining area (with the proposed Open Pits, Water Storage Facility, Rock Storage Facilities and Diversion Tunnels) and in the Tailing Management Facility (TMF) area (with the proposed Tailing Management Facility, Processing Plant and Ore Transport Tunnel).

The baseline models were built using overburden and bedrock hydraulic conductivities determined from field tests, and from reasonable assumptions such as riverbed hydraulic conductivity. Model input parameters, such as the specific storage and specific yield, have been derived from similar modelling projects and the literature.

The predictive flow and solute transport models for the end of operation and post-closure scenarios were built on the basis of the calibrated baseline models with modifications to flow and transport boundary conditions and hydraulic properties (e.g., in the pits and for tailing materials) to best represent the mining conditions. The results have been used to calculate the water balance and to assess the effects of the proposed mining activities on groundwater quantity and quality in the mining area and the TMF area.

Mining Area Modelling Results

Pre-mining Groundwater Flow

The mining area baseline model is well calibrated to multiple targets including the observed groundwater levels in the monitoring wells/piezometers and baseflows in the creeks at the current pre-mining conditions. The NRMS (Normalized Root Mean Square) is 1.4% and the residual mean of the difference between the observed and simulated hydraulic heads is 2.7 m. The rule of thumb for a good calibration is that the NRMS is less than 10%. The good calibration results demonstrate that the conceptual and baseline model is valid and representative of the physical hydrogeological system in the mining area, and therefore that it is reliable for prediction.

The baseline model results show that simulated steady-state head (equipotential) contours at the pre-mining conditions generally mimic the surface topography, and that groundwater is deeper at high elevations than in lower elevations. The results demonstrate that the regional groundwater system is recharged in the mountain tops and slopes, and discharges into surface waterbodies on the valley bottoms.

The proposed Sulphurets and Kerr Pits are located in recharge zones at high elevations whereas the proposed Mitchell Pit is located in a groundwater recharge-discharge transition zone, receiving recharge from slopes and upper Mitchell Creek Valley but discharging into the downstream aquifer and Mitchell Creek. The proposed Sulphurets Rock Storage Facility is also located in groundwater recharge-discharge transition zone. The proposed McTagg/Mitchell Rock Storage Facility and the Water Storage Facility in Mitchell Creek Valley are located in groundwater discharge zones.

The flow budget results for the baseline model show that at pre-mining, the baseflow varies from 0.12 m^3/s to 1.49 m^3/s at the location where the Sulphurets Creek joins the Unuk River, 0.1 m^3/s to

1.39 m^3/s at the confluence of Mitchell and Sulphurets Creeks, and 0.01 m^3/s to 0.1 m^3/s at the McTagg Creek confluence with the Mitchell Creek. The pre-mining groundwater flows through the proposed pit areas are estimated to be approximately 10,158 m^3/d (117.6 L/s) for the Mitchell Pit, 758.5 m^3/d (8.8 L/s) for the Sulphurets Pit and 708.3 m^3/d (8.2 L/s) for the Kerr Pit.

The groundwater flows through the areas of the proposed Rock Storage Facilities are about 16,843 m^3/d (194.9 L/s) in Mitchell-McTagg valleys and 726.4 m^3/d (8.4 L/s) above Sulphurets Creek. The flow into the proposed Water Storage Facility area is 2,545 m^3/d (29.5 L/s) at the operational low water level and 4,366.0 m^3/d (50.5 L/s) at the operational high water level. The sensitivity analysis results show that the model calibration and the estimated groundwater flows are highly sensitive to the recharge rates, the hydraulic conductivities of glacial till materials and bedrock formations in the top/shallow, upper and middle zones in the mining area, as well as their anisotropy ratios.

Impact of Mining on Flow Patterns and Water Quantity

The dewatered Mitchell Pit at the end of operation, and the post-closure pit lake, will cause a significant change in the local groundwater flow patterns compared to the pre-mining scenario. The dewatered Mitchell Pit and the refilled pit lake will behave as a large sink and draw groundwater into the pit from the surrounding formations and the proposed Mitchell Rock Storage Facility area. The pit lake will therefore be affected by potentially poor quality water leaching from the Rock Storage Facility. The groundwater flow direction will reverse in the upper Mitchell Creek Valley as a result of the Mitchell Pit dewatering and refill (whose level will be controlled), during operation and post-closure. A groundwater divide will form in the Mitchell Rock Storage Facility area between the Mitchell Pit and the Water Storage Facility.

The proposed Sulphurets and Kerr Pits will also become groundwater sinks during operational dewatering, and affect groundwater flows locally, but the effects are much smaller compared to the Mitchell Pit. Unlike the Mitchell Pit Lake at post-closure, the Sulphurets and Kerr Pit Lakes, will refill to their spill elevations and become constant sources of aquifer recharge. The water from the Pit Lakes will recharge the deep bedrocks and flow downstream to the Sulphurets Lake and the upstream of Sulphurets Creek.

The results of modelling show that at the end of operation and post-closure, some seepage from the Mitchell Rock Storage Facility flows to the Mitchell Pit and Pit Lake and some, together with effluent from the Rock Storage Facility in McTagg Creek Valley, will discharge into the Water Storage Facility under natural gradients. A small portion may report to the McTagg Diversion Tunnel.

In the Sulphurets Rock Storage Facility area, the modelling results indicate that the majority of the seepage from the facility will discharge to the downstream Sulphurets Creek and the small streams on the slopes while a small portion will discharge into the Water Storage Facility and the Seepage Collection System in Mitchell Creek valley. The travel (residence) time of the seepage from the Sulphurets Rock Storage Facility into the receiving waters is estimated to be 20 to 30 years in average, but it could be as short as 2 to 3 years through permeable fracture networks or faults in the bedrocks. For the Water Storage Facility, the results show that the seepage from the facility will be captured by the Seepage Collection System during the mine operation and at post-closure.

The results demonstrate that of all the mine facilities, the Sulphurets Rock Storage Facility is likely to have the most significant role in affecting water quality in the Sulphurets Creek. Therefore, seepage control measures should be considered. The results suggest that seepage from the Water Storage Facility is unlikely to be a major concern when a grout curtain is installed to 100 m depth with effective hydraulic conductivity of 10^{-8} m/s. The seepage from the McTagg-Mitchell Rock Storage

Facility will report to the Water Storage Facility and be managed there. The effect of the pits on groundwater flows will be localized and they will have no effect on groundwater flows downgradient of the Water Storage Facility or the Sulphurets Rock Storage Facility.

The Base Case results show that at the end of operation and post-closure, the baseflow at the outlet of the Sulphurets Creek joining the Unuk River will be reduced by about 50% from the pre-mining baseflow. This is because the McTagg Creek and upper Mitchell Creek will disappear beneath the McTagg-Mitchell Rock Storage Facility, the Mitchell Pit and the Water Storage Facility and the contribution to baseflow from these creeks and streams will be lost to the downstream Sulphurets Creek. However, the loss of baseflow in the downstream Sulphurets Creek is likely to be compensated by the discharge of diverted surface runoff through the tunnels and discharge of treated water from the Water Storage Facility. Furthermore, the results show that there is no change in the baseflows into Sulphurets Lake, Sulphurets Creek upper reach, Ted Morris Creek, Joe Mandy Creek and Gingras Creek. The effects of the mining activities to the stream baseflow quantities are limited to within the McTagg and Mitchell valleys above the Water Storage Facility.

The seepage out of the Water Storage Facility is predicted to be small (3 L/s in Base Case and 22 L/s in the upper case with 10x higher permeability overburden and bedrocks) at both the end of operation and the post-closure. The steep hydraulic gradients in the Mitchell Canyon limit the seepage out of the facility. The seepage out of the Sulphurets Rock Storage Facility is estimated to be about 32 L/s to 33 L/s in the Base Case, and varies from 17 L/s to 59 L/s in sensitivities at the end of operation and post-closure. The seepage from this facility would be the major factor influencing downstream water quality in Sulphurets Creek. Groundwater flows into the pits and the tunnels are variable with bedrock hydraulic conductivities and groundwater recharge; generally there will be more flow into these facilities in wet years, less in dry years, more flow into tunnels from Mitchell and Sulphurets Pit Lakes at post-closure than at end of operation.

Impact of Mining on Water Quality

The non-reactive solute transport modelling results for the post-closure scenario represent the conservative long-term “worst” effects without consideration of any retardation and attenuation (e.g. from biogeochemical processes and dilution) that the mining activities are likely to cause. For the Base Case, the results demonstrate that the plume from Mitchell Pit Lake migrates only a very limited distance. This is because the Pit Lake acts as a local groundwater sink and therefore the solute migration to the deeper bedrocks is limited and the impact on downstream surface water quality is unlikely. In contrast, the solute plumes from Sulphurets and Kerr Pit Lakes extend to Sulphurets Lake and Sulphurets Creek, and they are very likely to affect groundwater quality in deep bedrock aquifers and may impact water quality in the Creek.

For the Rock Storage Facilities, the results indicate that the solute plume from the McTagg-Mitchell Rock Storage will migrate into the Water Storage Facility; the plume from the Sulphurets Rock Storage will migrate into Mitchell and Sulphurets Creeks and possibly reach the Mitchell/Sulphurets confluence (at the location of the monitoring well RES-MW-11) and the outlet of Gingras Creek (upstream of the proposed compliance point SC-2). The results demonstrate that the seepage from Sulphurets Rock Storage Facility would be the major factor to influence the downstream Sulphurets Creek water quality.

For the Water Storage Facility, the Base Case transport results demonstrate that the plume migration is limited within the Seepage Collection System and the seepage from the facility is unlikely to be a concern for downstream surface water quality, due to the facility’s location in the deep Mitchell Canyon where the upward hydraulic gradients restrict seepage out of the facility.

TMF Area Modelling Results

Pre-mining Groundwater Flow

The TMF area baseline model is well calibrated to multiple targets including the observed groundwater levels in the monitoring wells and the measured baseflows in the creeks. The NRMS (Normalized Root Mean Square) is 2.9% and the residual mean of the difference between the observed and simulated hydraulic heads is 2.1 m. The good calibration results demonstrate that the conceptual and baseline model is a valid representation of the physical hydrogeological system in the TMF area, and therefore reliable for groundwater flow and transport predictions.

The baseline model results show that simulated steady-state head equipotential contours at the pre-mining conditions generally mimic the surface topography. The results indicate that the groundwater table is deep in high elevations but are shallow in low elevations. Groundwater recharge occurs in the mountainous uplands and slopes, and discharges into the surface water bodies in the valley bottoms. The proposed Tailing Management Facility (TMF) is located in a groundwater discharge zone on the valley bottom. The simulated baseflow rates under pre-mining conditions vary between 0.03 m^3/s and 0.30 m^3/s in the Teigen South Tributary, and between 0.02 m^3/s and 0.14 m^3/s in the Treaty North Tributary. Groundwater discharge into the proposed TMF footprint area is estimated to be 3,551.8 m^3/d (41.1 L/s).

Impact of TMF on Flow Patterns and Water Quantity

The Base Case flow results show that the local groundwater flow patterns will be affected by the proposed TMF together with the Teigen-Mitchell Tunnel during the mine operation and post-closure, but the regional groundwater flow outside the TMF area will be not affected. Compared to the baseline, the proposed TMF won't change the baseflow to the Teigen Creek upper and lower reaches, and the Treaty Creek upper and lower reaches.

The results indicate that groundwater will discharge from the valley slopes into the TMF where it will mix with process-affected water within the tailing. A small amount of this water will seep through the TMF into the underlying overburden and bedrocks and flow toward the north and South Tailing Dams. The results of the end of operation and post-closure modelling with the designed ultimate tailing pond level at 1,085 masl show that the seepage flow rate out of the TMF is estimated to be 8.9 L/s passing the North Dam and 7.7 L/s passing the South Dam. Most of the seepage will be captured by the Seepage Collection Systems located downgradient of the North and South Dams, while a small portion may report to the Teigen-Mitchell Tunnel. The total groundwater flow into Teigen-Mitchell Tunnel in TMF study area is estimated to be 38.3 L/s in Base Case. Only about 2.1 L/s (~ 5%) of this flow is estimated to comprise process-affected groundwater. The steep valley topography and hydraulic gradients limit the rate of seepage out of the TMF, the estimates above represent the maximum seepage that could flow out of the ultimate tailing pond.

The results also indicate that the time it takes for the seepage from the TMF to reach the Seepage Collection Dams (residence time) is estimated to about 10 to 20 years in the north seepage collection area and 20 to 30 years in the south seepage collection area. The residence time could be 10 times less through permeable fracture networks or faults in the bedrocks.

Impact of TMF on Water Quality

The conservative solute transport results for the Base Case post-closure scenario with the designed ultimate tailing pond show that migration of a potential contaminant plume from the TMF will be constrained by the steep hydraulic gradients (both horizontally and vertically) that prevail to the east and west of the proposed TMF location. Solute plumes will migrate dominantly to the north and south of the TMF along the valley bottom but the majority of the solute plumes will be captured by the Seepage Collection Systems under the North and South Tailing Dams. Some of the solute plume may migrate beyond the Seepage Collection Dams, but at concentrations of less than 1% of the source zone concentration for the worst scenario without consideration of any attenuation and surface water dilution.

Sensitivity analysis shows similar plume behaviour to the Base Case. In the upper case (high permeability geological materials) and in dry years (when the hydraulic containment is diminished), the solute plumes may migrate further down the valleys but also at low concentrations. The concentrations would be even lower if attenuation and surface water dilution are considered. The results show that seepage from the TMF will have a limited effect on downstream groundwater quality and therefore on the water quality in downstream creeks (Teigen South Tributary and Treaty North Tributary).

Recommendations

The Base Case results for flow and solute transport are recommended to be used for overall water balance calculations and for the environmental effect assessment of water quantity and quality in the mining area and the TMF area by incorporating the attenuation of the complex biogeochemical processes, surface water dilution, as well as the background concentrations in groundwater and surface water. The results of the Base Case end of operation and post-closure represent the largest potential effects that the mining activities could cause. The results from the sensitivity analyses provide an indication of the possible ranges associated with the uncertainties in the hydraulic properties of the geological materials and the climate conditions but are not considered representative of likely flow rates and solute transport.

For water quality monitoring in the mining area, the locations for monitoring wells are recommended at the downgradient of the Water Storage Facility and downgradient of the Sulphurets Rock Storage Facility, including the existing well RES-MW-11 and the proposed environmental compliance points. For water quality monitoring in the TMF area, the locations for monitoring wells are recommended at the downgradient of the North and South Seepage Collection Dams, as well as the proposed environmental compliance points.

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Acronyms and Abbreviations

Acronyms and abbreviations used in this document are defined where they are first used. The following list of abbreviations will assist readers who may choose to review only portions of the document.

3D	Three-Dimensional
BC	British Columbia
BGC	BGC Engineering Inc.
KCBL	Klohn Crippen Berger Ltd.
masl	Metres Above Sea Level
mbgs	Metres Below Ground Surface
MSC	Meteorology Service of Canada
NRMS	Normalized Rooted Mean Squared
PCG4	Pre-Conditioned Conjugate Gradient
PEST	Parameter Estimation Program
Rescan	Rescan Environmental Services Ltd.
RSF	Rock Storage Facility
TMF	Tailing Management Facility
USGS	United States Geological Survey
KSM Project	Kerr-Sulphurets-Mitchell Copper/Gold Mine Project

1. Introduction

Seabridge Gold Inc. (Seabridge) intends to acquire approvals and permits for the development of its owned KSM (Kerr-Sulphurets-Mitchell) Copper/Gold Mine Project (the KSM Project). The preliminary economic assessment of the KSM Project has been completed by Wardrop (Wardrop 2008, 2009), the pre-feasibility geotechnical investigation and design of the mining has been conducted by Klohn Crippen Berger Ltd. (KCBL 2010a, Sub-Appendix H2 of Appendix 4-C of the EA Chapter 4; 2010b), and the Open Pit depressurization analysis has been performed by BGC Engineering (BGC 2010a; Appendix 11-I of the EA Chapter 11). Rescan Environmental Services Ltd. (Rescan) has been commissioned to conduct a comprehensive environmental assessment required for the permitting and approval of the Project on the basis of the prefeasibility study (Wardrop 2010).

1.1 PROJECT DESCRIPTION

The KSM project is located in the rugged coastal mountainous terrain of northwestern British Columbia, approximately 950 km northwest of Vancouver, British Columbia and approximately 65 km northwest of Stewart, British Columbia (Figure 1.1-1). The proposed project lies approximately 20 km southeast of Barrick Gold's recently-closed Eskay Creek Mine and 30 km northeast of the Alaska border, and it is comprised of two distinct and geographically separate areas: the mining area, and the Tailing Management Facility and Processing Plant area (TMF area) as shown in Figure 1.1-2. The mining area is located in the headwater drainage basins of the Sulphurets Creek, which is a major tributary of the Unuk River. The TMF area is located in the headwaters of tributaries of Teigen and Treaty Creeks, which flow to the Bell-Irving River. The two areas are connected by a pair of parallel Mitchell-Teigen tunnels.

The mining area include the Open Pits in the ore deposits (the Mitchell Pit, the Sulphurets Pit and the Kerr Pit), the Rock Storage Facilities in the Mitchell and McTagg creek valleys and on the south-facing side of the ridge between the Sulphurets and the Mitchell creek valleys, the Water Storage Facility in the downstream Mitchell valley to collect the seepage from the Rock Storage Facilities, the Diversion Tunnels near the Mitchell Pit to divert the flow in the Mitchell Creek southwards towards Sulphurets Lake (away from the Mitchell Pit area), and the Diversion Tunnel to divert the flow in the McTagg Creek to the lower Sulphurets Creek (away from the Rock Storage Facility). The TMF area includes the Processing Plant and the Tailing Management Facility in Teigen South Tributary and the headwater of the Treaty North Tributary, the North and South Tailing Dams to contain the tailing, the Seepage Collection Systems to collect the seepage from the TMF, and the Diversion Ditches to divert clean surface runoff away from the tailing impoundment, as well as the ore-transport Teigen-Mitchell Tunnel.

The ore deposits in the KSM mining area will be exploited at an average rate of 120,000 tonnes per day from three Open Pits. The Tailing Management Facility in the Teigen South Tributary valley is designed with a total capacity to store 1.62 billion tonnes of tailing produced over a 37 year mine life. Detailed information for the KSM Project including meteorology, hydrology, geology, exploration drilling, geotechnical investigation, hydrogeological drilling and testing, and feasibility study can be found in the Project Description (Rescan 2008), the Preliminary Economic Assessment (Wardrop 2008, 2009), KSM Project Open Pit Depressurization Analysis (BGC 2010a; Appendix 11-I of the EA Chapter 11), Seismic Refraction Investigation for Kerr Sulphurets Mitchell Project and KCBL's 2009 Site Investigation Report (KCBL 2010a; Sub-Appendix H2 of Appendix 4-C of the EA Chapter 4), Pre-Feasibility Design of Tailing Management Facility (KCBL 2010b), and Rescan's Meteorology, Hydrology and Hydrogeology Baseline Reports (Rescan 2010a, 2010b, 2010c, Appendix 11-B of the EA Chapter 11). The reader is directed to these reports for supporting Project information.

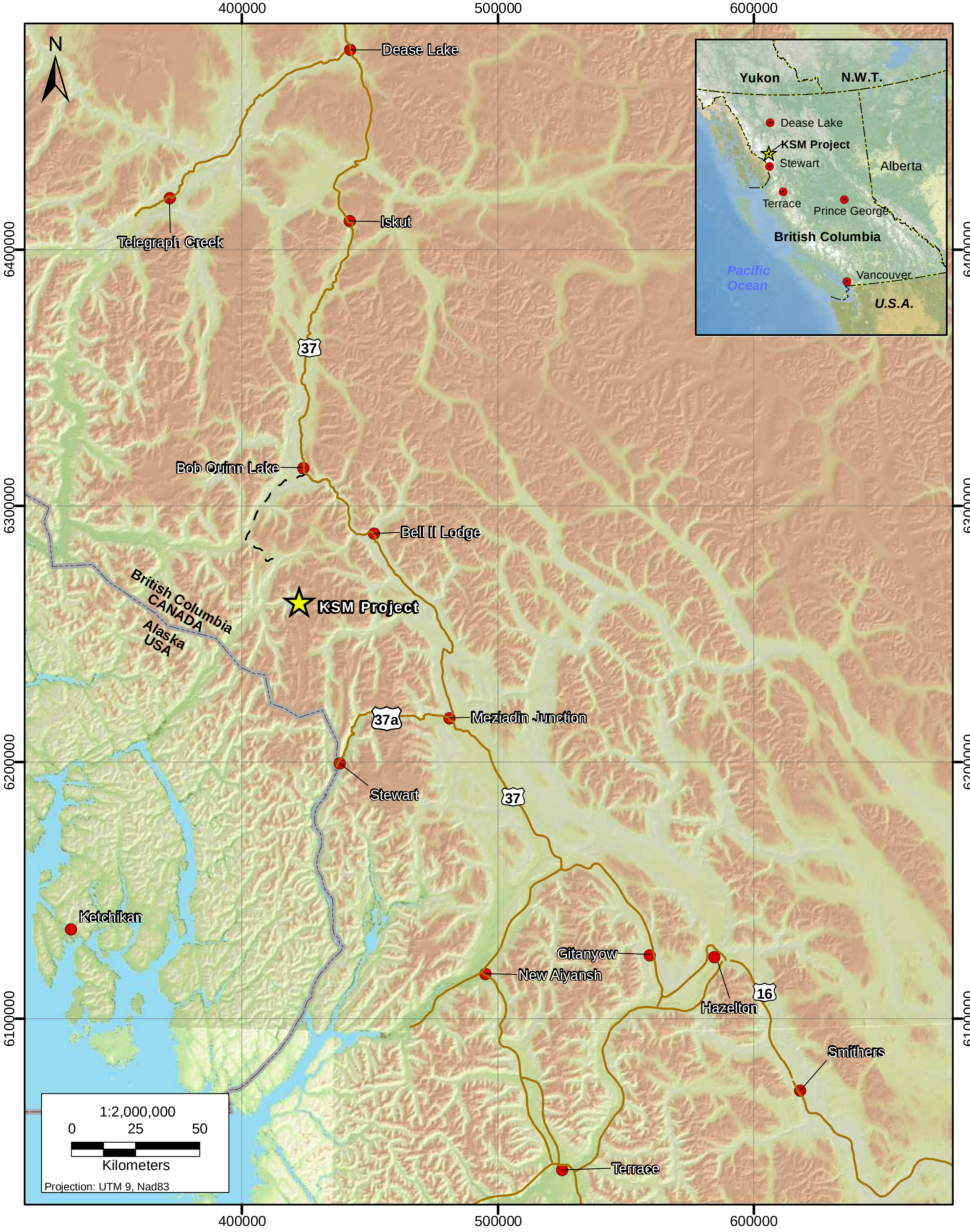

FIGURE 1.1-1

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KSM Project Location

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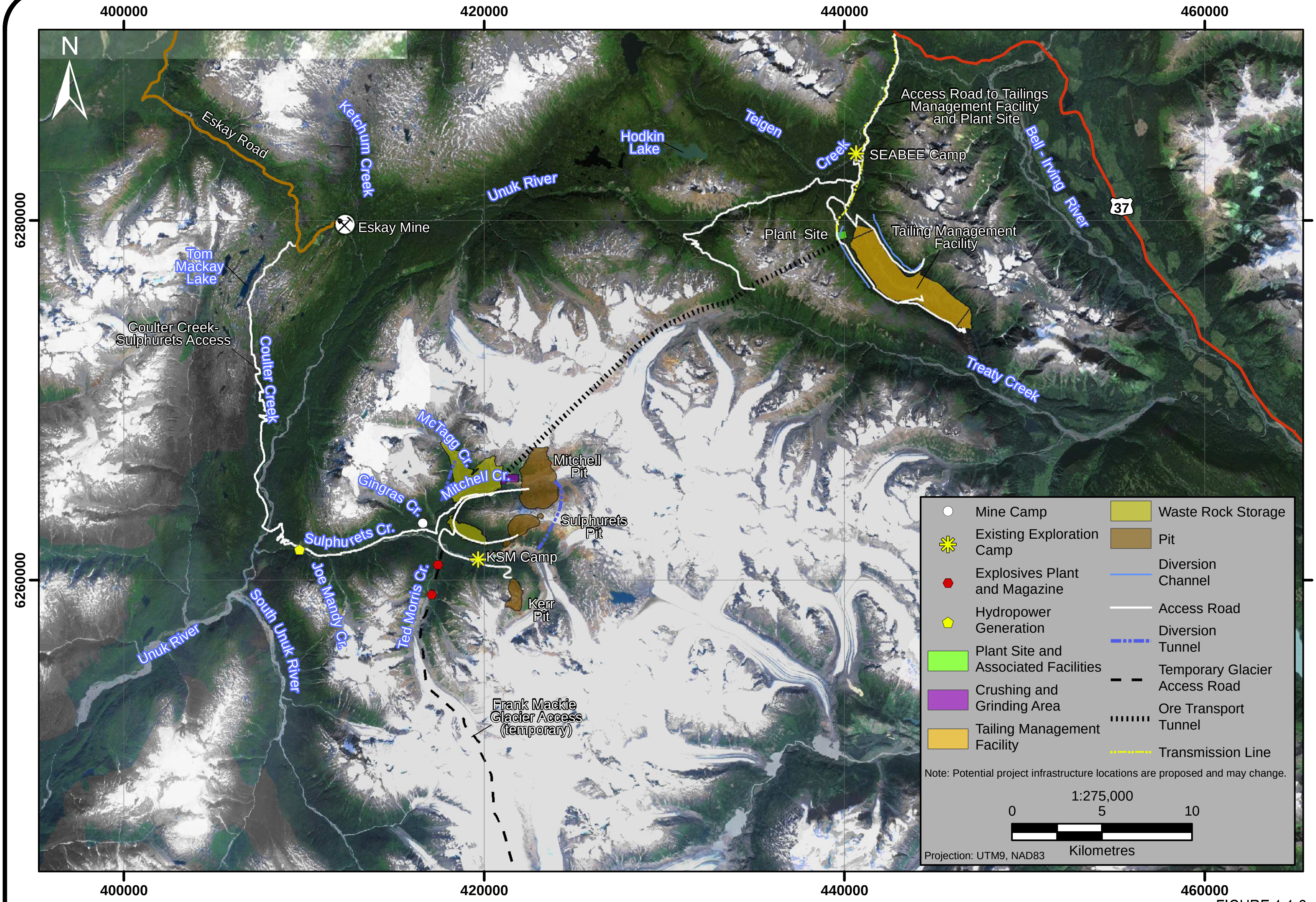

Note: Potential project infrastructure locations are proposed and may change.

Projection: UTM9, NAD83

FIGURE 1.1-2

KSM Project Layout

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1.2 OBJECTIVES

This study has used the available information and tested hydraulic data to develop a three-dimensional (3D) hydrogeological numerical model in the mining area where the proposed Open Pits, Rock Storage Facilities and Water Storage Facility are located, and in the TMF area where the proposed processing plant and Tailing Management Facility are located.

The objectives of the hydrogeological models are to characterize the regional and local groundwater flow regimes during pre-mining conditions and to use the models to predict the potential effects of the proposed mining activities on water quantity and quality, respectively, in the mining area and in the TMF area. The results will be used for calculation of mine water balance and for environmental impact assessment of the KSM Project.

1.3 METHODOLOGIES

The study boundaries for the models in the KSM mining area (412 km^2) and TMF area (392.9 km^2) are shown in Figure 1.3-1 and Figure 1.3-2, respectively. The boundaries are established to reflect only those watershed areas where effects of the proposed mining activities on water quantity and quality may occur.

The models were developed using the graphical user interface of the software Visual MODFLOW version 4.3, which is commercially available from Schlumberger Water Services (Schlumberger 2008). MODFLOW is an industry standard, three-dimensional, finite difference flow model developed by the United States Geological Survey (Harbaugh et al 2000). MODFLOW utilizes Surfact version 3.0 (HydroGeologic Inc. 1996) to simulate variably saturated flow, and MT3DMS version 5.2 (Zheng and Wang 1999) to simulate solute transport. The software packages have been tested thoroughly in simulations of groundwater flow and contaminant transport, and applied successfully for years in assessing the environmental impacts of mining activities on water quantity and quality.

The model uses an equivalent porous medium approach to simulate flow and solute transport through fractured bedrock. This approach is considered to be appropriate on a regional scale of flow and transport in highly heterogeneous fractured bedrock, and it has been successfully applied for decades in numerous simulations of groundwater flow in regional hydrogeological modelling for mining (e.g., Stone and Fontaine 1998; Jones 2002; Davis 2003; Larry et al. 2005; Wels et al. 2006; Lyford et al. 2007; Gleeson and Manning 2008; Water Management Consultants 2008; Wels and Findlater 2008; BGC 2009; Cho 2009; Rescan 2009).

The general methodologies and steps for developing the models for the KSM Project mining area and TMF area include:

- Collecting, reviewing and analyzing all relevant regional and local meteorological, topographic, geomorphologic, geologic, hydrologic, hydrogeologic information and observation data available for the Project.
- Developing a conceptual model for each area based on the available information and data to characterize the hydrogeologic system on the site.
- Building a baseline model for each area based on the conceptual model to represent the pre-mining condition on the site.
- Calibrating the baseline model for each area to the targets including observed hydraulic heads in monitoring wells and the measured baseflows in the creeks, and identifying the most and least sensitive input parameters for the calibration results.

  - Running the calibrated baseline model to simulate the steady-state hydrogeologic conditions and baseflows at the pre-mining conditions in each area.
  - Using the calibrated model to assess the potential impacts and residual effects (spatial and temporal) of the proposed mine plan on the hydrogeological system (i.e., Open Pit dewatering, pit refill, seepage from Water Storage Facility and Rock Storage Facilities, and seepage from Tailing Management Facility, and solute transport from the mine zones), and predict the changes to water quantity and quality.
  - Using the model results to identify the necessary water quality monitoring networks to meet the requirements of the regulatory compliance and environmental protection.

This report presents the details of these methodologies and the results of the comprehensive hydrogeological modelling for the KSM Project mining area and TMF area. The outputs from the modelling analysis will be used in the environmental effects assessment of groundwater and surface water quantity and quality due to the mine development.

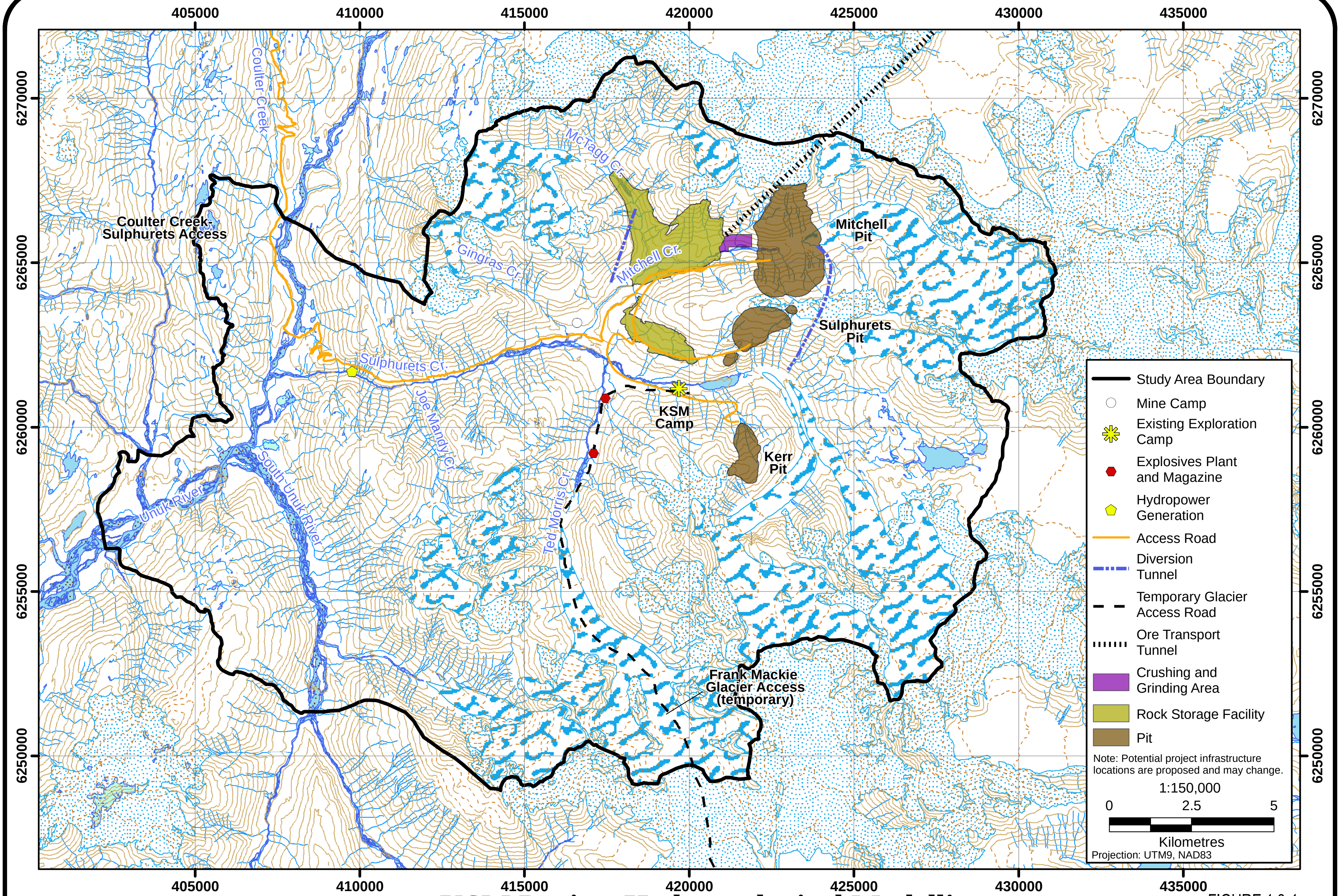

FIGURE 1.3-1

KSM Project Hydrogeological Modelling
Study Boundary - Mining Area

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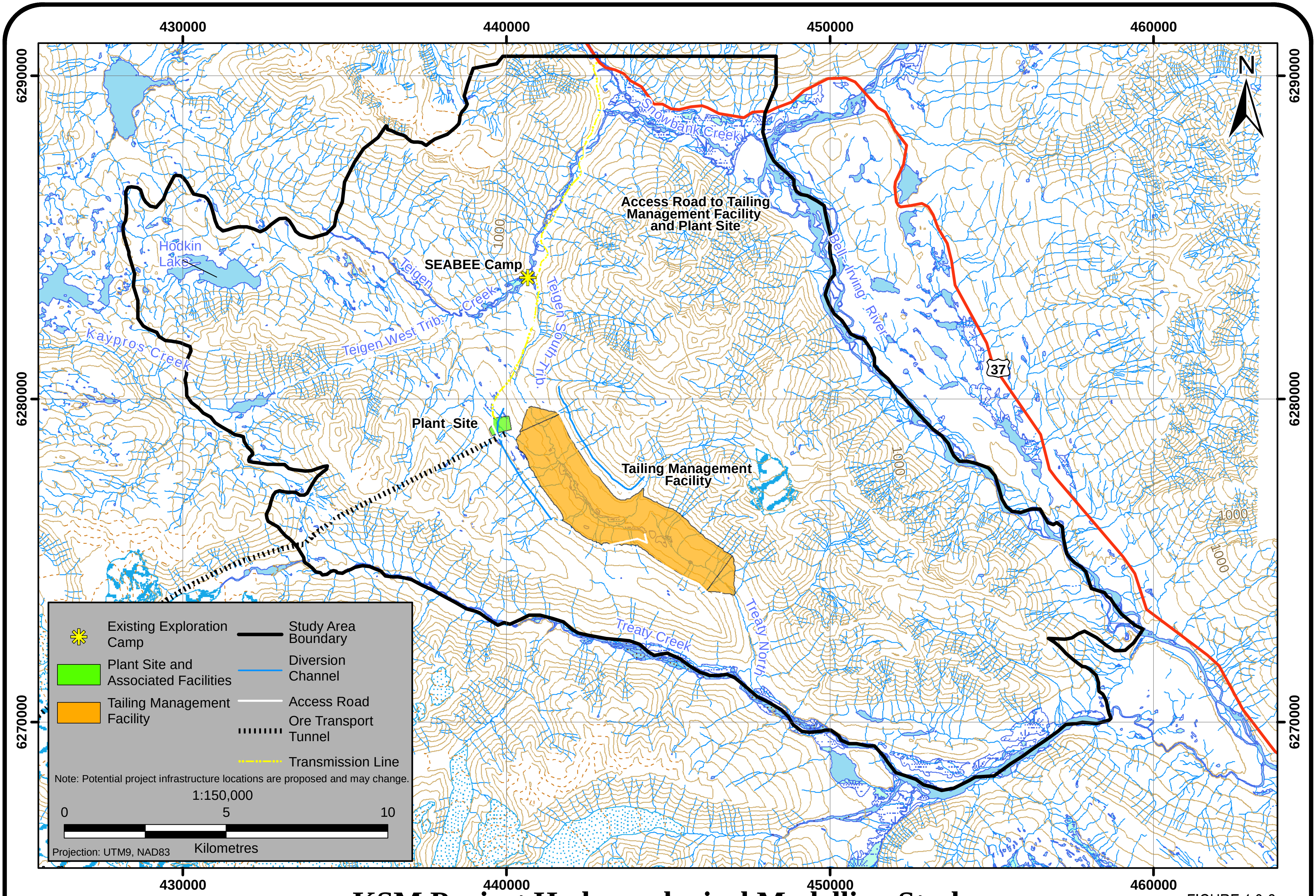

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KSM Project Hydrogeological Modelling Study Boundary - Tailing Management Area

FIGURE 1.3-2

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2. Hydrogeological Data

This chapter summarizes the regional and local hydrogeological information and test data available for the KSM project. These data have been used to develop a conceptual model of the hydrogeological system and for modelling the pre-mining baseline and predicting the impacts of the proposed mining plan in the mining area and the Tailing Management Facility (TMF) area.

Rescan's baseline reports (Rescan 2010a, 2010b, 2010c, Appendix 11-B of the EA Chapter 11) provide the basis for the groundwater model and include meteorology, hydrology and hydrogeology. Information and data from Wardrop, Klohn Crippen Berger and BGC reports, the British Columbia Geological Survey (2006) and previous geological studies such as Gibson (1990) and Lechner (2009) are also incorporated.

2.1 CLIMATE AND METEOROLOGY

The climatic and meteorological data available for the hydrogeological modelling of the KSM project is from the meteorological baseline studies conducted by Rescan from October 2007 to November 2009. The local meteorological data was collected from four automated weather stations installed in Mitchell Creek valley and Sulphurets Creek valley of the mining area and in Teigen Creek valley and Unuk-Teigen Creek valley of the TMF area, and twelve standalone tipping bucket rain gauges installed at different elevations, as well as manual snow survey at the KSM Project site (Table 2.1-1). The regional and long-term climate data was collected from the stations at Unuk River-Eskay Creek (elevation 887 masl), Bob Quinn AGS (elevation 610 masl), Wrangell Airport (elevation 13 masl) and Stewart Airport (elevation 7 masl) operated by Environment Canada within the region. The detail information of all the meteorological stations including the exact locations and the methodologies used in collecting the data can be found in Rescan's KSM Project 2009 Meteorology Baseline Report (Rescan 2010a).

Table 2.1-1. KSM Project Meteorology, Snow Course, and RainWise Tipping Bucket Rain Gauge Station Locations

	UTM Coordinates		Elevation
Station Name	**Easting**	**Northing**	**(masl)**
Meteorology Stations			
Mitchell Deposit	421615	6265311	830
Sulphurets Creek	419656	6261999	880
Teigen Creek	439012	6279647	1,085
Unuk-Teigen	432260	6277120	593
Snow Courses			
KSM-SC01	419650	6262000	880
KSM-SC02	439761	6279739	1,080
KSM-SC03	446487	6271533	636
RainWise Tipping Bucket Stations			
Teigen 1	443479	6278489	1567
Teigen 2	442738	6278770	1327
Teigen 3	438611	6278128	1388
Teigen 4	437912	6278029	1607

(continued)

Table 2.1-1. KSM Project Meteorology, Snow Course, and RainWise Tipping Bucket Rain Gauge Station Locations (completed)

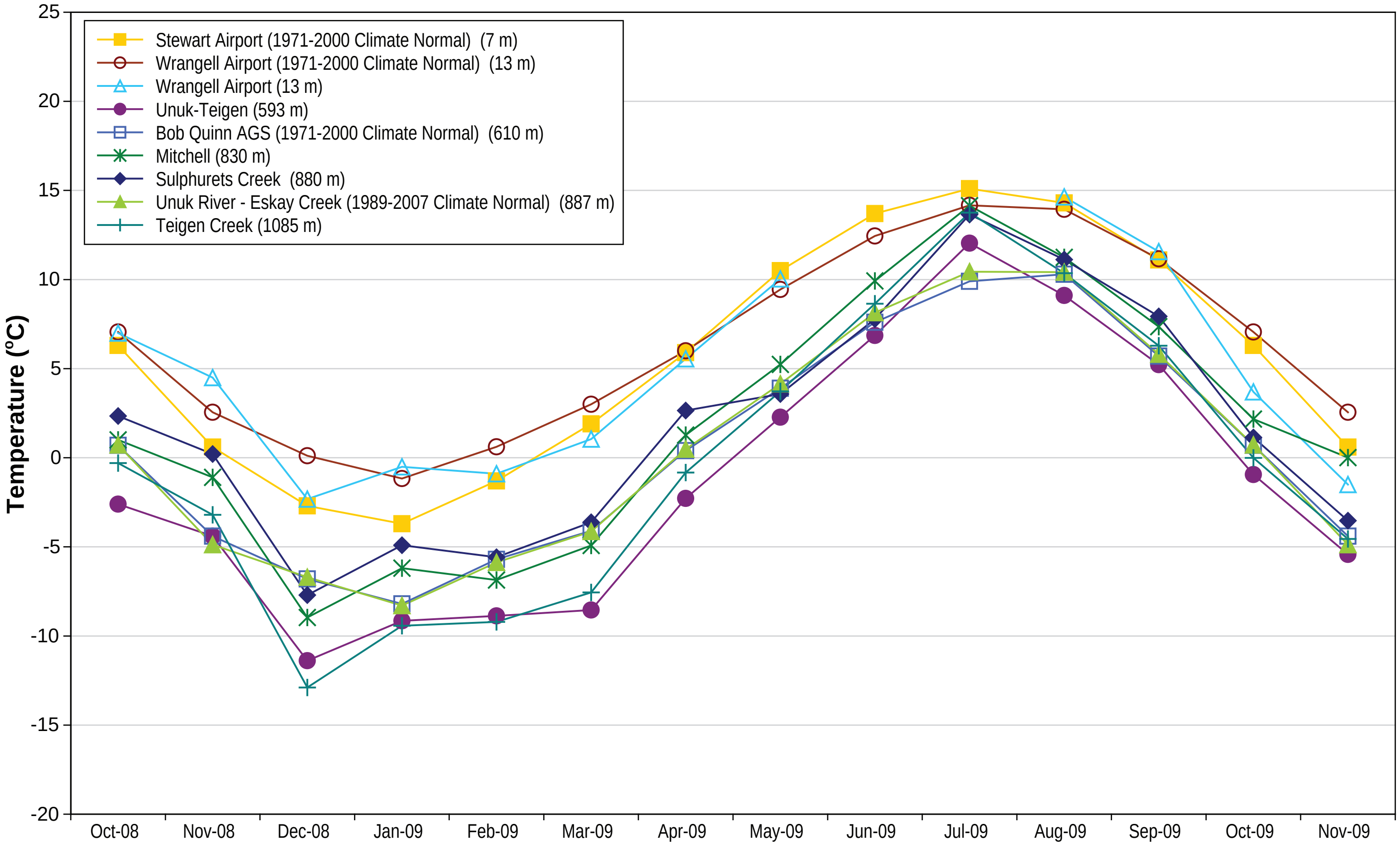
Station Name	UTM Coordinates		Elevation
	Easting	Northing	(masl)
RainWise Tipping Bucket Stations (cont'd)			
Unuk 1	434369	6278564	1745
Unuk 2	433095	6278585	1201
Unuk 3	431007	6281333	1687
Unuk 4	430279	6280306	1148
Mitchell 1	421461	6263821	1557
Mitchell 2	422065	6264791	1172
Mitchell 3	422412	6266630	1459
Mitchell 4	422509	6265983	1186

The information shows that the meteorology at the KSM Project site is complex due to the proximity to the Pacific Ocean, steep mountain topography and the presence of glaciers. The orographic influence of the mountain ranges on the Pacific and continental air masses results in highly variable air temperature and precipitation over the Project footprint and surrounding areas. Lower elevations in the vicinity of the proposed Project, such as near the lower Unuk River, typically exhibit mild, damp coastal conditions, while higher elevation areas have climate characteristics more typical of the interior of the Province of British Columbia (cooler with higher rates of snowfall).

Figure 2.1-1 summarizes the mean monthly air temperatures at the KSM meteorological stations for the period of October 2008 to November 2009. For 12 months of data, the mean monthly air temperatures at Mitchell Station (830 masl) ranged from a low of -9.0°C in December 2008 to a high of 14.1°C in July 2009 with an average of 1.8°C; the mean monthly air temperatures at Teigen Creek Station (1,085 masl) ranged from -12.9°C in December 2008 to 13.8°C in July 2009 with an average of -0.1°C; the mean monthly air temperatures at Unuk-Teigen Station (593 masl) ranged from a low of -11.4°C in December 2008 to a high of 12.0°C in July 2009 with an average of -1.0°C. The 12 months of record from the Teigen Creek Station show that the extreme maximum temperature was 29°C and the extreme minimum temperature was -27°C. Strong temperature gradients were observed in the valleys especially during winter season. Overall, the observation shows that the air temperatures at the KSM project site are generally low especially at high elevations where the glaciers exist.

The average annual precipitation for the KSM Project site is estimated to be 1,652 mm in the mining area with approximately 45% of its precipitation falling as snow between November and March, and 1,083 mm at the proposed Tailing Management Facility (TMF) with approximately 40% of it as snow between November and March. The maximum precipitation in both areas occurs in the fall due to frequent development of Pacific storms. The variations of the monthly precipitation are shown in Figure 2.1-2.

In addition, it was observed that the precipitation gradients at the KSM project site vary spatially depending on local topography (e.g., presence of orographic effects) and also temporally depending on individual storm events and annual weather patterns. Nonetheless, the observation data suggests that generally a positive increase in precipitation with elevation exists. This is similar to what has been observed within similar mountainous terrain: an orographic influence of increased precipitation with increased elevation (Loukas and Quick 1996).



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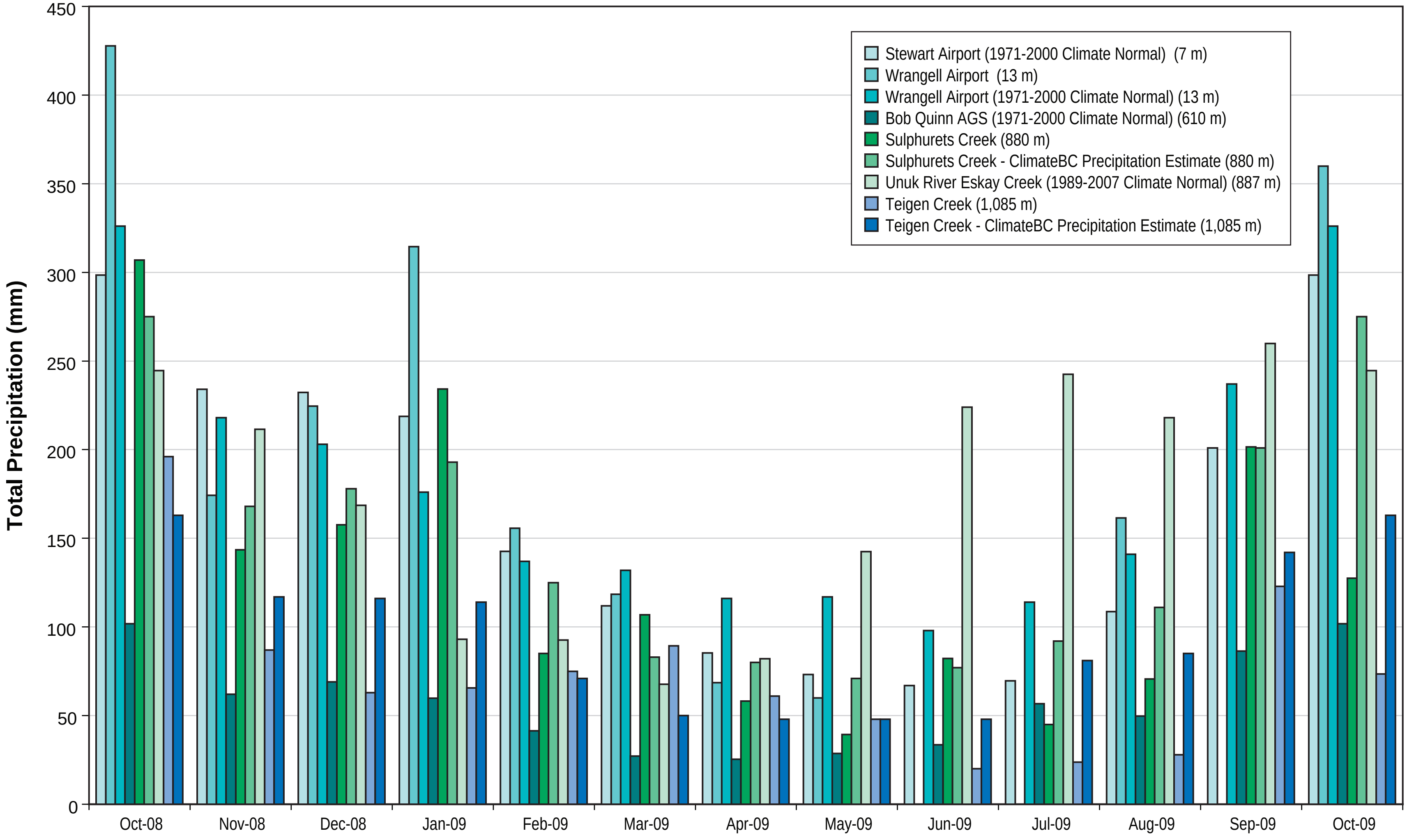
KSM Project Mean Monthly Air Temperature, October 2008 to November 2009

FIGURE 2.1-1

Rescan™



KSM Project Monthly Precipitation, October 2008 to October 2009

FIGURE 2.1-2

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2.2 TOPOGRAPHY AND GEOMORPHOLOGY

The KSM Project mining area (with the ore deposits and the proposed Open Pits, Water Storage Facility and Rock Storage Facilities) are located in the Mitchell, Sulphurets and McTagg creek valleys, which are the headwaters of the Sulphurets watershed draining into the Unuk River. The elevations in the mining area hydrogeological model study area (seeing Figure 1.3-1) ranges from 173.6 masl at Unuk River mouth to 2537.5 masl at the highest peaks near the Mitchell deposit. The elevations of the Mitchell valley floor ranges from about 480 masl to 1,070 masl, the Sulphurets valley floor ranges from 480 masl to 1,200 masl, and the McTagg valley floor ranges from 630 masl to 1,050 masl. The tree line lies at about 1,240 masl, below which a mature forest of mostly hemlock and balsam fir is present.

Glaciers cover the upper portions of the larger valleys from just below tree line and upwards (about 20.9% of the whole mining site model study area 412 km^2), but have been retreating for at least the last several decades. The valleys in the mining area are typical U-shaped glaciated valleys with steep slope valley walls and broad and gently sloping valley floors (Plate 2.2-1). The topography suggests that the valley floors where the major surface water bodies such as Mitchell Creek, Sulphurets Creek, McTagg Creek and Unuk River are located will be the dominant regional groundwater discharge zones.

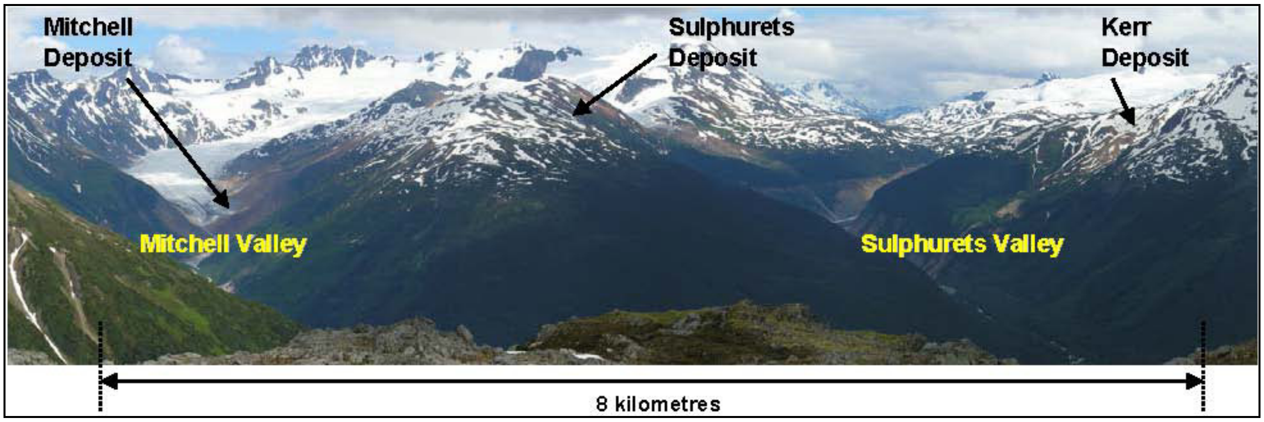


Plate 2.2-1. Mitchell and Sulphurets Valley in KSM Mining Area (view to East).

The Tailing Management Facility area of the KSM Project is located approximately 25 km northeast of the mining area and is situated in the U-shaped glaciated valleys of the Teigen South Tributary and the Treaty North Tributary (Plate 2.2-2), which are the headwaters of the Teigen Creek and Treaty Creek watersheds. Both the Teigen and Treaty Creeks discharge into the Bell-Irving River. The elevations within the TMF hydrogeological modelling study area (seeing Figure 1.3-2) vary from 483.5 masl in the downstream of Bell-Irving River to 2012.8 masl at the ridge peaks, and the valley floor elevations under the TMF vary from 840 m to 900 m. Glaciers and permanent snow packs exist only in some small spots on the ridge peaks (about 0.44% of the whole TMF model study area 392.9 km^2). The topographic features suggest that the Tailing Management Facility located on the bottom of the valleys will be the regional groundwater discharge zone.

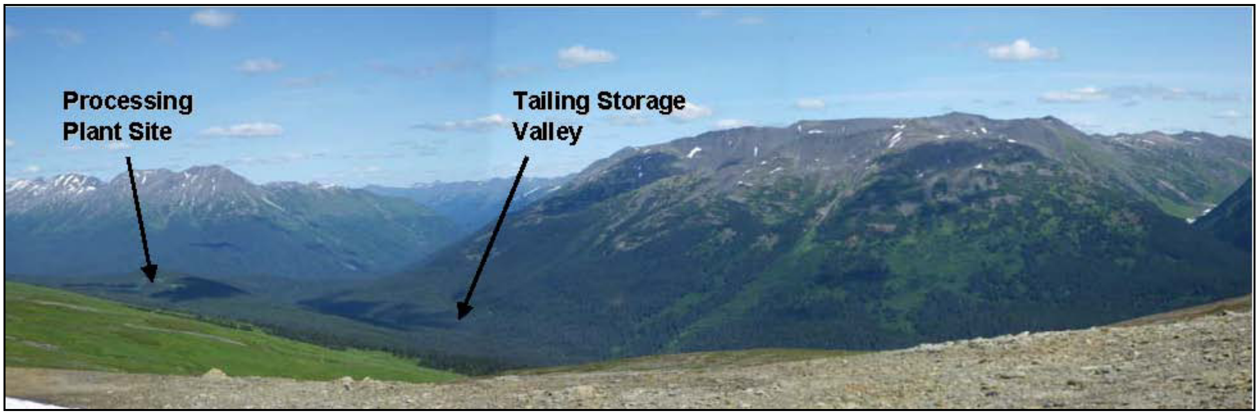


Plate 2.2-2. Teigen South Tributary Valley in KSM Tailing Management Area (view to North).

2.3 GEOLOGY AND STRUCTURE

The types and distribution of the surficial and subsurface geological materials and structures in the KSM project area, including overburden, bedrock and faults, were determined from the above-referred regional and local geological reports, maps, exploration boreholes, groundwater monitoring wells, geophysical survey, as well as interpretation of aerial photography and remote sensing. Figures 2.3-1 and 2.3-2 show the locations of monitoring wells drilled for hydrogeologic characterization in the mining area and the TMF area. Details of the large number of mineral exploration boreholes drilled in the ore deposits of the mining area can be found in the KSM Preliminary Economic Assessment Report (Wardrop 2008, 2009). Overall, the information available shows that there is a substantial difference in bedrock geology between the KSM Project mining area and TMF area.

2.3.1 Mining Area

2.3.1.1 Overburden

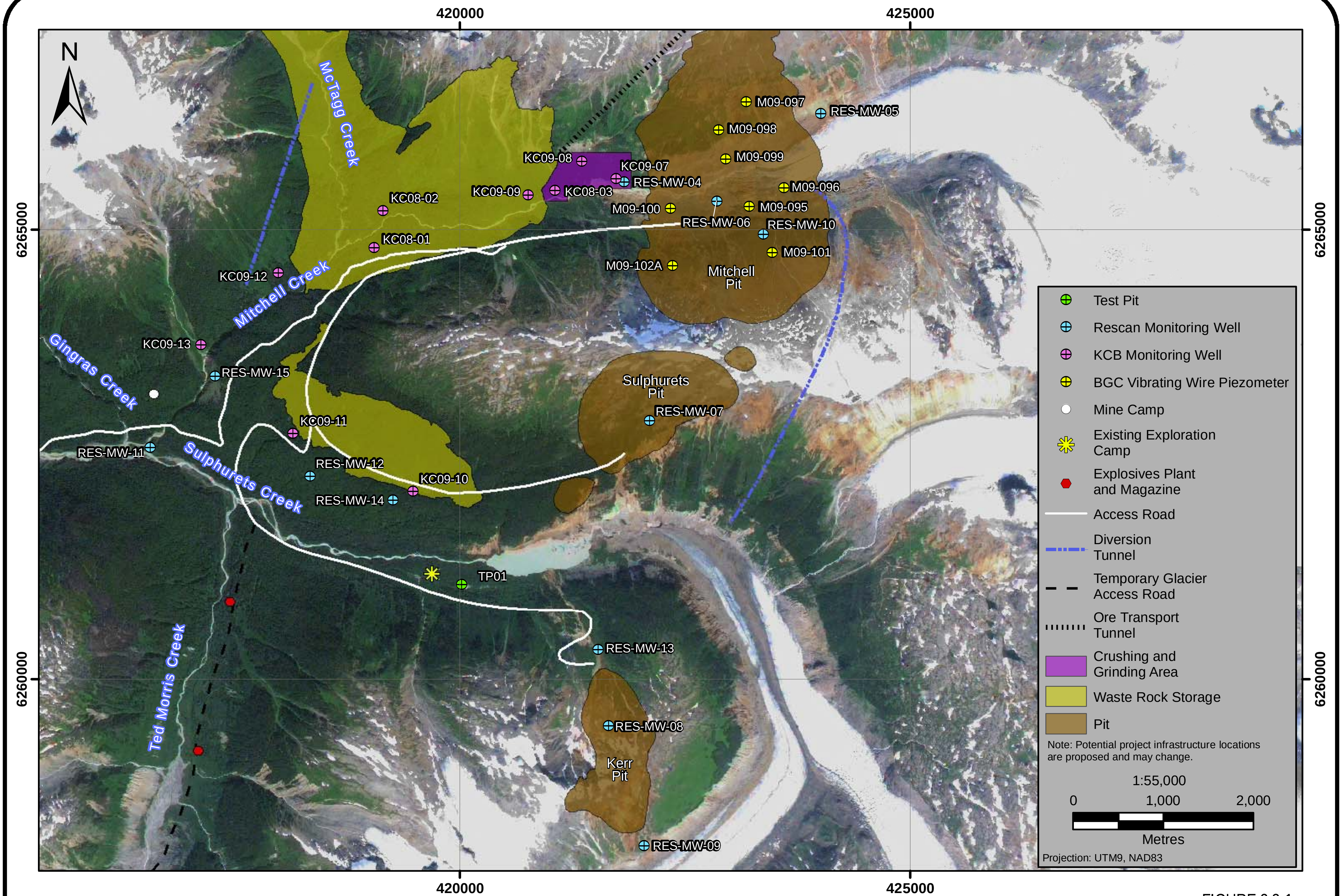
Table 2.3-1 lists the overburden thickness and material types identified within all the boreholes that Rescan, KCBL and BGC drilled in the KSM mining area (Rescan 2010c, Appendix 11-B of the EA Chapter 11). The borehole logs show that the overburden varies from zero (in BGC's boreholes located in the proposed Mitchell Pit area) to 94.6 m (in KCBL's borehole KC09-09 located in the Mitchell valley bottom). The overburden is generally thin or very thin on the high elevations and steep slopes, and becomes thicker at lower elevations and the valley bottoms. The overburden materials consist of glacial till, colluvium and fluvial sediments, but glacial sediments predominate.

Figure 2.3-3 shows the overburden and surficial geology map developed by KCBL with the isopleths of overburden thickness in the mining area (including Mitchell, Sulphurets and McTagg valleys) based on the borehole logs and geophysical survey. This map shows that overburden in the mining area with thickness greater than 5 m is mainly distributed on the bottom of the Mitchell, Sulphurets and McTagg valleys. The maximum depth of overburden is estimated to be about 140 m in the Mitchell valley, 40 m in the Sulphurets valley (between Sulphurets Lake and the confluence of Sulphurets and Mitchell Creeks), and 10 m in the McTagg valley.

gis no. KSM-09-034

Job No. 0868-007-06

April 5, 2010



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KSM Project Groundwater Monitoring Well Locations - Mining Area

FIGURE 2.3-1

Rescan™

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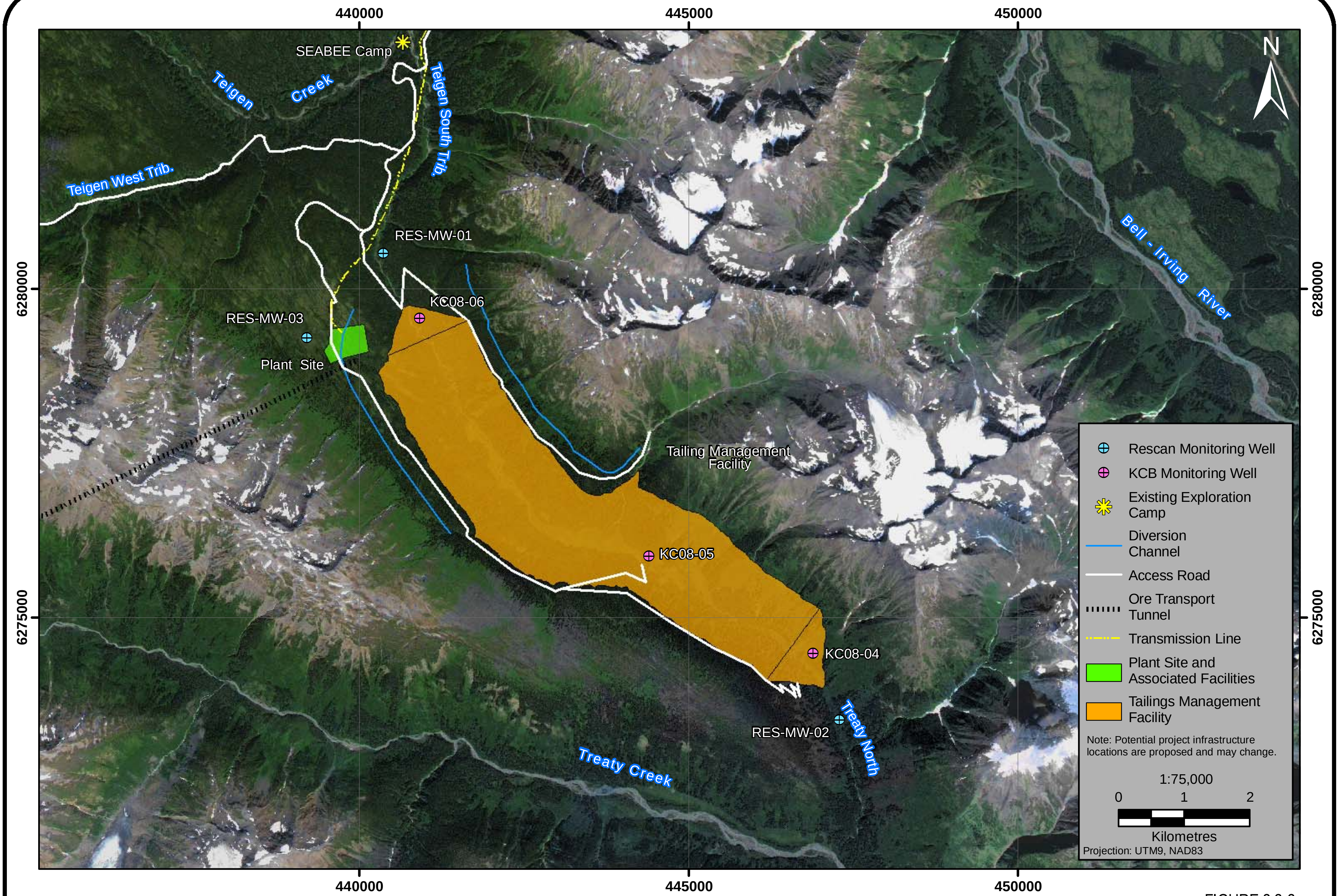

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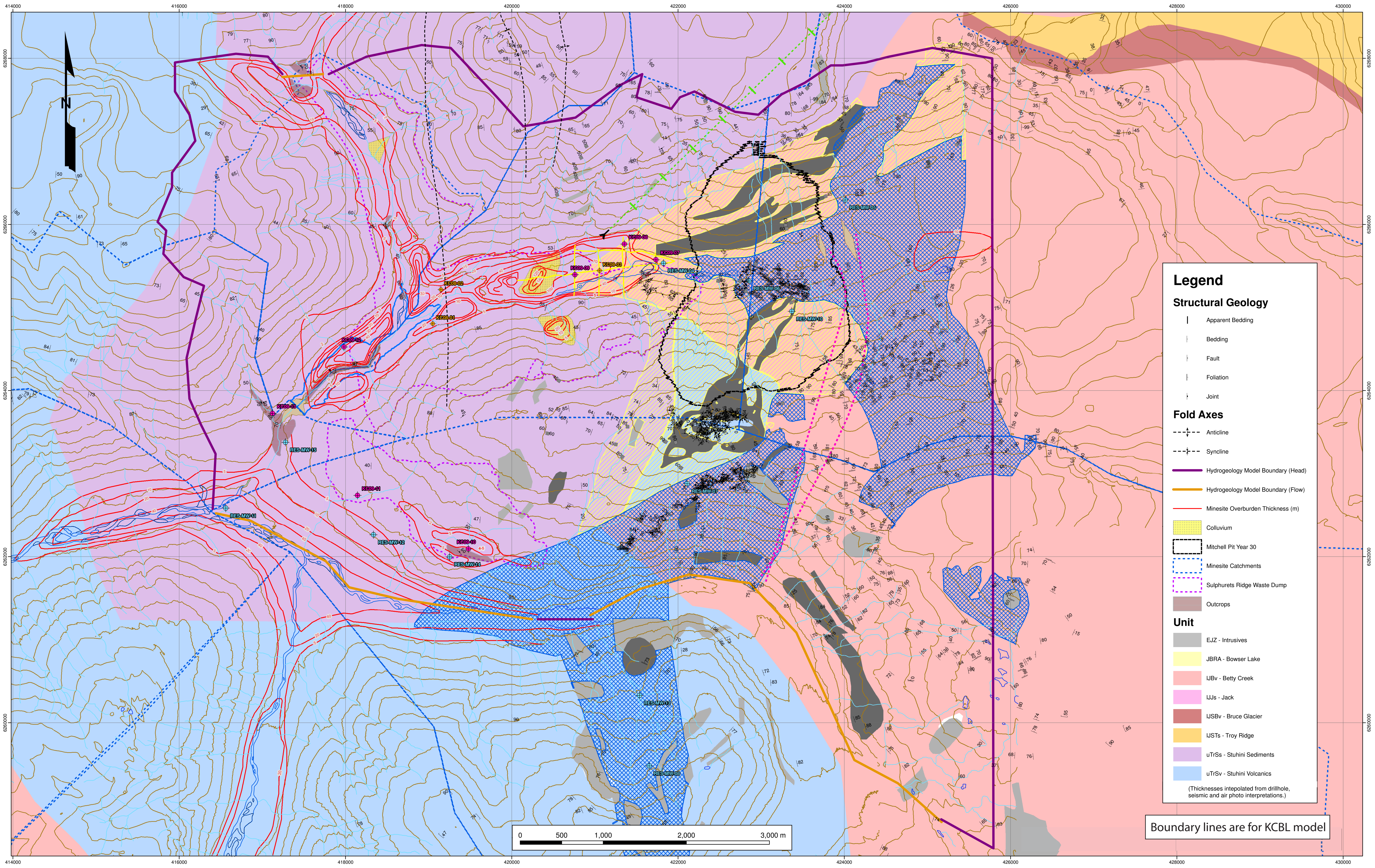
KSM Project Groundwater Monitoring Well Locations - TMF Area

FIGURE 2.3-2

Rescan™



Source: *Klohn Crippen Berger*

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KSM Project Surficial Geology and Overburden – Mining Area (KCBL)

FIGURE 2.3-3

Rescan™

Table 2.3-1. Overburden Thickness and Material Types in Boreholes – Mining Area

Well Name	Depth (mbgs)	Composition	Location
Rescan wells			
RES-MW-04A	2.68	Colluvium	Mitchell Deposit Slope
RES-MW-04B	2.68	Colluvium	Mitchell Deposit Slope
RES-MW-05A	0.75	Colluvium	Mitchell Deposit Slope
RES-MW-05B	0.75	Colluvium	Mitchell Deposit Slope
RES-MW-06A	3.95	Colluvium	Mitchell Deposit Slope
RES-MW-06B	3.95	Colluvium	Mitchell Deposit Slope
RES-MW-07A	3.30	Colluvium	Sulphurets Deposit Slope
RES-MW-07B	3.30	Colluvium	Sulphurets Deposit Slope
RES-MW-08A	0.10	Colluvium	Kerr Deposit Slope
RES-MW-09A	0.35	Colluvium	Kerr Deposit Slope
RES-MW-09B	0.35	Colluvium	Kerr Deposit Slope
RES-MW-10A	24.01	Fluvial	Mitchell Deposit Platform
RES-MW-10B	24.01	Fluvial	Mitchell Deposit Platform
RES-MW-11A	38.54	Fluvial dominated, with glacial till	Confluence of Mitchell and Sulphurets Creeks, Valley Base
RES-MW-11B	16.62	Fluvial dominated, with glacial till	Confluence of Mitchell and Sulphurets Creeks, Valley Base
RES-MW-12A	5.12	Colluvium	Sulphurets Valley Slope
RES-MW-12B	5.12	Colluvium	Sulphurets Valley Slope
RES-MW-13A	59.70	Fluvial	Kerr Deposit Slope
RES-MW-13B	27.70	Fluvial	Kerr Deposit Slope
RES-MW-14A	9.39	Colluvium	Sulphurets Valley Slope
RES-MW-14B	9.39	Colluvium	Sulphurets Valley Slope
RES-MW-15A	2.50	Colluvium	Mitchell Valley Slope
RES-MW-15B	2.50	Colluvium	Mitchell Valley Slope
BGC wells			
M-09-095	0.00		Mitchell Deposit Slope
M-09-096	0.00		Mitchell Deposit Slope
M-09-097	0.00		Mitchell Deposit Slope
M-09-098	0.00		Mitchell Deposit Slope
M-09-099	0.00		Mitchell Deposit Slope
M-09-100	0.00		Mitchell Deposit Slope
M-09-101	0.00		Mitchell Deposit Slope
M-09-102a	0.00		Mitchell Deposit Slope
KCBL wells			
KC08-01	26.80	Moraine and Till	Mitchell Valley Base
KC08-02	21.60	Colluvium and Till	Mitchell Valley Base
KC08-03	75.40	Till	Mitchell Valley Base
KC09-07	3.00	Moraine	Mitchell Valley Base
KC09-08	28.40	Moraine	Mitchell Valley Base
KC09-09	93.57	Moraine, Colluvium and Till	Mitchell Valley Base
KC09-10	4.75	Overburden	Sulphurets Valley Slope
KC09-11	1.20	Overburden	Sulphurets Valley Slope
KC09-12	33.00	Moraine and Till	Mitchell Valley Base
KC09-13	6.35	Moraine and Till	Mitchell Valley Base

Figure 2.3-4a and 2.3-4b show the overburden classification made by Rescan in KSM Unuk River hydrogeology assessment area (including the downstream of Sulphurets Creek, Unuk River and South Unuk River valleys) on the basis of interpretation of terrain map, LiDAR map, TRIM map, slope gradient classification, satellite image and aerial photography. The overburden deposits downstream of the Sulphurets valley base are estimated to be less than 5 m thick except at the mouth where the creek empties in Unuk River. The depth of overburden in the Unuk River and South Unuk River area is not known, however fluvial and glaciofluvial sediments greater than 5 m thick are expected in these areas.

2.3.1.2 Bedrock Geology

The regional bedrock geology in the mining area is presented in Figure 2.3-5 and Table 2.3-2. The KSM Project lies within the fault-bounded terrain of “Stikinia” in the Intermontane Belt, located between the Coast Mountain intrusives and the Foreland Belt continental margin sedimentary prisms (Rocky Mountains). Early Jurassic sub-volcanic intrusive hydrothermal systems are abundant in the region and are important sources of base and precious metals (Wardrop 2008).

Similar to the hydrothermal systems hosting other gold-copper porphyry in the surrounding area such as Galore Creek, Red Chris and Kemess, the mineral deposits at the KSM Project are associated with a large hydrothermal alteration system associated with late Jurassic monzonite porphyry intrusions into Triassic and Jurassic volcaniclastics. Upper Triassic rocks include marine sedimentary and intermediate volcanic rocks of the Stuhini Group. Intermediate volcanic rocks with pillowed and breccia textures are sandwiched between turbiditic argillite and sandstone. Overlying the Stuhini Group is the Jack Formation comprised of fossiliferous and limey mudstones and sandstones. The base is marked by a granodiorite and limestone conglomerate. Overlying the Jackman Formation is the Hazelton Group, dominated by andesitic flows and breccias deposited in a volcanic chain with high paleogeographic relief. Being closely associated with the Eksay Creek deposit, felsic welded tuff horizons of the Mount Diworth Formation are a distinct and important stratigraphic marker in the Hazelton Group. To the east of the KSM Project, Late Jurassic and Cretaceous volcanic back-arc basins were filled with sedimentary rocks of the Bowser Group. Early Jurassic intrusions such as dikes, sills and plugs of diorite, monzodiorite, syenite and granite collectively referred to as the “Mitchell Intrusions” are also found in the area (SRK 2007; Wardrop 2008).

More specifically, the Mitchell deposit consists of a foliated, schistose zone of intensely altered sulphide-bearing rocks. The concentrations of metals in the Mitchell deposit is low and the distribution is finely disseminated and pervasively dispersed distinguishing the Mitchell deposit from the Sulphurets and Kerr deposits where there are more abrupt breaks in mineralization and grade due faulting that resulted in juxtaposition of weak and moderate mineralized domains. The Mitchell deposit is dominated by andesitic volcanic rocks from the Hazelton group and dioritic to gabbroic intrusive rocks. The minerals encountered in the Mitchell deposit are hosted in feldspar, quartz porphyritic granite. Copper mineralization occurs as disseminated and fracture filling chalcopyrite, and with quartz-magnetite veinlets. Phyllic and potassic alteration as well as stockworks were observed. Deformed quartz veins are seen in the sericite-chlorite altered rock. Calcite veinlets are present and likely related to regional deformation (Savell and Huard 2005; Wardrop 2008). The Kerr deposit (south) is characterized by host rock from the Stuhini Group: Triassic sedimentary and volcaniclastic rocks with intrusions of Early Jurassic monzonite. The core of the zone is described as composed of “sericite schist” and “chlorite schist” (Wardrop 2008). The rocks encountered in this formation exhibit gossanous, limonitic weathering typical of pyriterich, phyllic and silicic alteration. Crackled quartz stockwork, anhydrite veining and chlorite alteration are also present. Common rock forming minerals of monzonite are orthoclase, plagioclase, hornblende, augite and biotite.

gis no. KSM-10-051 Job No. 0868-007-06 March 31 2010

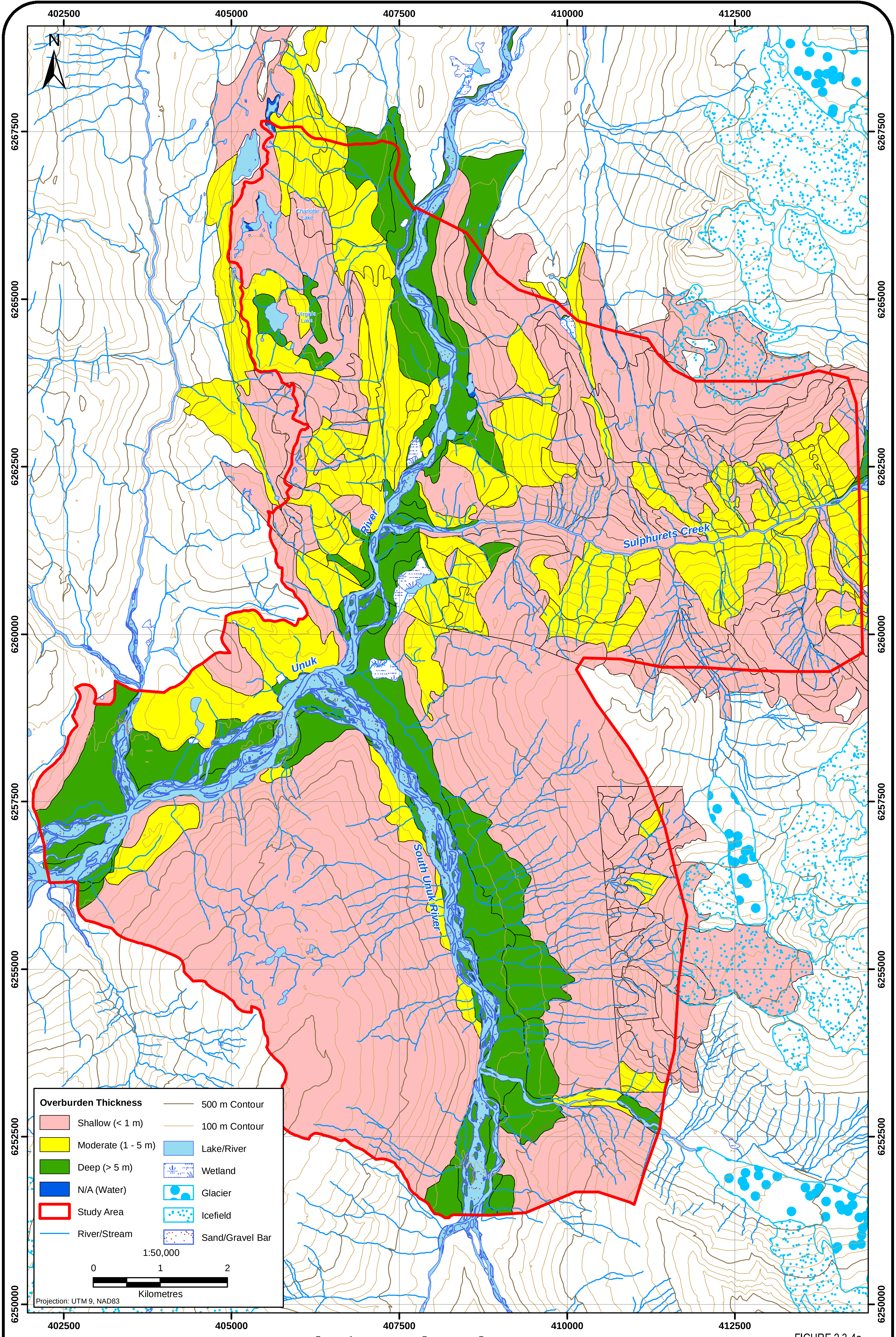

FIGURE 2.3-4a

KSM Unuk River Hydrogeology Assessment Area - Overburden Thickness Class

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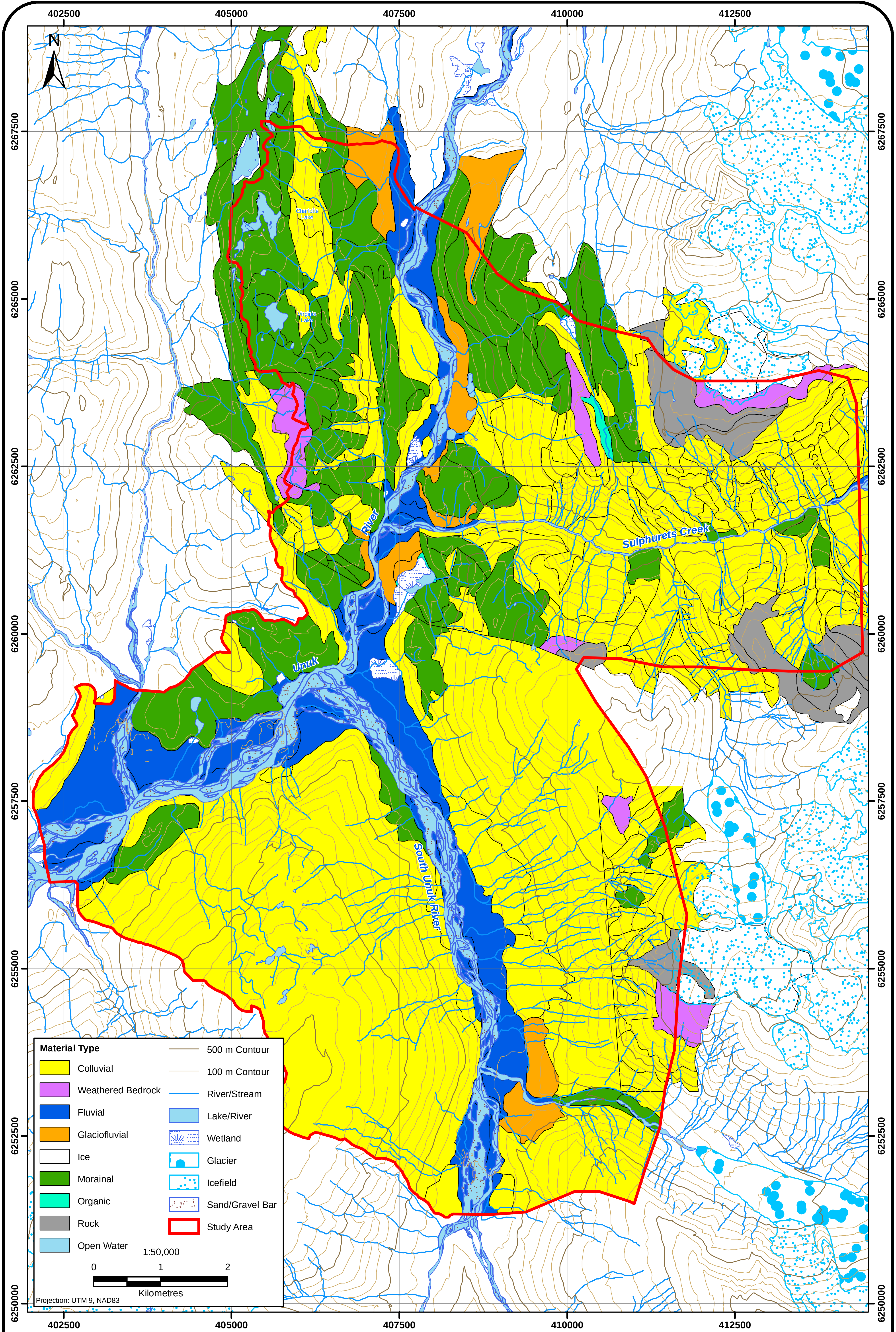

KSM Unuk River Hydrogeology Assessment Area – Overburden Material Type

FIGURE 2.3-4b

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Job No. 0868-007-06

April 1, 2010

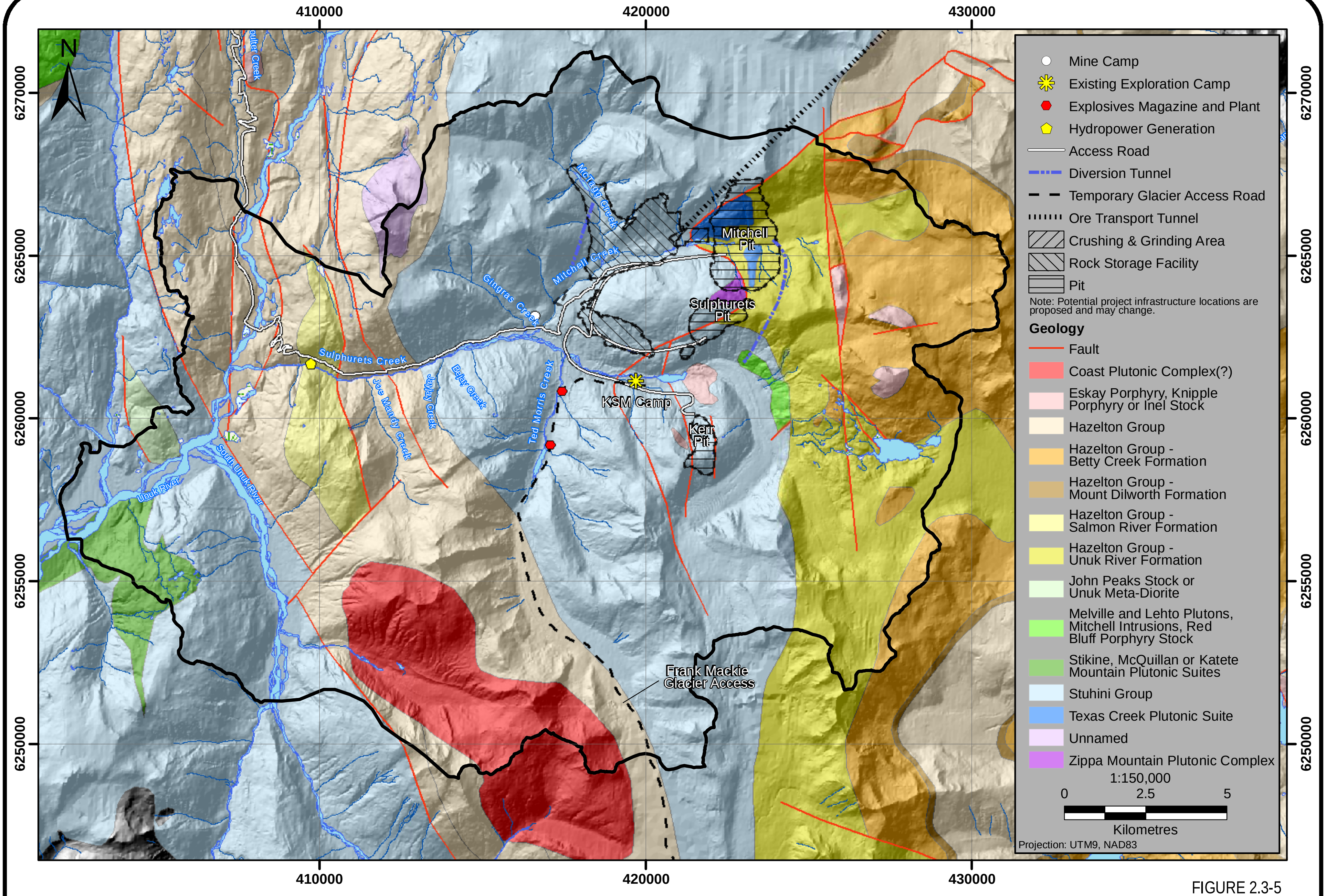

FIGURE 2.3-5

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KSM Project Bedrock Geology - Mining Area

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Table 2.3-2. Description of Bedrock Formations - Mining Area

Formation Name	Era	Period	Age	Rock Type	Rock Class	Description
Bowser Lake Group - Ritchie-Alger Assemblage	Mesozoic	Jurassic	Middle to Upper Jurassic	Sandstone, sitstone, rare conglomerate	Sedimentary rocks	Sandstone, sitstone, rare conglomerate
Coast Plutonic Complex	Cenozoic	Paleogene	Eocene	Quartz monzonitic intrusive rocks	Intrusive rocks	Quartz monzonite, local migmatite - granodiorite to quartz monzonite, locally K-feldspar phyric, 45 +/- 2 Ma (Ar/Ar (biotite) age) -- quartz monzonite - biotite quartz monzonite to granodiorite with sphene, +/- hornblende, medium to coarse
Eskay Porphyry, Knipple Porphyry or Inel Stock	Mesozoic	Jurassic	Early Jurassic	Feldspar porphyritic intrusive rocks	Intrusive rocks	Leucocratic porphyry plugs adjacent to the Sustut River - grey-green, plagioclase - K-feldspar - hornblende - biotite porphyry with up to 50% phenocrysts. A hypabyssal stock of dacitic or granitic composition, 186 +/- 2 Ma (U/Pb zircon age)
Hazelton Group	Mesozoic	Jurassic	Middle Jurassic	Basaltic volcanic rocks	Volcanic rocks	Mainly pillow lava, pillow breccia, minor mudstone
Hazelton Group - Betty Creek Formation	Mesozoic	Jurassic	Lower Jurassic	Volcaniclastic rocks	Volcanic rocks	Heterogeneous, purple, maroon, grey and green, massive to bedded pyroclastic and sedimentary rocks (Sinemurian to Pliensbachian).
Hazelton Group - Mount Dilworth Formation	Mesozoic	Jurassic	Middle Jurassic to Upper Jurassic	Calc-alkaline volcanic rocks	Volcanic rocks	Light-weathering, intermediate to felsic pyroclastics, including dust, ash, crystal, lithic, lapilli and welded tuff, locally pyritic and gossanous (Toarcian to Aalenian).
Hazelton Group - Salmon River Formation	Mesozoic	Jurassic	Middle Jurassic to Upper Jurassic	Basaltic volcanic rocks	Volcanic rocks	Basaltic to andesitic pillow lavas, pillow breccias and hyaloclastites, dark to light grey clasts in a calcareous, silty matrix, includes siltstone interbeds (Toarcian to Aalenian).
Hazelton Group - Unuk River Formation	Mesozoic	Jurassic	Lower Jurassic	Andesitic volcanic rocks	Volcanic rocks	Green and grey intermediate tuffs and flows, feldspar and hornblende phyric; local thick interbed of fine-granied sedimentary rocks; minor conglomerate and limestone (Hettangian to Sinemurian)
John Peaks Stock or Unuk Meta-Diorite	Mesozoic	Triassic to Jurassic	Triassic to Jurassic	Dioritic intrusive rocks	Intrusive rocks	Dark green, mesocratic to melanocratic, medium to coarse-grained hornblende diorite, with pervasive propylitic alteration or massive, foliated to gneissic, mesocratic to melanocratic, fine to coarse-grained, hornblende diorite to gabbro

(continued)

Table 2.3-2. Description of Bedrock Formations - Mining Area (completed)

Formation Name	Era	Period	Age	Rock Type	Rock Class	Description
Melville and Lehto Plutons, Mitchell Intrusions, Red Bluff Porphyry Stock	Mesozoic	Jurassic	Early Jurassic	Monzodioritic to gabbroic intrusive rocks	Intrusive rocks	Monzodiorite, Fleet Peak Pluton -- light to dark grey, locally pink, medium-grained, equigranular, biotite-hornblende diorite, monzodiorite and monzonite -- coarse K-feldspar +/- hornblende porphyritic monzodiorite, equigranular monzonite and
Stikine, McQuillan or Katete Mountain Plutonic Suites	Mesozoic	Triassic	Late Triassic	Dioritic intrusive rocks	Intrusive rocks	Massive to gneissic, fine to medium-grained, hornblende-biotite diorite, quartz diorite. Radiometric ages 220-230 Ma. - light grey, medium-grained, equigranular, biotite-hornblende diorite to monzodiorite, 226 +5/- 2 Ma U/Pb zircon age.
Stuhini Group	Mesozoic	Triassic	Upper Triassic	Marine sedimentary and volcanic rocks	Sedimentary rocks	Brown, black and grey, mixed sedimentary rocks interbedded with medium to dark green, mafic to intermediate volcanic and volcaniclastic rocks, felsic tuffs, limestone lenses (Carnian to Norian).
Texas Creek Plutonic Suite	Mesozoic	Jurassic	Early Jurassic	Quartz dioritic intrusive rocks	Intrusive rocks	Fine to coarse-grained quartz diorite, monzodiorite, quartz monzonite, syn to post-volcanic intrusions. Equigranular to porphyritictic, hypabyssal equivalents of Hazelton Group
Unnamed	Mesozoic	Triassic to Jurassic	Triassic to Jurassic	Intrusive rocks, undivided	Intrusive rocks	Granitoid intrusions of probable Triassic to Jurassic age
Zippa Mountain Plutonic Complex	Mesozoic	Jurassic	Early Jurassic	Dioritic intrusive rocks	Intrusive rocks	Gabbro-syenite-quartz monzonite-porphyry complex, ca. 200-211 Ma U/Pb zircon age, K/Ar biotite, hornblende ages range from 76.6 +/- 1.3 to 167.2 +/- 3.8 Ma

Two large thrust faults (Mitchell Thrust Fault and Sulphurets Thrust Fault) are present in the mining area where the proposed Mitchell and Sulphurets Open Pits and the Rock Storage Facilities are located. Beneath these low-angle thrust faults, there are a number of sills and plugs of coarse-grained feldspar porphyritic monzonite to low-silica granite that intruded sedimentary and volcanic rocks creating siliceous hornfels (Wardrop 2008). The thrust faults have gentle dips (<30°), and the bedrocks below the thrust faults are more fractured than those above the thrust fault. Figure 2.3-6 and 2.3-7 show the plan view of the Mitchell deposit geology and a cross-section illustrating the gently dipping Mitchell Thrust Fault. Plate 2.3-1 shows the Mitchell valley with the traces of the two faults and the outline of the proposed Mitchell Open Pit. Plate 2.3-2 shows the surface exposure of the Mitchell Thrust Fault on the north and south sides of the valley.

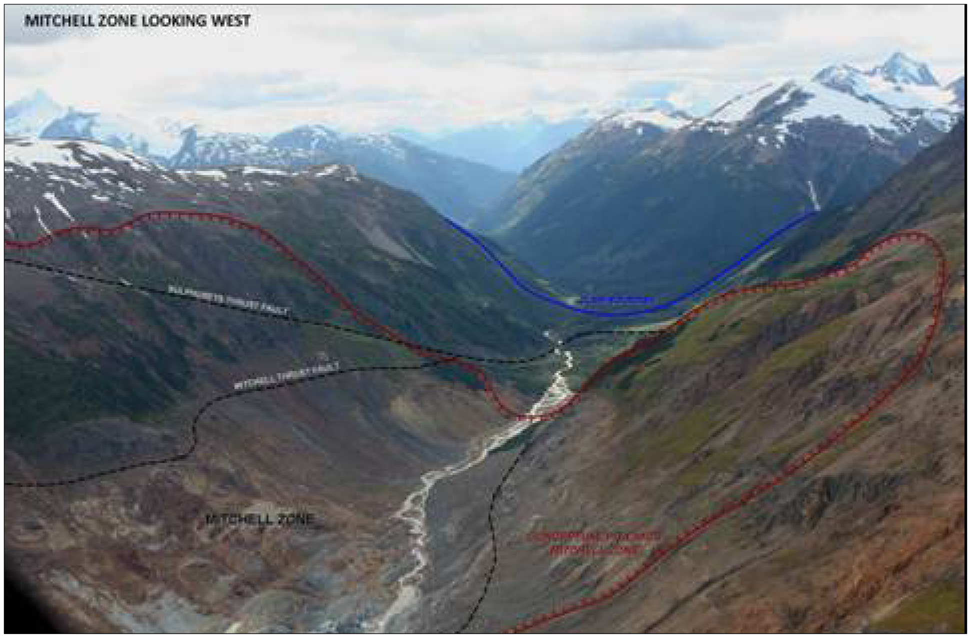

Plate 2.3-1. Surface traces of Mitchell and Sulphurets Thrust Faults in Mitchell Valley.

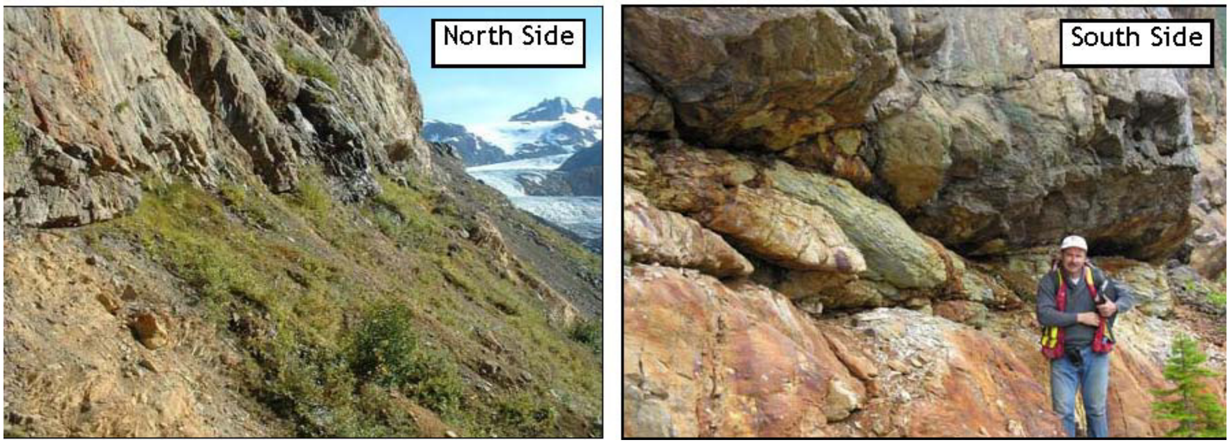

Plate 2.3-2. Surface exposure of Mitchell Thrust Fault on North and South Sides of Mitchell Valley.

Outside the mining zones, there are several large north-south striking faults as shown in the regional geological map (i.e., downstream of Sulphurets Creek, and Unuk River and South Unuk River watersheds). No information is available so far for these faults, such as their dips and filling materials.

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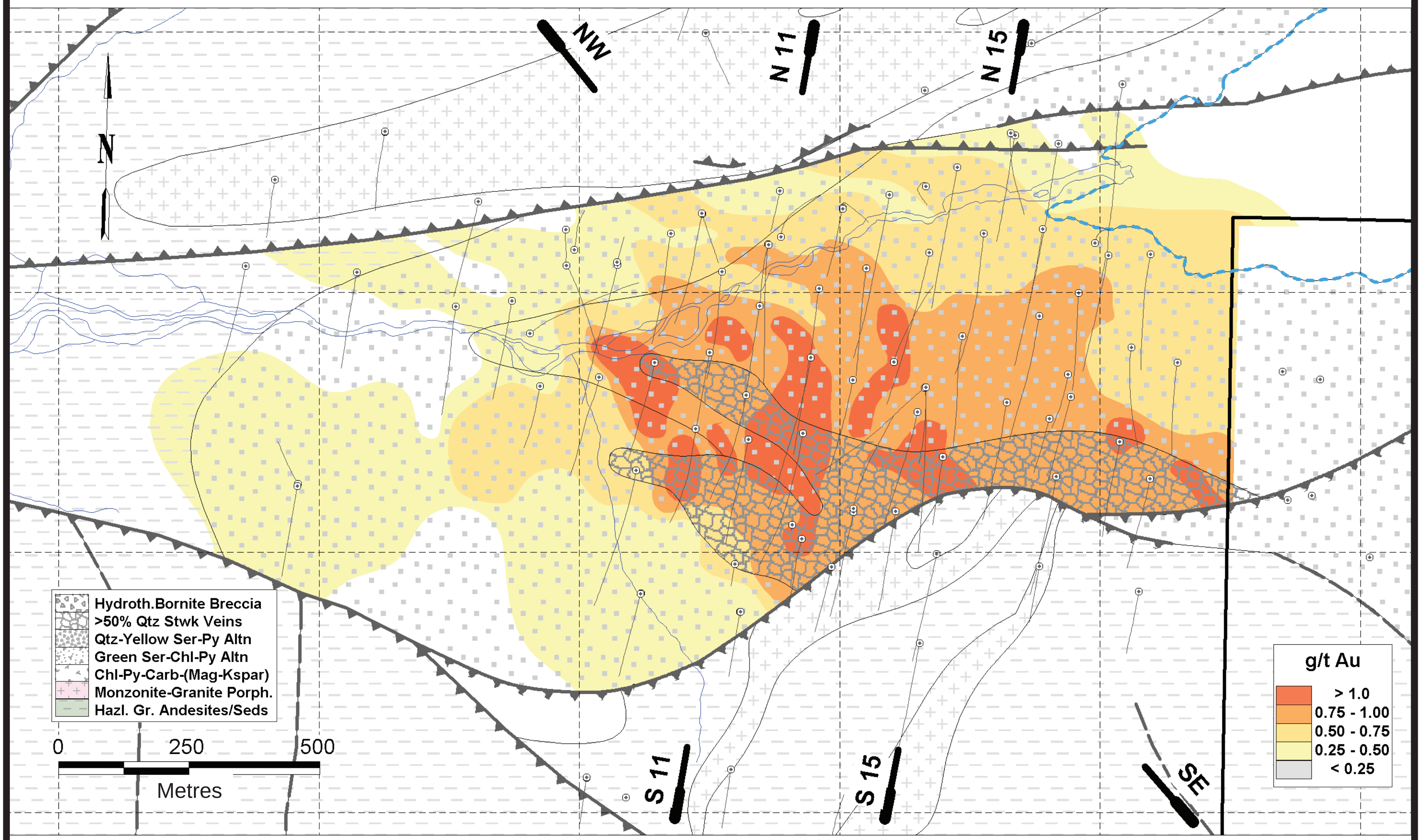

FIGURE 2.3-6

KSM Project Mitchell Deposit Geology (Plan View)

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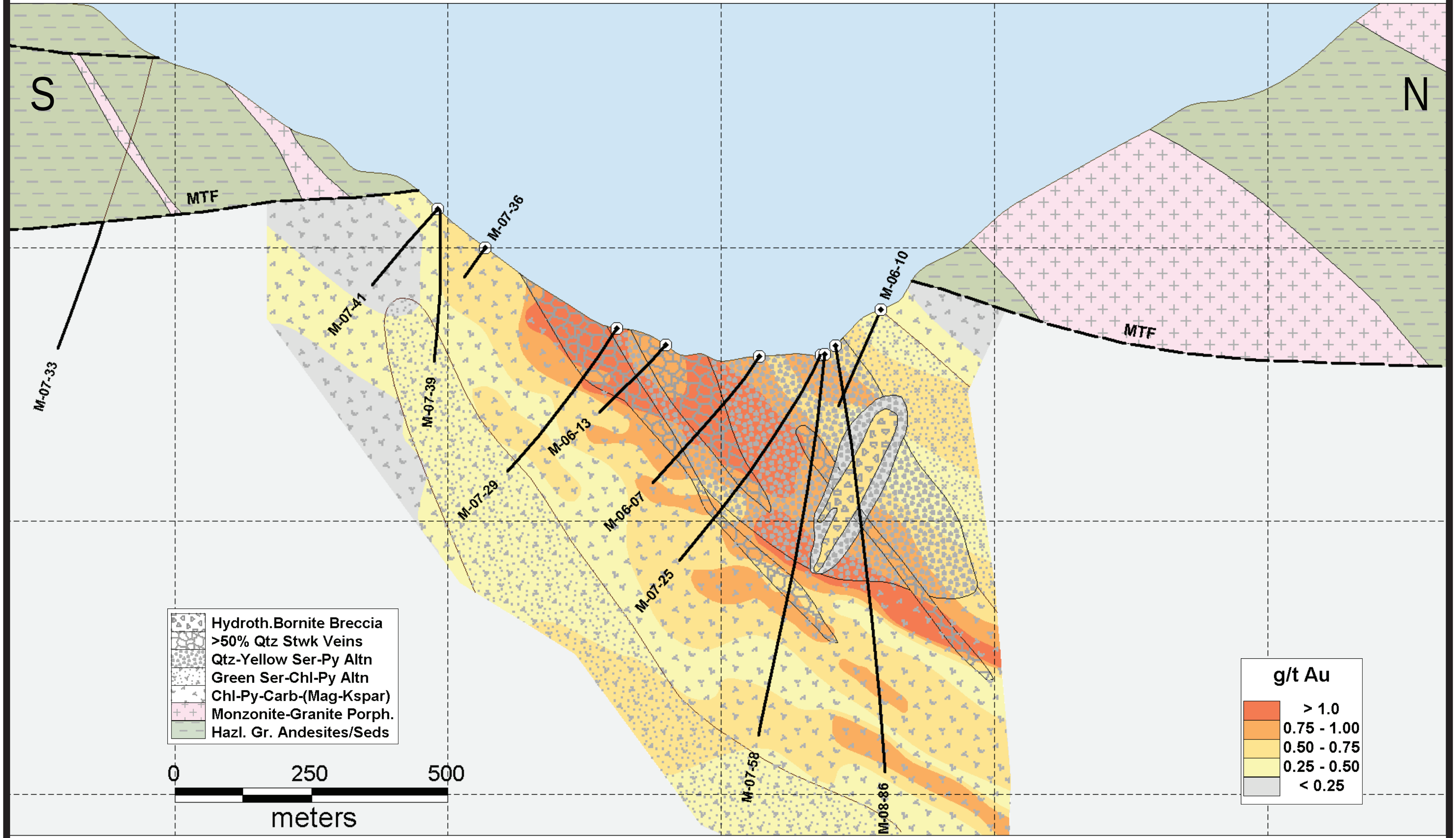

FIGURE 2.3-7

KSM Project Mitchell Deposit Geology (Cross Section)

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2.3.2 TMF Area

2.3.2.1 Overburden

Overburden thickness and material types identified within all the boreholes in the TMF area (Rescan 2010c, Appendix 11-B of the EA Chapter 11; KCBL 2010a, Sub-Appendix H2 of Appendix 4-C of the EA Chapter 4) are presented in Table 2.3-3. The overburden thickness varies from zero (at the monitoring well RES-MW-03 located near the proposed Processing Plant site in the Teigen South Tributary watershed) to 63.1 m (at monitoring well RES-MW-02 located downstream of the proposed South Tailing Cell in Treaty North Tributary watershed). The overburden map (Figure 2.3-8) shows the surficial geology and isopleths of overburden thickness under the TMF footprint, based on geotechnical borehole and monitoring well logs, geophysical survey and ground mapping. Overburden classification maps made by Rescan for the entire TMF model study area based on the information from borehole and well logs and geophysical survey, together with interpretation of terrain map, LiDAR map, satellite imagine and aerial photography are presented in Figures 2.3-9a and 2.3-9b.

Table 2.3-3. Overburden Thickness and Material Types in Boreholes – TMF Area

Well Name	Depth (mbgs)	Composition	Location
RES-MW-01A	4.61	Glacial Till dominated	Teigen south tributary, downstream TMF, slope
RES-MW-01B	4.61	Glacial Till dominated	Teigen south tributary, downstream TMF, slope
RES-MW-02A	39.06	Fluvial dominated	Treaty north tributary, downstream TMF, valley base beside creek
RES-MW-02B	25.30	Fluvial dominated	Treaty north tributary, downstream TMF, valley base beside creek
RES-MW-03A	0.00		Processing plant site
RES-MW-03B	0.00		Processing plant site
KC08-04	63.10	Colluvium and Till	Treaty north tributary, downstream TMF, valley base
KC08-05	14.60	Till	TMF south end, valley base
KC08-06	31.40	Till	TMF south end, valley base

Overburden in the proposed Tailing Management Facility area has a thickness of between 30 and 40 m in the centre of the valley between the North Tailing Dam and the South Tailing Dam and gets thinner going up the valley slopes (less than 10 m) before pinching out completely to bedrock outcrops near the tops of the slopes (little or no overburden observed). The overburden in the TMF area consists largely of glacial till with some colluvial materials. In the area of the North Tailing Dam, the eastern slope has glacial till overburden whereas the western slope has very little or no overburden. There is an alluvial fan located directly south of the South Tailing Dam beneath which the overburden reaches a maximum thickness of 60 m. To the south of the South Tailing Dam, fluvial gravel, cobbles, boulders and sand, interbedded with lacustrian silts and clays were observed to a depth of approximately 40 mbgs. Outside the TMF footprint, overburden with thickness of greater than 5 m is distributed mainly on the valley bases of Teigen Creek, Treaty Creek and Bell-Irving River, and overburden on steep slopes is less than 5 m or is not present. The overburden in the downstream valleys along Teigen Creek, Treaty Creek and Bell-Irving River is interpreted to be mainly composed of fluvial sediments especially near surface.

2.3.2.2 Bedrock Geology

The Tailing Management Facility area are situated within an extensive sedimentary basin formed in the Late Jurassic and Cretaceous (Figure 2.3-10). Government geology maps and reports (e.g., British Columbia Geological Survey, 2006; Gibson, 1990), supported by site investigations to date, suggest that the bedrock at the TMF site is relatively uniform layered sedimentary and meta-sedimentary rocks of the Bowser Lake Group. Weakly metamorphosed sandstones, siltstones, mudstones and occasional conglomerates were encountered on surface and in drill holes. Steeply dipping beds and occasional minor folded sections were observed. Although some regional jointing and strike slip faulting are interpreted in air photos cutting across and offsetting bedding planes with strike direction SW-NE in the TMF area, there is no clear evidence on the ground showing their exact locations and scales (widths and depths), or their fillings.

2.4 SURFACE HYDROLOGY

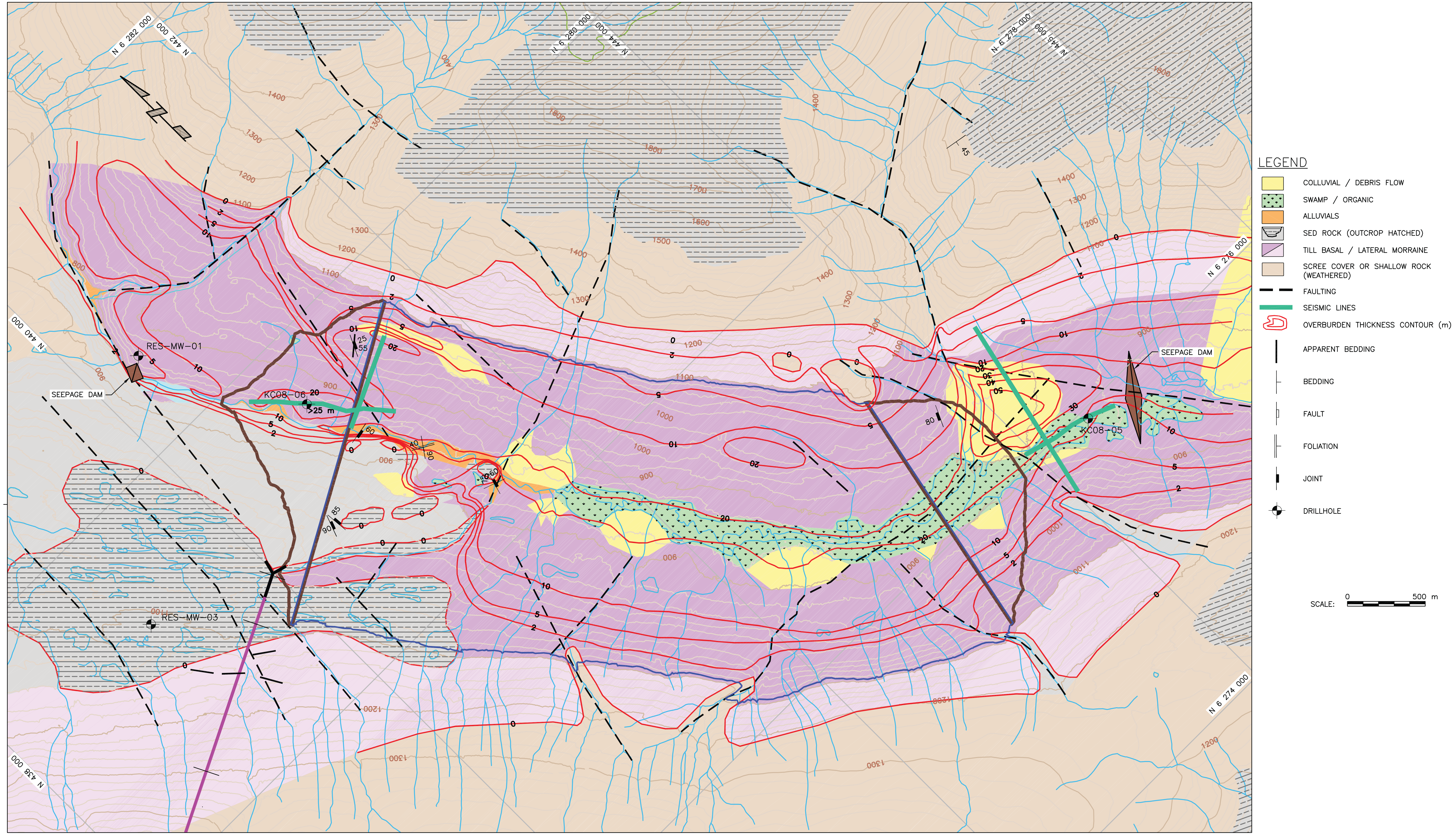
Rescan's 2009 Hydrology Baseline Report (Rescan 2010b) provides the information from surface hydrology observation and glacier monitoring conducted by Rescan since 2007 for the purpose of environmental impact assessment of the KSM Project. The critical surface hydrological data used in the hydrogeological modelling work is summarized in this section. The surface water system in the KSM study area is dominated with creeks and rivers. Wetlands are generally small and mainly located along the Unuk River and South Unuk River channels in the mining area and in the lower reaches of Teigen and Treaty Creeks and Bell-Irving River in the TMF area. The only lake to be potentially impacted by the proposed KSM project is the Sulphurets Lake near the Sulphurets deposit.

The surface water monitoring network with the automated hydrometric monitoring stations installed by Rescan are shown in Figures 2.4-1 and 2.4-2 for the mining area and the TMF area respectively. The monitoring network collects continuous water level data on major streams that might be impacted by the mining activities; a summary of the station details is provided in Table 2.4-1. The proposed Open Pits, Water Storage Facility and Rock Storage Facilities are located within the Sulphurets Creek watershed, which flows west into the Unuk River. The Unuk River flows southwest, crossing the Canada-U.S. border approximately 24 km downstream from its confluence with Sulphurets Creek, then drains into the Pacific Ocean. The proposed Tailing Management Facility is located across a watershed divide between the Teigen Creek and Treaty Creek watersheds. While the majority of the proposed Tailing Management Facility lies within the Teigen South Tributary, extension of the Tailing Management Facility into Treaty North Tributary has been proposed for the later years of the mine life. Both Teigen Creek and Treaty Creek flow east into the Bell-Irving River, which flows into the Nass River and ultimately empties into the Pacific Ocean as well.

According to the regional hydrological data, a typical hydrological year can be divided into four main flow periods:

- **Winter:** characterized by snow and/or ice covered streams with low to negligible stream flow depending on the elevation of the stream and catchment area. Stream flow is expected to be mainly from groundwater discharge (baseflow).
- **Spring/freshet:** characterized by high flows due to snowmelt and rain-on-snow events. This is typically the period that contains the annual peak flow.
- **Summer:** characterized by moderate flows, with flow rates decreasing throughout summer resulting from a diminishing input from snowmelt. However, for high elevation catchments, substantial contributions from snowmelt can occur late into the season. Flows from heavily glaciated catchments will be supplemented by glacial melting. Peak flow events are supplied primarily by rainfall.
- **Late summer/fall:** characterized by generally moderate to low flows, but interrupted by rain-fed storm events and rain-on-snow events. Generally, peak flows during the fall remain below the magnitude of the freshet peak flows but can exceed freshet flows if a large precipitation event occurs primarily as rainfall. Between rainstorms, baseflow levels decline towards low winter flows as more and more precipitation falls in the form of snow and is stored within the snowpack.

AI No. a27495w Project No. 868-006-06 17/03/2010-9:00am



Source: Klohn Crippen Berger

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FIGURE 2.3-8

KSM Project Surficial Geology and Overburden – Under TMF Footprints (KCBL)

Rescan™

gis no. KSM-17-024

Job No. 868-007-06

March 31, 2010

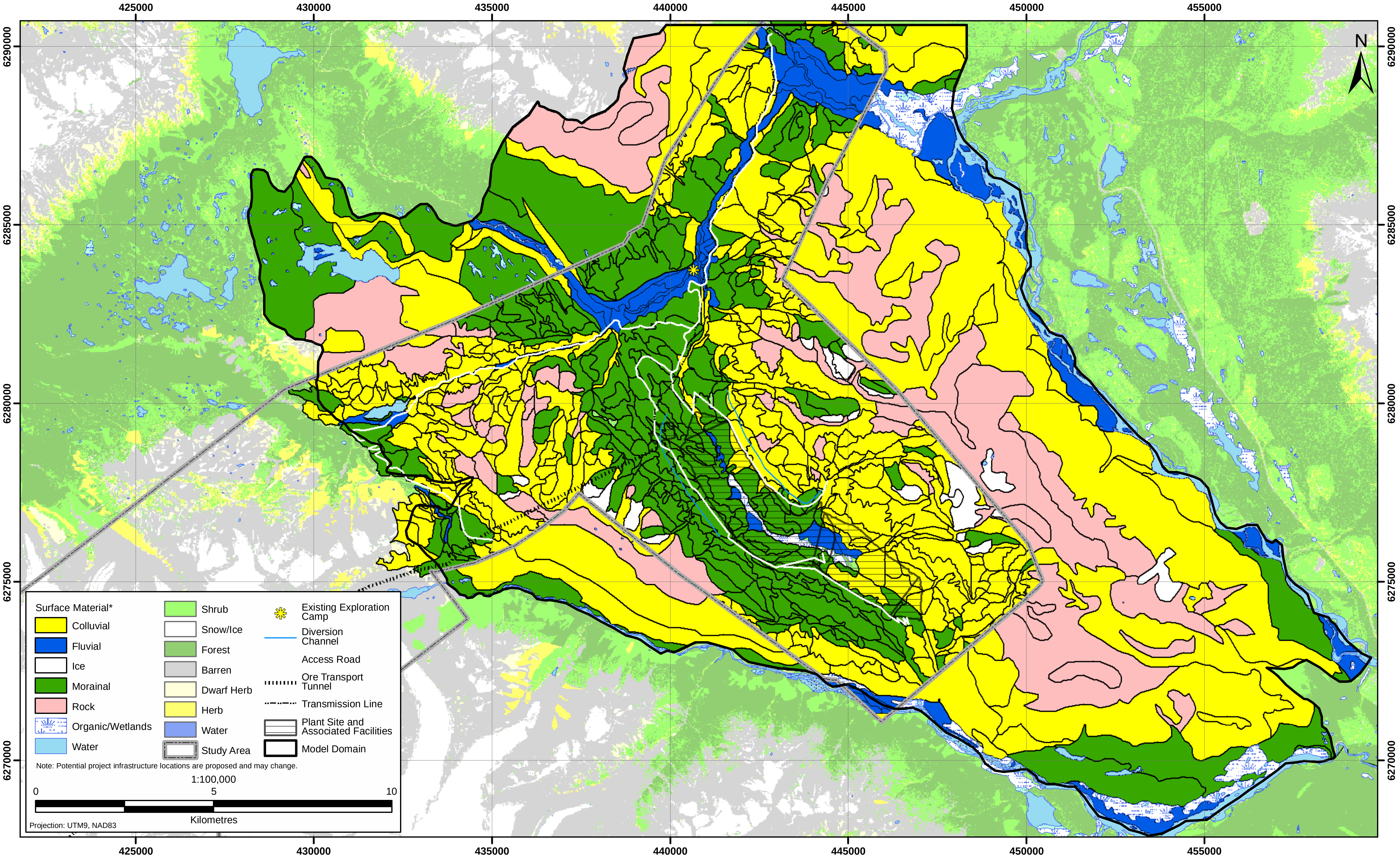

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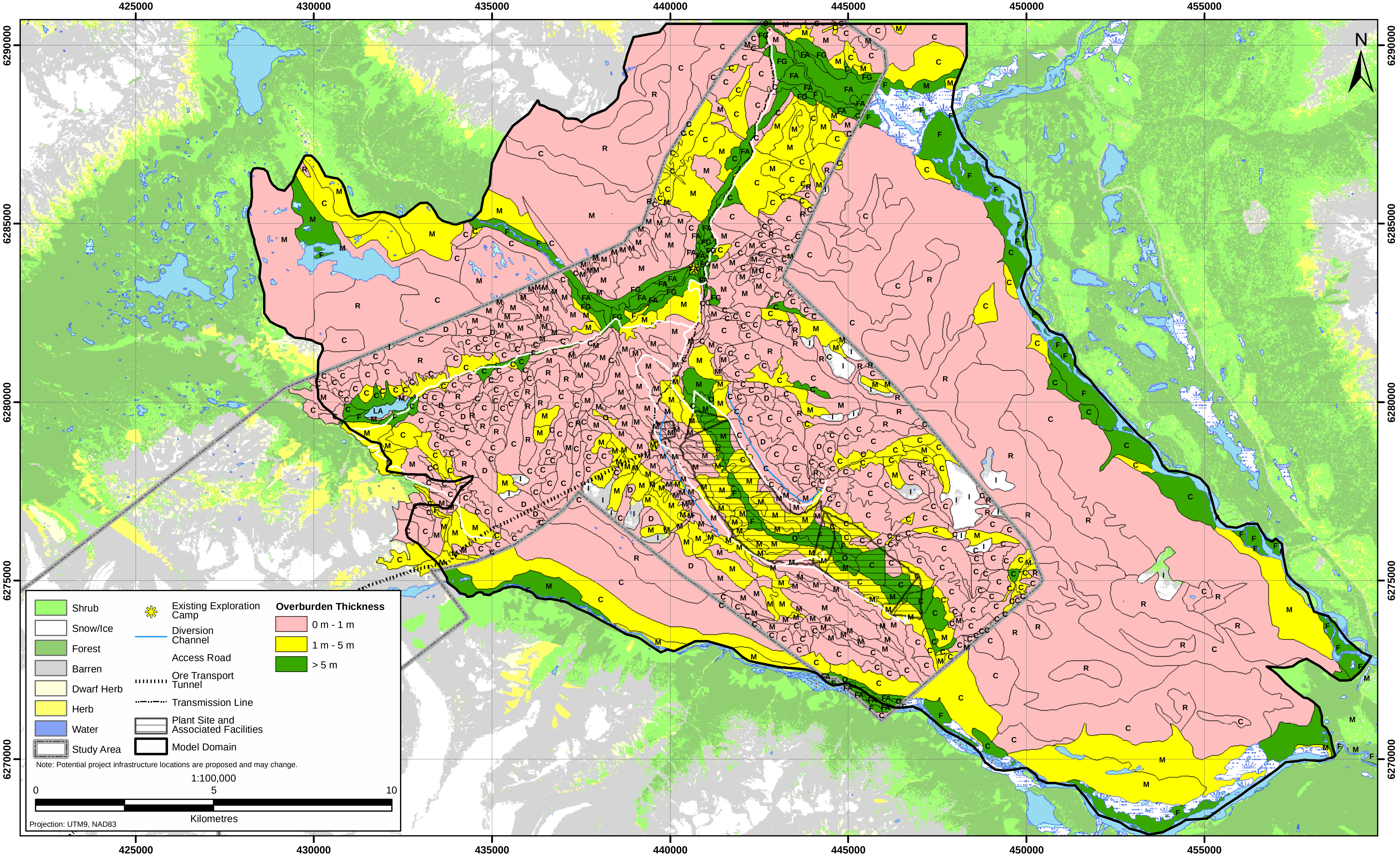
FIGURE 2.3-9a

KSM Project Overburden Classification - Entire TMF Study Area

Rescan



Note: Potential project infrastructure locations are proposed and may change.

FIGURE 2.3-9b

SEABRIDGE GOLD

KSM Project Overburden Thickness - Entire TMF Study Area

Rescan™

gis no. KSM-09-032 Job No. 0868-007-06 April 1, 2010

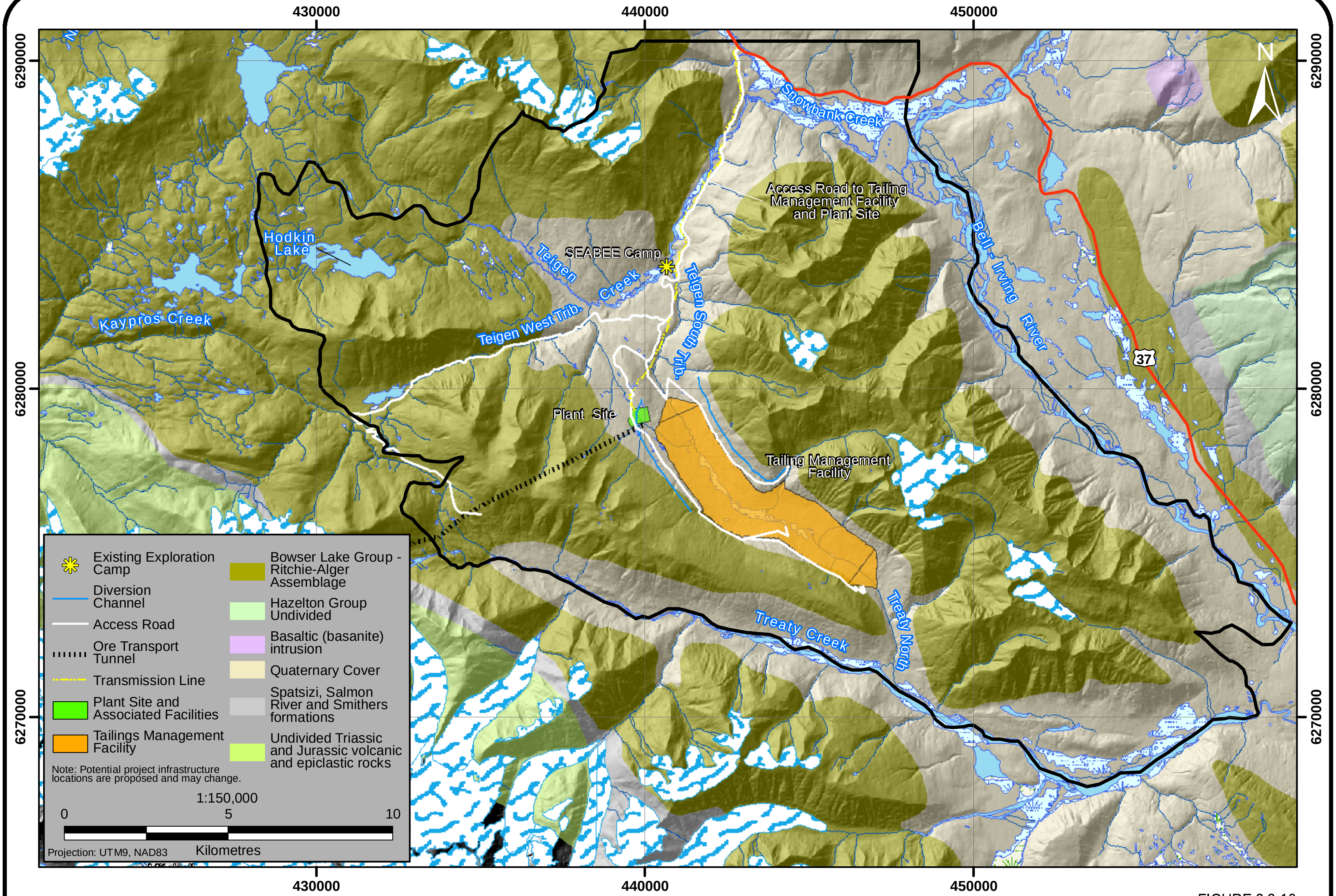


FIGURE 2.3-10

SEABRIDGE GOLD

KSM Project Bedrock Geology - TMF Area

Rescan™

gis no. KSM-10-049 Job No. 868-007-06 March 31, 2010

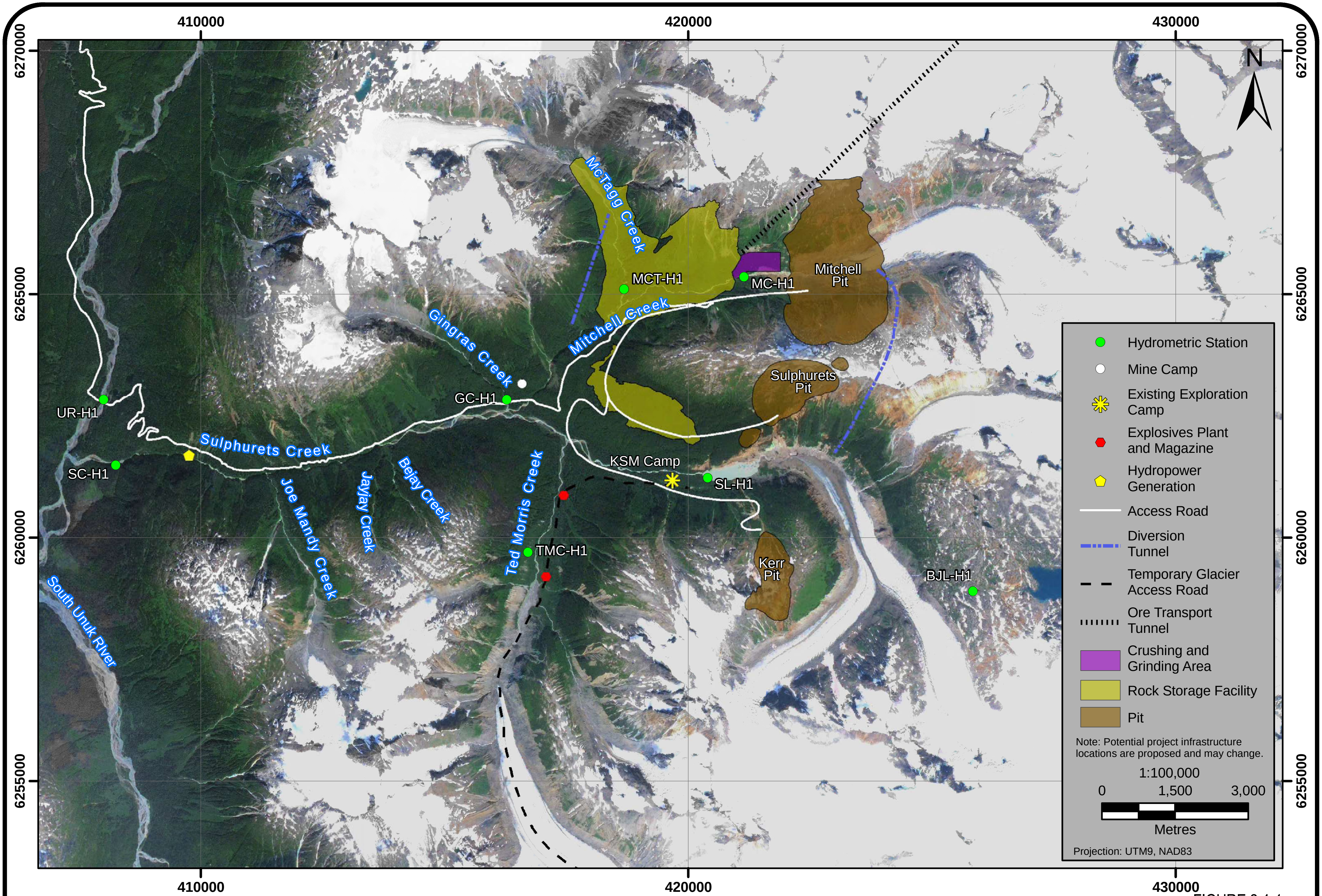


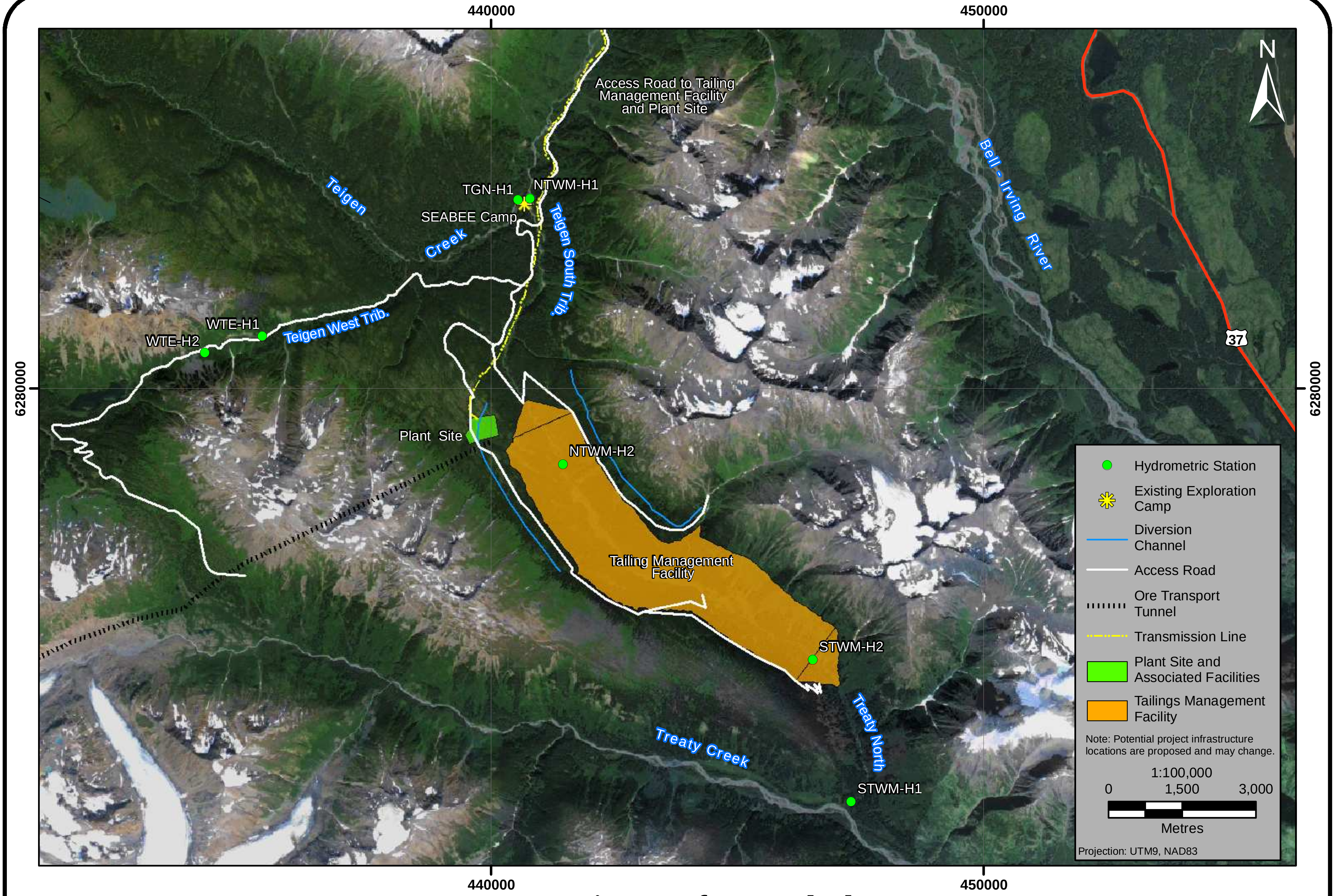
FIGURE 2.4-1

KSM Project Surface Hydrology Monitoring Stations – Mining Area

SEABRIDGE GOLD

Rescan™

gis no. KSM-10-050 Job No. 868-007-06 March 31, 2010



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KSM Project Surface Hydrology Monitoring Stations – TMF Area

FIGURE 2.4-2

Rescan™

Table 2.4-1. 2009 Automated Hydrometric Monitoring Stations

Station	Location	UTM Coordinates	Drainage Area (km^2)	Median Elevation (m)	Median Slope (%)	Glacier Cover (%)
Teigen and Treaty Watersheds						
TC-H1	Treaty Creek South	459417 6270088	411	1322	40	27
STWM-H1	Treaty North Tributary	447,310 6,271,601	33	1284	54.0	5
STWM-H2	Treaty North Tributary headwaters	446528 6274487	11	1119	45.0	0
NTWM-H2	Teigen South Tributary	441,456 6,278,464	35	1354	34	0
TGN-H1	Teigen Creek	440,543 6,283,389	162	1150	32	1
NTWM-H1	Teigen South Tributary	440,788 6,283,865	61	1360	40	2
WTE-H1	Teigen West Tributary	435,353 6,581,073	15	1193	55	0
WTE-H2	Teigen West Tributary	434,183 6,280,733	12	1188	50	0
Unuk and Sulphurets Watersheds						
UR-H2	Kaypros Creek	426,121 6,281,581	36	1328	37	10
UR-H1	Lower Unuk River	408,007 6,262,837	400	1118	34	14
SC-H1	Sulphurets Creek before confluence with Unuk River	408,256 6,261,490	299	1481	47	38
GC-H1	Gingras Creek near confluence with Sulphurets Lake	416277 6262834	10	1535	54	30
TMC-H1	Ted Morris Creek South Tributary of Sulphurets Creek	416,854 6,259,533	57	1565	51	49
MCT-H1	McTagg Creek North Tributary of Mitchell Creek	418,685 6,265,104	32	1540	55	38
MC-H1	Mitchell Creek	421,145 6,265,356	42	1662	38	54
SL-H1	Sulphurets Lake at outlet of lake	420,398 6,261,229	84	1610	36	48
BJL-H1	Bruce Jack Lake at outlet of lake	425,840 6,258,899	18	1625	32	41

For the surface hydrology within the KSM Project study area, the on-site hydrometric stations in the Unuk and Sulphurets watersheds (the mining area) and the Teigen and Treaty watersheds (the TMF area) exhibit distinct runoff regimes due to the hydroclimatology of the area. The Unuk and Sulphurets watersheds have a high percent of glacier cover and their hydrologic regimes are predominantly driven by snow and glacial melting. The Teigen and Treaty watersheds have very little coverage of glaciers and snow packs on the top of ridges, and their hydrologic regimes are dominated by snow melting and rainfall.

High flow events occurred from May to August at the Teigen and Treaty watersheds and from May to September at the Unuk and Sulphurets watersheds when snow and the glaciers are melting at higher temperatures. Low flow occurs during the winter months in both watershed areas as precipitation falls mostly as snow. Hydrographs from the monitoring stations in the two watershed groups for 2007-2009 are shown in Figures 2.4-3, 2.4-4 and 2.4-5. The observed peak flows (Table 2.4-2) and the observed and estimated low flows (Table 2.4-3) are provided; the low flows were used for calibration of the baseline model.

Table 2.4-2. Observed Peak Flows in Mining and TMF Areas

	Peak flow (m^3/s)					
	2009			2008		
Station	**Instantaneous**	**Daily**	**Date**	**Instantaneous**	**Daily**	**Date**
Teigen and Treaty Watersheds (TMF Area)						
STWM-H1	17.6	14.8	Jun-05	18.5	15.1	May-25
NTWM-H2	14.9	11.9	Jun-07	12.2	9.22	Jul-02
TGN-H1	128	89.4	Jun-07	103	80.5	May-27
NTWM-H1	25	19.3	Jun-08	12.9	10.9	May-27
WTE-H1	n/a	n/a	n/a	0.452	0.420	Jul-29
Unuk and Sulphurets Watersheds (Mining Area)						
UR-H1	315	200	Sep-22	122	95.7	Sep-29
SC-H1	160	134	Jul-30	66.6	56.8	Aug-18
TCM-H1	36.4	29.0	Jul-30	n/a	n/a	n/a
MCT-H1	39.6	12.8	Jul-11	16.2	9.14	Aug-18
SL-H1	55.1	52.2	Jul-30	9.01	7.35	Aug-24
MC-H1	66.9	46.1	Jul-30	12.1	9.58	Aug-18

n/a - data not available

At the time of the hydrogeological modelling analysis, no field observation has been conducted on the wetlands and the lakes in the KSM study area, and the information is limited to what is shown on the maps. Glaciers are present in both the mining area and the TMF area, and glacial monitoring has been carried out in the Mitchell valley but is limited to delineate the glaciers and characterize the glacial mass balance. No information is available for the contributions of the glaciers to groundwater recharge and streamflow in both the mining area and the TMF area. It is believed that there is more glacial melting at and near the toes but the ground surface is generally frozen under the glaciers, especially at higher elevations.

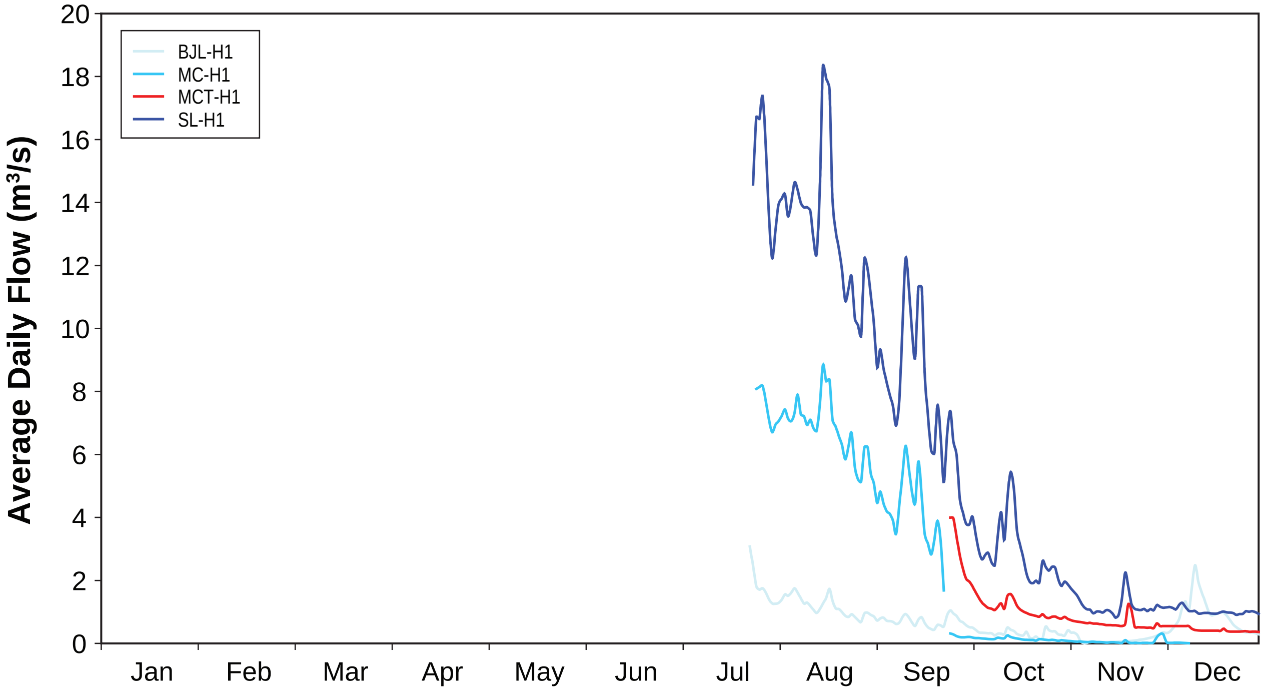
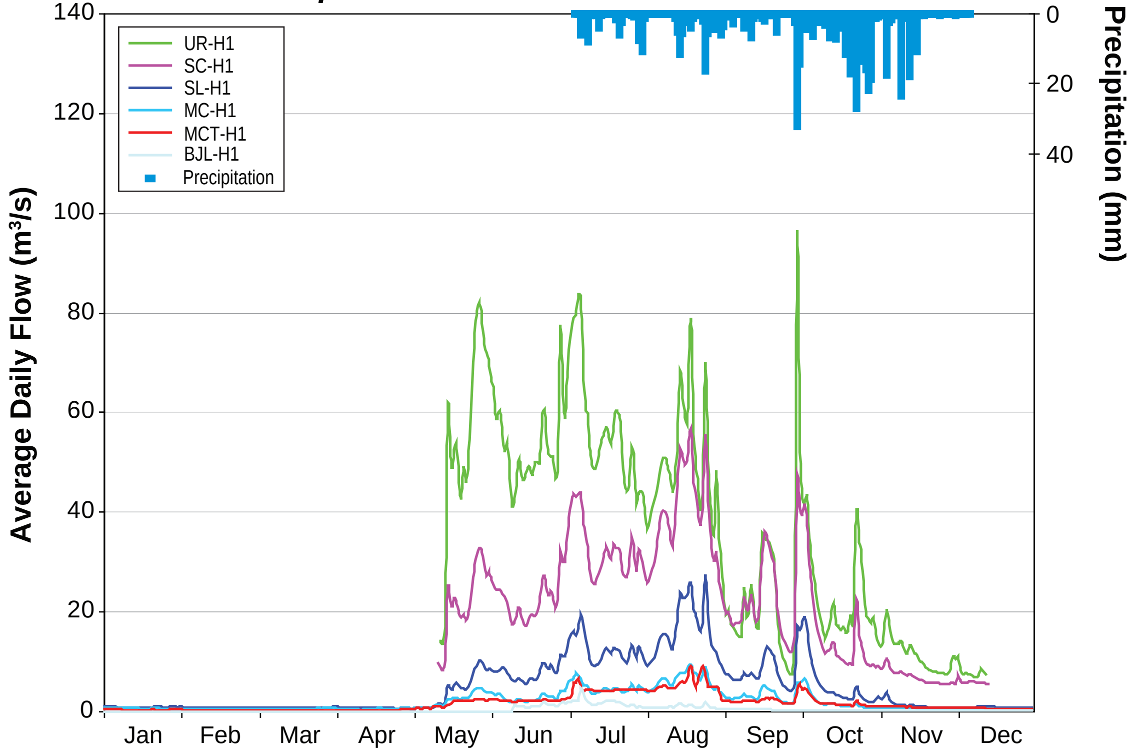
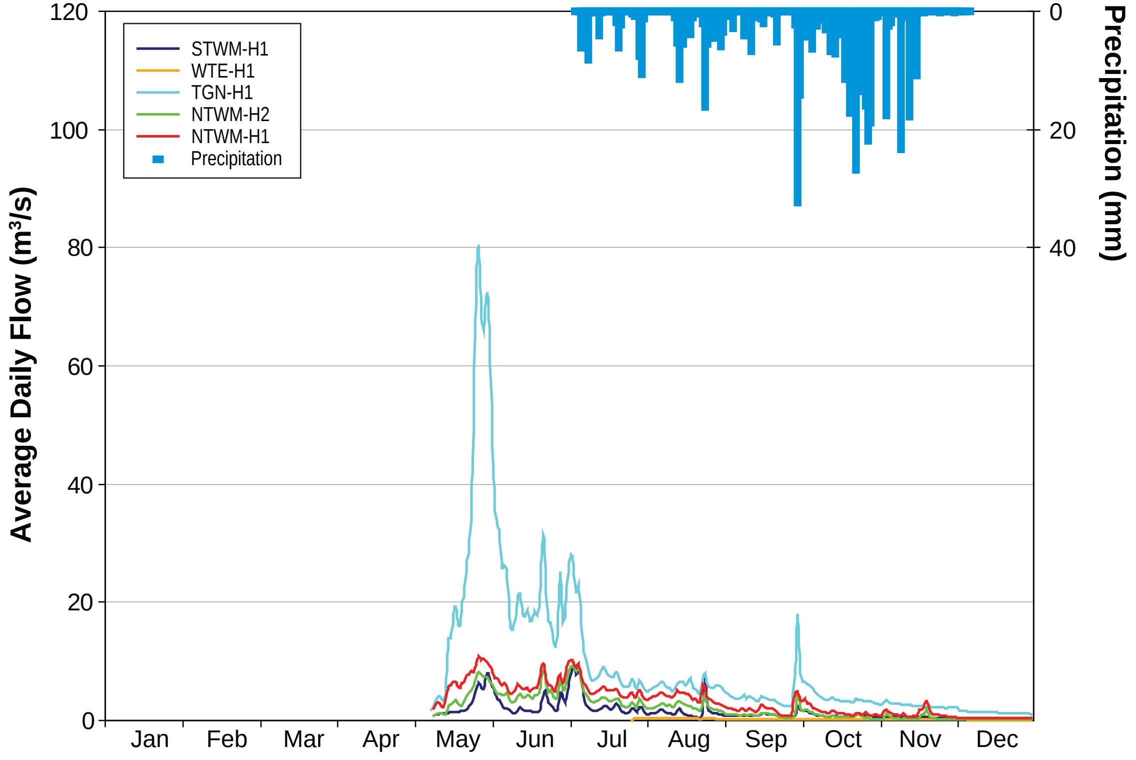


FIGURE 2.4-3

2007 Annual Flow Hydrographs



Unuk and Sulphurets Watersheds



Teigen and Treaty Watersheds

Notes: Precipitation data from Plant Site 1 (Teigen Creek) Met Station.
Unreliable precipitation data before July 5, 2008.

FIGURE 2.4-4

2008 Annual Flow Hydrographs

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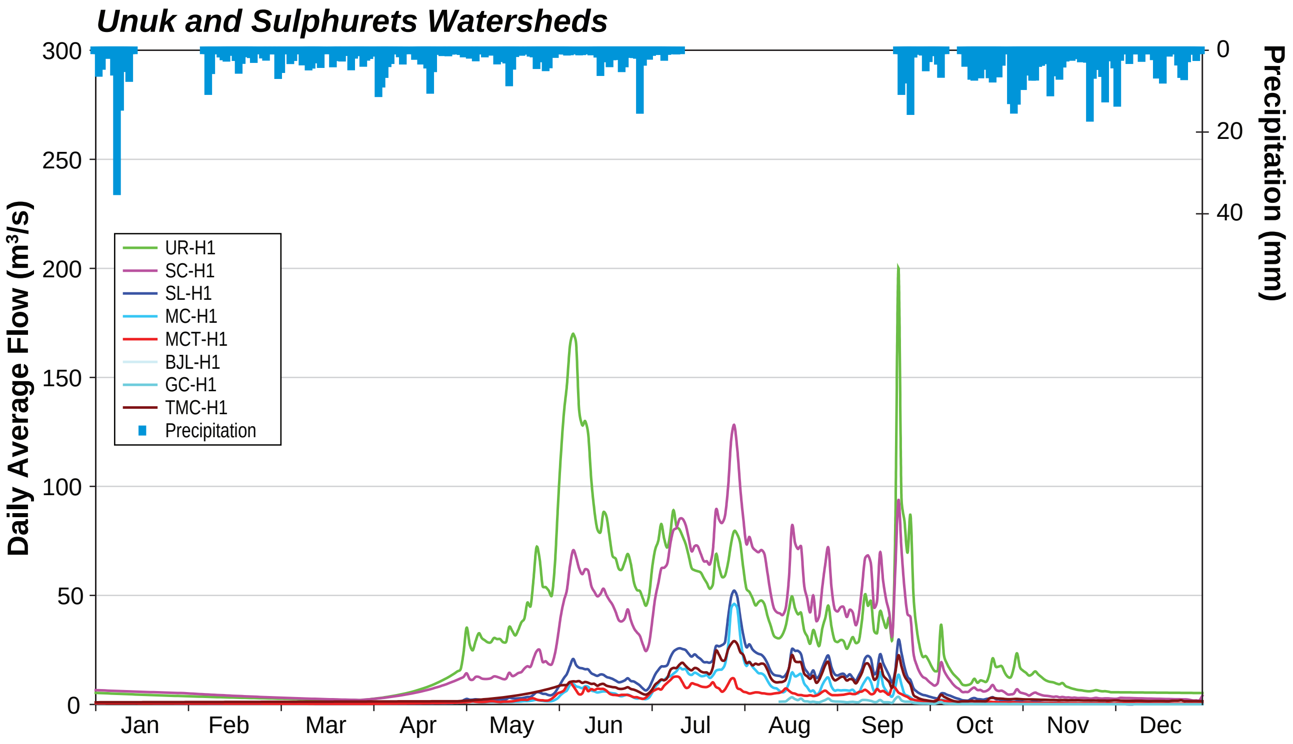

Note: missing precipitation data from Aug 20 to Sept 20, 2009

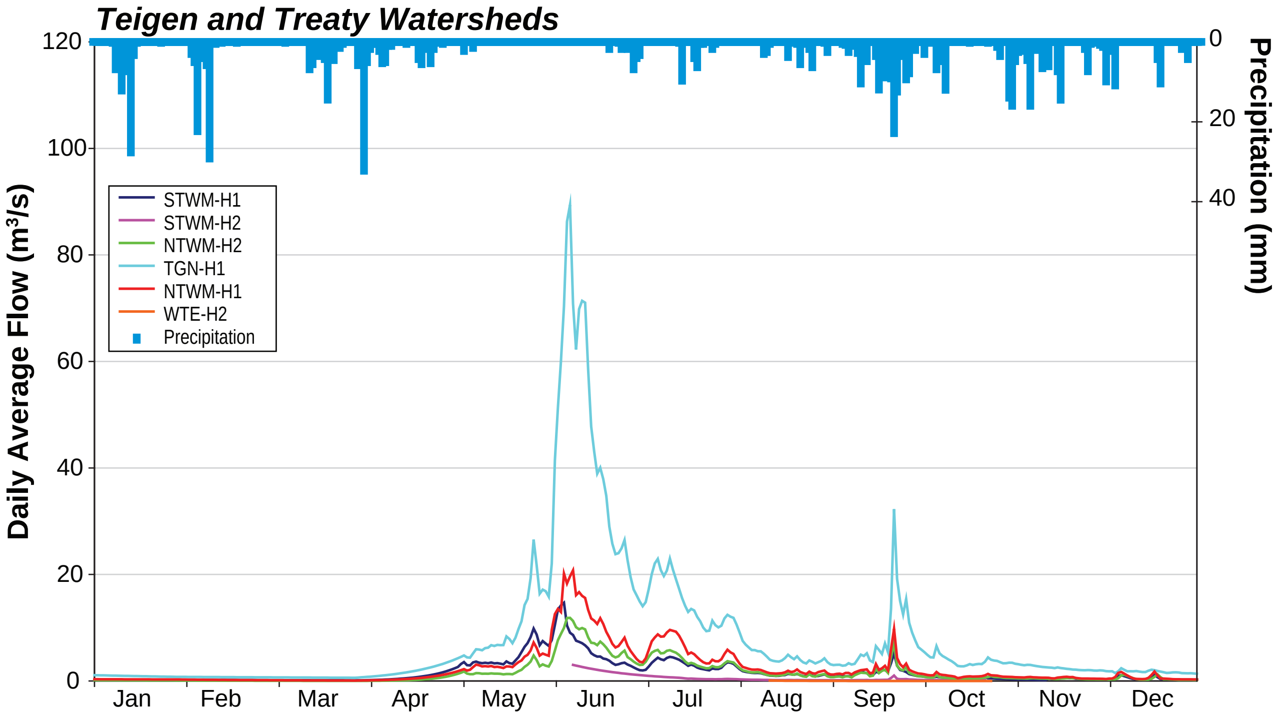

FIGURE 2.4-5

2009 Annual Flow Hydrographs

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Table 2.4-3. Observed and Estimated Low Flows in Mining and TMF Areas

Watershed	Watershed Area (km^2)	Observed Instantaneous Low Flows (m^3/s)			Estimated Annual Low Flows (m^3/s)	
		2008	2009	2010	7-day	7-day Q10[1]
Teigen and Treaty Watersheds						
STWM-H1	33	n/a	0.10	0.20	0.11	0.05
NTWM-H2	35	n/a	0.01	0.09	0.05	0.03
TGN-H1	162	n/a	0.61	1.06	0.57	0.32
NTWM-H1	61	n/a	0.07	0.24	0.16	0.10
Unuk and Sulphurets Watersheds						
UR-H1	400	n/a	1.96	5.09	1.49	0.88
SC-H1	299	n/a	2.02	3.56	1.09	0.63
TMC-H1	57	n/a	n/a	n/a	0.19	0.10
MCT-H1	32	0.26	0.27	0.36	0.10	0.05
SL-H1	84	0.44	0.28	0.47	0.29	0.15
MC-H1	42	0.41	0.16	n/a	0.14	0.07
GC-H1	10	n/a	n/a	0.10	0.10	0.05

[1] Q10 represents the estimated low flows at an occurrence of once in every 10 years; n/a - data not available.

2.5 GROUNDWATER HYDROLOGY

The understanding of the groundwater hydrologic system in the KSM Project study area is based upon the analysis and interpretation of the information and data obtained from the field hydrogeological investigations conducted by Rescan, BGC and KCBL during 2008-2009 as well as previous studies, which include monitoring of groundwater levels and determination of the hydraulic properties of the geologic materials. The details of the available groundwater hydrologic information at the time of this modelling analysis can be found in 2009-2010 Hydrogeology Baseline Report prepared by Rescan (Rescan 2010c, Appendix 11-B of the EA Chapter 11). This section presents the data used in developing a conceptual hydrogeological model and building a baseline model to represent the hydrogeological system respectively in the KSM Project mining area and TMF area for environmental impact assessment.

So far, Rescan has installed 29 groundwater monitoring wells at 15 locations in the entire KSM study area (23 wells at 12 locations in the mining area and 6 wells at 3 locations in the TMF area), KCBL has installed 13 groundwater monitoring wells (10 in the mining area and 3 in the TMF area), and BGC installed 11 vibrating wire piezometers (VWP) within the proposed Mitchell Pit. The locations of the monitoring wells and piezometers are shown in Figures 2.3-1 and 2.3-2 in the previous Section 2.3. The measured water levels in the wells and the piezometers are shown in Table 2.5-1, and the potentiometric surface maps drawn with the measured water levels are shown in Figures 2.5-1 and 2.5-2, respectively, for the mining area and the TMF area.

Hydrostrategraphically, the hydrogeological system is dominated by fractured bedrock formations (intrusive and sedimentary rocks in the mining area, and sedimentary rocks in the TMF area) with overburden in the valley bases playing a minor role. In both the mining and TMF areas, the groundwater table tends to reflect topography with depth to the water table increasing with increasing ground elevations. Groundwater flow is from higher elevations, where downward gradients predominate, to lower elevations in the valleys, where artesian conditions and upward gradients are common. Groundwater recharge is considered to be greater at higher elevations because of more precipitation and glacier/snow melting occurring at higher elevations. Recharge to groundwater in the bedrock occurs by infiltration through overburden or directly through exposed fractured bedrock. Groundwater discharges into rivers, creeks and streams at lower elevations. Groundwater seeps are common on valley slopes, indicting the groundwater discharge areas (Figure 2.5-3).

Table 2.5-1. Water Level Measurements

Well Location	Well Elevation* (masl)	Well Distinction	Stick up (mags)	Screened Interval Midpoint (mbgs)	Installation Date	Development Date	WL Measurement Date	Measured Water Level (mbts)	Water Level (mbgs)	Water Level (masl)	Vertical Gradient	Comments
RES-MW-01	850	A	1.01	77.27	September 14th, 2009	September 30th, 2009	October 5th, 2009	-9.82	-10.83	860.83	up	Artesian pressures measured with pressure gauge. Water in 01A standpipe frozen for Jan 11, 2010 reading.
							October 22nd, 2009**	-10.7	-11.71	861.71	-0.574	
							Average:		*-11.27*	*861.27*		
	850	B	0.94	50.45	September 14th, 2009	September 30th, 2009	September 30th, 2009	7.68	6.74	843.26		
							October 5th, 2009	6.31	5.37	844.63		
							October 22nd, 2009**	4.62	3.68	846.32		
							January 11th, 2010	4.69	3.75	846.25		
							May 3rd, 2010	5.22	4.28	845.72		
							Average:		*4.76*	*845.24*		
RES-MW-02	760	A	0.76	73.46	September 1st, 2009	September 30th, 2009	September 30th, 2009	6.33	5.57	754.43	up	
							October 5th, 2009**	7.43	6.67	753.33	-0.051	
							October 23rd, 2009	7.28	6.52	753.48		
							May 4th, 2010	7.03	6.27	753.73		
							Average:		*6.26*	*753.74*		
	760	B	0.90	21.20	August 30th, 2009	September 30th, 2009	August 30th, 2009	10.6	9.70	750.30		
							September 2nd, 2009	10.54	9.64	750.36		
							September 5th, 2009	10.79	9.89	750.11		
							September 30th, 2009	10.27	9.37	750.63		
							October 5th, 2009**	10.23	9.33	750.67		
							October 23rd, 2009	10.29	9.39	750.61		
							May 4th, 2010	9.9	9.00	751.00		
							Average:		*9.47*	*750.53*		
RES-MW-03	1106	A	0.70	78.81	September 17th, 2009	September 30th, 2009	October 5th, 2009**	10.34	9.64	1096.36	down	
							October 24th, 2009	10.225	9.53	1096.48	0.008	
							January 14th, 2010	10.57	9.87	1096.13		
							May 3rd, 2010	10.11	9.41	1096.59		
							Average:		*9.61*	*1096.39*		
	1106	B	0.94	48.77	September 18th, 2009	September 30th, 2009	September 30th, 2009	11.64	10.70	1095.30		
							October 5th, 2009**	10.35	9.41	1096.59		
							October 24th, 2009	10.32	9.38	1096.62		
							January 14th, 2010	10.52	9.58	1096.42		
							May 3rd, 2010	10.09	9.15	1096.85		
							Average:		*9.77*	*1096.23*		
RES-MW-04	780	A	0.58	88.19	September 20th, 2009	September 16th, 2009	September 21st, 2009**	-1.91	-2.49	782.49	up	Artesian pressures measured with pressure gauge
							October 21st, 2009	-0.99	-1.57	781.57	-0.032	
							May 5th, 2010	-0.70	-1.28	781.28		
							Average:		*-1.78*	*781.78*		

(continued)

Table 2.5-1. Water Level Measurements (continued)

Well Location	Well Elevation* (masl)	Well Distinction	Stick up (mags)	Screened Interval Midpoint (mbgs)	Installation Date	Development Date	WL Measurement Date	Measured Water Level (mbts)	Water Level (mbgs)	Water Level (masl)	Vertical Gradient	Comments
RES-MW-04 *(con'td)*	780	B	1.38	19.67	September 22nd, 2009	September 16th, 2009	August 29th, 2009	2.84	1.46	778.54		Artesian pressures measured with pressure gauge
							September 21st, 2009**	1.08	-0.30	780.30		
							October 21st, 2009	2.46	1.08	778.92		
							Average:		*0.56*	*779.44*		
RES-MW-05	1090	A'	0.59	79.89	July 18th, 2009	September 17th, 2009	September 22nd, 2009**	0.703	-1.44	1091.44	up	Artesian pressure of 05A' was < 1 psi, taken as 1 psi
							May 8th, 2010	0.95	0.37	1089.64		
											-0.309	
	1090	B	0.79	38.95	July 10th, 2009	September 17th, 2009	August 29th, 2009	12.46	11.68	1078.33		
							September 16th, 2009	12.56	11.78	1078.23		
							September 22nd, 2009**	12.01	11.23	1078.78		
							May 8th, 2010	12.96	12.18	1077.83		
							Average:		*11.50*	*1078.50*		
RES-MW-06	830	A	1.61	80.31	June 27th, 2009	September 17th, 2009	August 29th, 2009	2.18	0.57	829.43	down	
							September 17th, 2009	2.45	0.84	829.16	0.006	
							September 23rd, 2009**	1.32	-0.29	830.29		
							May 5th, 2010	2.89	1.28	828.72		
							Average:		*0.60*	*829.40*		
	830	B	1.25	26.17	June 28th, 2009	September 17th, 2009	August 29th, 2009	1.75	0.50	829.50		
							September 17th, 2009	2.09	0.84	829.16		
							September 23rd, 2009**	0.62	-0.63	830.63		
							May 5th, 2010	2.88	1.63	828.37		
							Average:		*0.59*	*829.42*		
RES-MW-07	1460	A	1.33	79.66	August 7th, 2009	September 17th, 2009	September 1st, 2009	15.35	14.02	1445.98	down	
							September 17th, 2009	15.13	13.80	1446.20	0.058	
							September 24th, 2009**	12.49	11.16	1448.84		
							October 26th, 2009	14.76	13.43	1446.57		
							November 26th, 2009	15.05	13.72	1446.28		
							January 15th, 2010	16.02	14.69	1445.31		
							May 6th, 2010	15.59	14.26	1445.74		
							Average:		*13.58*	*1446.42*		
	1460	B	0.96	27.82	August 7th, 2009	September 17th, 2009	September 1st, 2009	12.29	11.33	1448.67		
							September 17th, 2009	11.98	11.02	1448.98		
							September 24th, 2009**	9.09	8.13	1451.87		
							October 26th, 2009	12.44	11.48	1448.52		
							January 15th, 2010	13.89	12.93	1447.07		
							May 6th, 2010	13.3	12.34	1447.66		
							Average:		*11.21*	*1448.80*		
RES-MW-08	1400	A	1.57	86.23	August 13th, 2009	Not developed - dry well	September 19th, 2009	Below Bottom of Hole	> 88.88	<1311.12	-	

(continued)

Table 2.5-1. Water Level Measurements (continued)

Well Location	Well Elevation* (masl)	Well Distinction	Stick up (mags)	Screened Interval Midpoint (mbgs)	Installation Date	Development Date	WL Measurement Date	Measured Water Level (mbts)	Water Level (mbgs)	Water Level (masl)	Vertical Gradient	Comments
RES-MW-09	1330	A	1.52	92.47	August 23rd, 2009	September 25th, 2009	September 21st, 2009	26.8	25.28	1304.72	up	
							September 28th, 2009**	26.28	24.76	1305.24	-0.049	
							Average:		*25.02*	*1304.98*		
	1330	B	1.33	52.00	August 24th, 2009	September 25th, 2009	September 21st, 2009	28.14	26.81	1303.19		
							September 28th, 2009**	28.07	26.74	1303.26		
							October 28th, 2009	28.55	27.22	1302.78		
							Average:		*26.92*	*1303.08*		
		A	1.27	86.09	August 29th, 2009	September 25th, 2009	October 3rd, 2009**	58.62	57.35	1132.65	0.036	
							May 8th, 2010		>90.38	<1099.62		
							Average:		65.67	1124.34		
	1190	B	1.00	62.47	August 31st, 2009	September 25th, 2009	September 20th, 2009	65.35	64.35	1125.65		
							October 3rd, 2009**	57.49	56.49	1133.51		
							May 8th, 2010		>65.57	<1124.43		
							Average:		*60.42*	*1129.58*		
		A	1.48	65.61	September 7th, 2009	September 23rd, 2009	October 2nd, 2009**	0.15	-1.33	501.33	-0.046	
							October 21st, 2009	0.04	-1.44	501.44		
							May 4th, 2010	0.1	-1.38	501.38		
							Average:		*-1.57*	*501.57*		
	500	B	1.50	14.87	September 8th, 2009	September 23rd, 2009	September 20th, 2009	2.85	1.36	498.65		
							October 1st, 2009**	2.48	0.99	499.02		
							October 21st, 2009	2.79	1.30	498.71		
							January 12th, 2010	2.97	1.48	498.53		
							May 4th, 2010	2.42	0.93	499.08		
							Average:		*1.21*	*498.79*		
RES-MW-12	710	A	1.32	85.68	July 29th, 2009	September 18th, 2009	August 30th, 2009	38.56	37.24	672.76	down	
							September 18th, 2009	39.91	38.59	671.41	0.292	
							September 27th, 2009**	30.22	28.90	681.10		
							October 21st, 2009	30.02	28.70	681.30		
							January 13th, 2010	36.01	34.69	675.31		
							May 7th, 2010	22.25	20.93	689.07		
							Average:		*31.51*	*678.49*		
	710	B	1.47	23.95	July 30th, 2009	September 18th, 2009	August 30th, 2009	12.66	11.19	698.81		
							September 18th, 2009	12.99	11.52	698.48		
							September 27th, 2009**	12.32	10.85	699.15		
							October 21st, 2009	12.535	11.07	698.94		
							January 13th, 2010	12.14	10.67	699.33		
							May 7th, 2010	10.57	9.10	700.90		
							Average:		*10.73*	*699.27*		

(continued)

Table 2.5-1. Water Level Measurements (continued)

Well Location	Well Elevation* (masl)	Well Distinction	Stick up (mags)	Screened Interval Midpoint (mbgs)	Installation Date	Development Date	WL Measurement Date	Measured Water Level (mbts)	Water Level (mbgs)	Water Level (masl)	Vertical Gradient	Comments
RES-MW-13	1020	A	1.59	86.53	August 17th, 2009	September 23, 2009	September 19th, 2009**	10.38	8.79	1011.21	up	Water levels taken after development in 13A have likely not recovered to static as of October 22nd, 2009
							September 29th, 2009	32.13	30.54	989.46	-0.022	
							October 22nd, 2009	18.05	16.46	1003.54		
							May 5th, 2010	14.22	12.63	1007.37		
							Average:		*17.11*	*1002.90*		
	1020	B	1.35	24.33	August 18th, 2009	September 20, 2009	September 19th, 2009**	11.51	10.16	1009.84		
							September 29th, 2009	11.47	10.12	1009.88		
							October 22nd, 2009	11.665	10.32	1009.69		
							May 5th, 2010	11.88	10.53	1009.47		
							Average:		*10.28*	*1009.72*		
RES-MW-14	850	A	0.84	73.58	July 22nd, 2009	September 18th, 2009	August 30th, 2009	36.56	35.72	814.28	down	
							September 18th, 2009	36.96	36.12	813.88	0.163	
							September 27th, 2009**	35.61	34.77	815.23		
							October 26th, 2009	33.75	32.91	817.09		
							January 16th, 2010	35.07	34.23	815.77		
							May 8th, 2010	32.49	31.65	818.35		
							Average:		*34.23*	*815.77*		
	850	B	1.42	46.18	July 23rd, 2009	September 18th, 2009	August 30th, 2009	32.36	30.94	819.06		
							September 18th, 2009	32.64	31.22	818.78		
							September 27th, 2009**	31.72	30.30	819.70		
							October 27th, 2009	29.76	28.34	821.66		
							November 23rd, 2009	29.12	27.70	822.30		
							January 16th, 2010	29.64	28.22	821.78		
							May 7th, 2010	26.82	25.40	824.60		
							Average:		*28.87*	*821.13*		
RES-MW-15	580	A	1.48	98.70	September 15th, 2009	September 25th, 2009	September 20th, 2009**	11.41	9.93	570.07	up	Water levels taken after development in 15A have likely not recovered to static as of October 24nd, 2009
							October 2nd, 2009	59.04	57.56	522.44	-0.164	
							October 24th, 2009	32.56	31.08	548.92		
							May 6th, 2010	17.54	16.06	563.94		
							Average:		*28.66*	*551.34*		
	580	B	1.44	20.81	September 16th, 2009	September 24th, 2009	September 20th, 2009**	24.16	22.72	557.28		
							October 2nd, 2009	20.8	19.36	560.64		
							May 6th, 2010	21.5	20.06	559.94		
							Average:		*20.71*	*559.29*		
KC08-01	665	-	0.74	19.78	NA	Not developed	October 27th, 2009	6.39	5.65	659.35	-	
							May 9th, 2010	6.1	5.36	659.64		
							NA[c]		8.28	656.72		
							Average:		*5.51*	*659.50*		

(continued)

Table 2.5-1. Water Level Measurements (continued))

Well Location	Well Elevation* (masl)	Well Distinction	Stick up (mags)	Screened Interval Midpoint (mbgs)	Installation Date	Development Date	WL Measurement Date	Measured Water Level (mbts)	Water Level (mbgs)	Water Level (masl)	Vertical Gradient	Comments
		-	1.00	15.24	NA	Not developed	January 16th, 2010	13.49	12.49	667.51	-	
							NA[c]		7.50	672.50		
							Average:		*12.48*	*667.52*		
KC08-03	770	-	NA	80.25	NA		NA[c]		7.70	762.30	-	
KC08-04	868	-	1.00	66.81	NA	Not developed	November 25th, 2009		16.37	852.04	-	
							NA[c]		18.42	849.99		
KC08-05	886	-	-0.15	19.66	NA	Not developed	November 26th, 2009	5.08	5.23	880.75	-	
							NA[c]		5.09	880.89		
KC08-06	880	-	NA	36.40	NA	Not developed	NA[c]		3.05	876.95		
KC08-07	772	-	NA	23.53	NA	Not developed	NA[c]		artesian	> 772	-	
KC09-08	830	-	0.68	47.38	NA	Not developed	October 22nd, 2009	35.72	35.04	794.96	-	
							May 9th, 2010	34.84	34.16	795.84		
							NA[c]		39.85	790.15		
							Average:		*34.60*	*795.40*		
KC09-09	772	OB	1.21	32.85	NA	Not developed	October 27th, 2009**	30.69	29.48	742.52	up	- Screened in overbur
							May 9th, 2010	30.72	29.51	742.49		
							NA[c]		12.90	759.10	-0.185	RK - Screened in bedr
							Average:		*29.50*	*742.51*		
	772	BDRK	1.31	123.60	NA	Not developed	October 27th, 2009**	14.03	12.72	759.28		
							NA[c]		29.51	742.49		
KC09-10	894	-	NA	25.28	NA	Not developed	NA[c]		1.04	892.96	-	
KC09-11	789	-	NA	27.7	NA	Not developed	NA[c]		5.70	783.30	-	
		-	1.26	54.75	NA	Not developed	November 23rd, 2009	11.43	10.17	629.83	-	
							May 9th, 2010	10.71	9.45	630.55		
							NA[c]		13.77	626.23		
							Average:		*9.97*	*630.03*		
KC09-13	670	-	0.51	57.80	NA	Not developed	October 24th, 2009	31.82	31.31	638.69	-	
							May 9th, 2010	27.72	27.21	642.79		
							NA[c]		31.31	638.69		
							Average:		*29.26*	*640.74*		

(continued)

Table 2.5-1. Water Level Measurements (continued)

M-09-095	1020	-	NA	393.9	NA	-	June 22nd, 2009		130.46	889.54	-	VWP data are inconsistent with monitoring well data and are considered to be inaccurate. It is probable that water levels had not
							July 10th, 2009		132.94	887.06		
							July 20th, 2009		132.09	887.91		
							September 11th, 2009		139.17	880.83		
							Average:		*133.67*	*886.34*		
M-09-096	1010	S	NA	41.9	NA	-	June 22nd, 2009		101.16	908.84	down 0.057	VWP data are inconsistent with monitoring well data and are considered to be inaccurate. It is
							July 10th, 2009		101.06	908.94		
							July 20th, 2009		101.18	908.82		
							Average:		*101.20*	*908.80*		
M-09-096	1010	D	NA	234.9	NA	-	June 22nd, 2009		109.31	900.69		
							July 10th, 2009		108.62	901.38		
							July 20th, 2009		109.36	900.64		
							September 11th, 2009**		112.37	897.63		
							Average:		*109.92*	*900.09*		
M-09-097	1360	S	NA	82.8	NA	-	June 25th, 2009		82.30	1277.70	up -0.036	VWP data are inconsistent with monitoring well data and are considered to be inaccurate. It is probable that water levels had not reached static at the time of measurement.
							July 10th, 2009		85.09	1274.91		
							July 30th, 2009		90.74	1269.26		
							August 10th, 2009		93.78	1266.22		
							August 24th, 2009		98.36	1261.64		
							September 1st, 2009		100.01	1259.99		
							September 11th, 2009**		101.89	1258.11		
							Average:		*92.25*	*1267.75*		
	1360	D	NA	256.3	NA	-	June 25th, 2009		56.27	1303.73		
							July 10th, 2009		77.68	1282.32		
							July 30th, 2009		83.60	1276.40		
							August 9th, 2009		87.10	1272.90		
							August 24th, 2009		92.03	1267.97		
							August 31st, 2009		93.70	1266.30		
							September 10th, 2009**		95.69	1264.31		
							Average:		*83.02*	*1276.98*		
M-09-098	1240	-	NA	87.5	NA	-	June 27th, 2009		122.62	1117.38	-	VWP data are inconsistent with monitoring well
							July 10th, 2009		123.30	1116.70		
							September 11th, 2009		123.84	1116.16		
							Average:		*123.30*	*1116.70*		

(continued)

Table 2.5-1. Water Level Measurements (completed)

M-09-099	980	-	NA	377.8	NA	-	July 10th, 2009		236.85	743.15	-	VWP data are inconsistent with monitoring well data and are considered to be inaccurate. It is probable that water
							July 20th, 2009		263.10	716.90		
							September 11th, 2009		222.27	757.73		
							Average:		*240.74*	*739.26*		
M-09-100	810	S	NA	45.4	NA	-	July 10th, 2009		15.46	794.54	down	VWP data are inconsistent with monitoring well data and are considered to be inaccurate. It is probable that water levels had not reached static at the time of measurement.
							July 20th, 2009		15.23	794.77	0.526	
							September 15th, 2009**		15.46	794.54		
							Average:		*15.38*	*794.62*		
	810	D	NA	233.3	NA	-	July 10th, 2009		28.29	781.71		
							July 20th, 2009		71.09	738.91		
							July 31st, 2009		90.79	719.21		
							August 8th, 2009		98.36	711.64		
							August 18th, 2009		104.64	705.36		
							August 24th, 2009		107.76	702.24		
							September 1st, 2009		110.62	699.38		
							September 11th, 2009**		114.24	695.76		
							Average:		*90.72*	*719.28*		
M-09-101	1270	-	NA	188.1	NA	-	July 16th, 2009		69.65	1200.35	-	VWP data are inconsistent with monitoring well data and are considered to be
							July 20th, 2009		74.86	1195.14		
							September 11th, 2009		121.30	1148.70		
							Average:		*88.60*	*1181.40*		
M-09-102A	1290	-	NA	343.7	NA	-	July 18th, 2009		206.89	1083.11	-	VWP data are inconsistent with monitoring well data and are considered to be inaccurate. It is probable that water
							July 20th, 2009		206.36	1083.64		
							September 11th, 2009		202.56	1087.44		
							Average:		*205.27*	*1084.73*		

mbgs - meters below ground surface

NA - not available

** Well elevations interpreted from topographic maps. M-09 wells show elevations of vibrating wire piezometer (VWP) tips.*

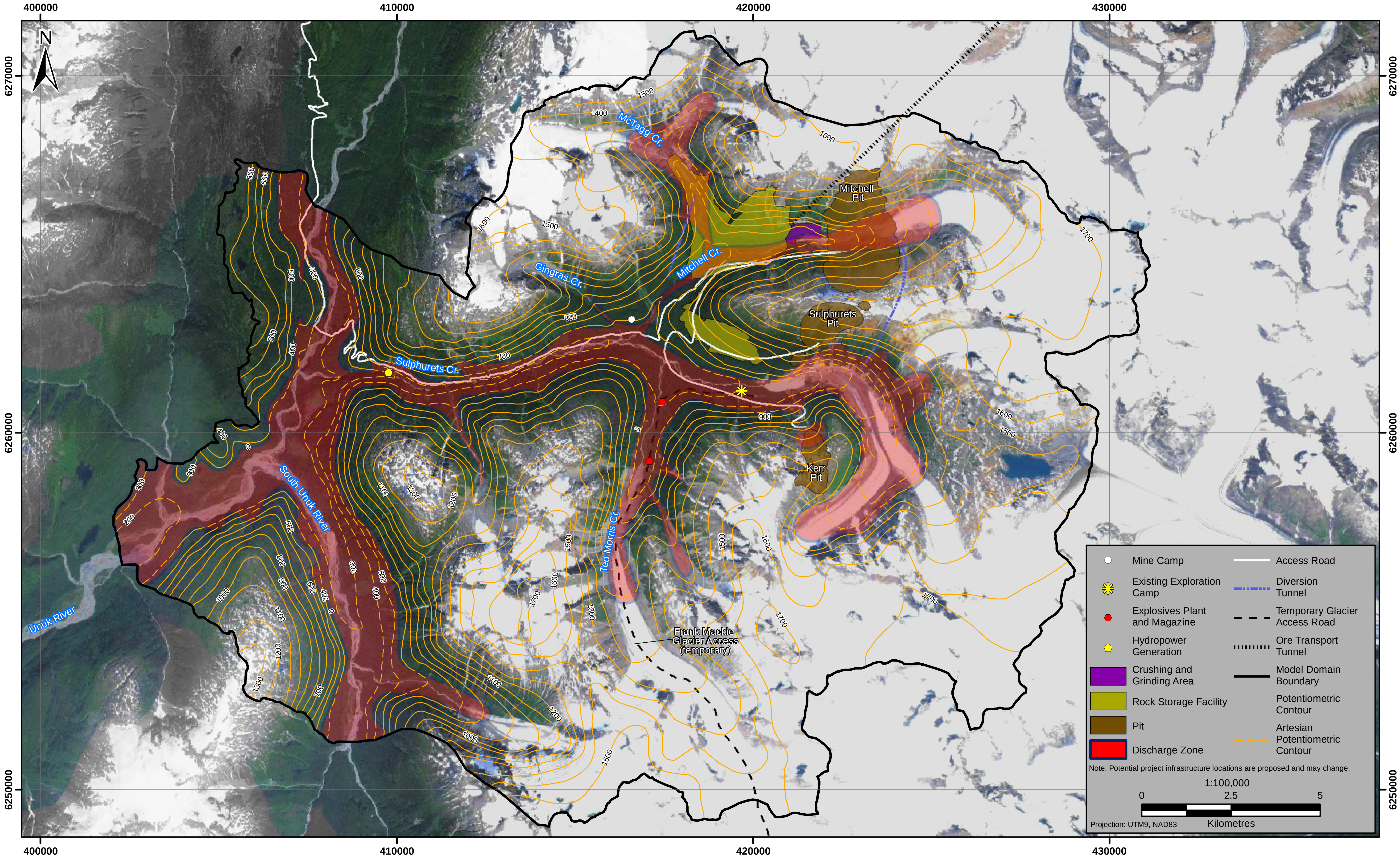
*** Water levels from these dates were used to calculate vertical gradients.*

[c] *Data provided by KCB. Not considered when calculating average water levels.*

gis no. KSM-09-036

Job No. 0868-007-06

April 20, 2010



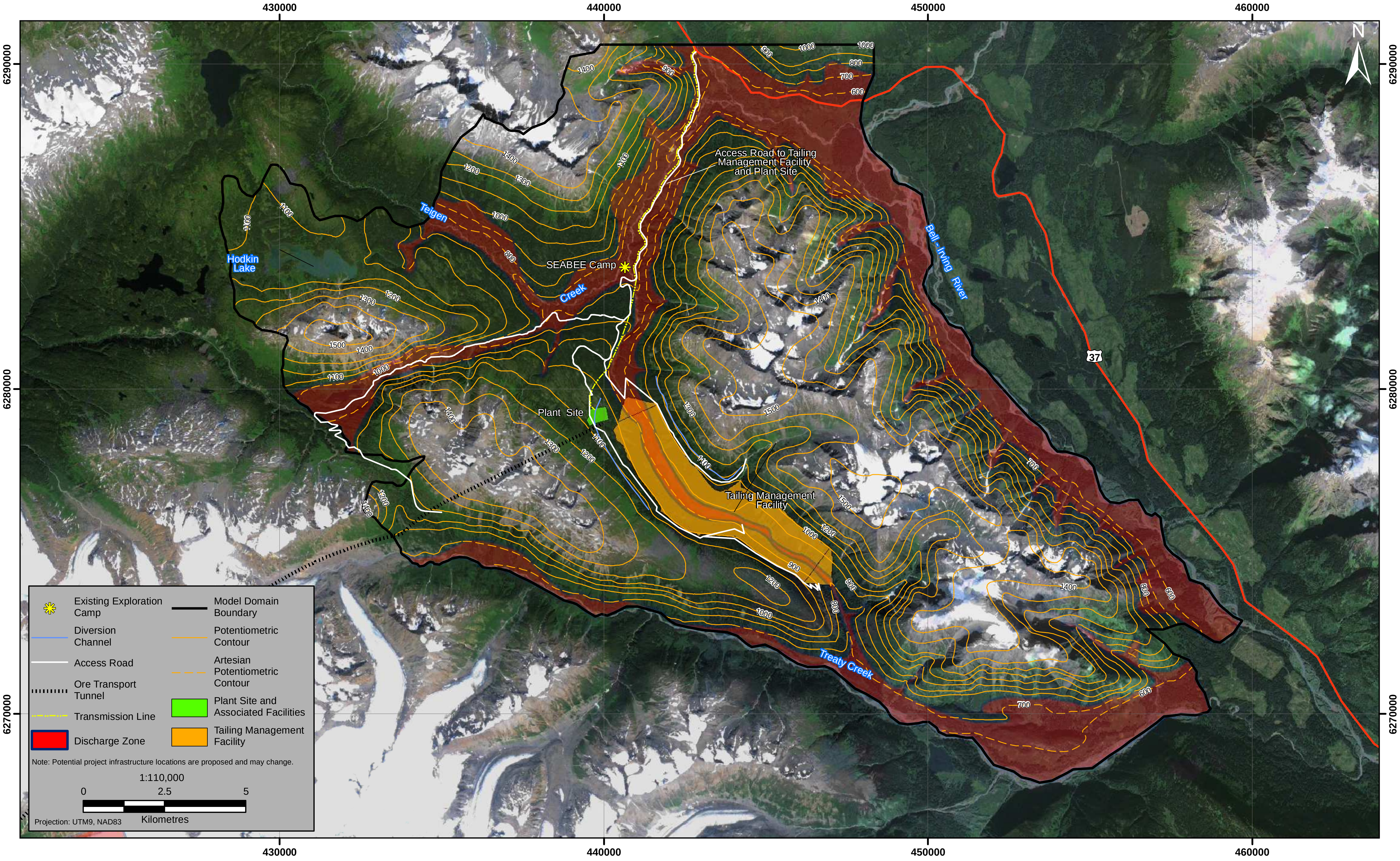
SEABRIDGE GOLD

FIGURE 2.5-1

KSM Project Potentiometric Surface Map - Mining Area

Rescan™

gis no. KSM-09-037 Job No. 0868-007-06 April 20, 2010



SEABRIDGE GOLD

FIGURE 2.5-2

KSM Project Potentiometric Surface Map – TMF Area

Rescan™

gis no. KSM-09-035 Job No. 0868-007-06 April 8 2010

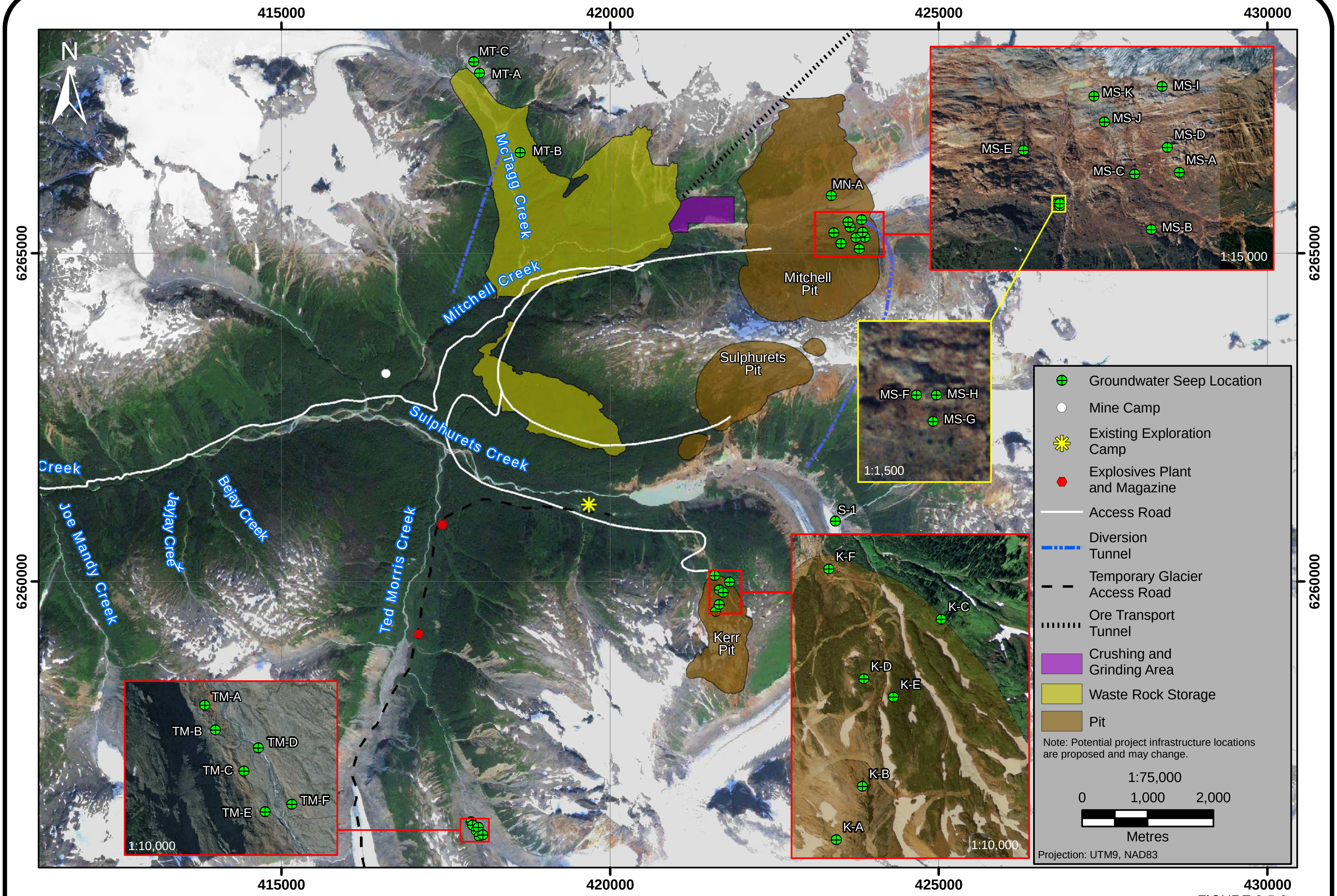


FIGURE 2.5-3

SEABRIDGE GOLD

KSM Project Groundwater Seep Locations – Mining Area

Rescan™

The proposed Mitchell Pit is located in both groundwater recharge and discharge zones whereas the proposed Sulphurets and Kerr Pits are located in groundwater recharge zones. The proposed Rock Storage Facility in the Mitchell and McTagg valley bases are located in the groundwater discharge areas while some of the area on the steep slopes is in groundwater recharge zone, but the Rock Storage Facility above the Sulphurets Creek (on the slopes) is located in a groundwater recharge zone. The proposed Water Storage Facility in the Mitchell Canyon is located in a groundwater discharge zone as is the proposed Tailing Management Facility, which is beneficial to hydraulic containment within these facilities.

In both the mining and TMF areas, groundwater level monitoring demonstrates that the seasonal variation of the groundwater table is relatively small (several metres), particularly at lower elevations and the valley floors (Figure 2.5-4). Larger seasonal fluctuations were observed in a few wells located at high elevations such as RES-MW-07 on the top of Sulphurets deposit (a groundwater recharge zone and more influence by rainfall and melting snow).

2.6 HYDRAULIC TESTING DATA

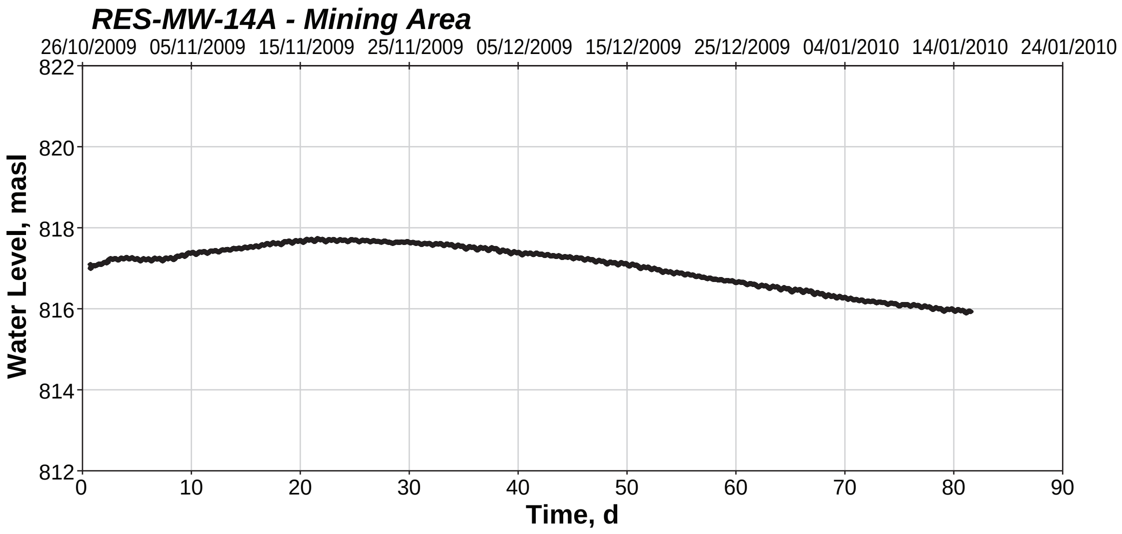
The hydraulic conductivities (K) of overburden and bedrock within the KSM Project mining and TMF areas have been estimated from packer tests during drilling operations and from slug tests in completed monitoring wells and piezometers. There is no pumping test from which estimates of the hydraulic conductivities of the large-scale aquifer or the anisotropy of geological materials can be made. Full details of the hydraulic tests and results available at the time of the hydrogeological modelling analysis can be found in Rescan's Hydrogeology Baseline Report (Rescan 2010c, Appendix 11-B of the EA Chapter 11). The results were carefully examined and checked against the geological materials shown in the borehole logs, in order to build a model that represents the hydrogeological system in each area.

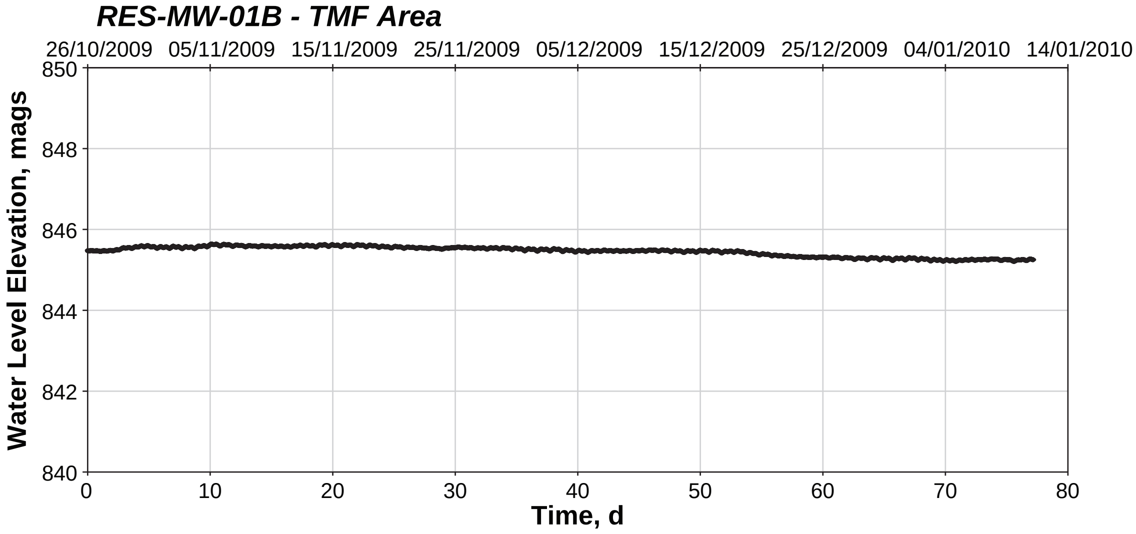
2.6.1 Hydraulic Conductivities of Overburden

As described in the previous sections, the overburden in the KSM Project study area is generally thin colluvium (less than 5 m) on valley slopes and at high elevations, and thicker (greater than 5 m) on the valley bases where glacial, colluvial and fluvial deposits occur. The field measured hydraulic conductivities for overburden in the KSM Project study area are shown in Table 2.6-1. Overburden hydraulic conductivities are generally low for glacial till sediments and Kerr colluvium (2.4×10^{-9} m/s to 1.0×10^{-6} m/s with the geometric mean 6.8×10^{-8} m/s) and show a trend of decreasing hydraulic conductivity with depth (Figure 2.6-1). Fluvial deposits close to river beds demonstrate a much higher hydraulic conductivity (only one estimate at 6.4×10^{-5} m/s). The tests of the hydraulic conductivities for the glacial till and colluvial materials were conducted in the monitoring wells located in the mining area, while only one test of fluvial deposits was conducted in the monitoring well RES-MW-02B located in the TMF area.

2.6.2 Hydraulic Conductivities of Bedrock

The field measured hydraulic conductivities for bedrocks in the KSM Project study area are shown in Tables 2.6-2 and 2.6-3. As described previously, bedrock formations in the mining area are highly complex consisting of various volcanic, intrusive and sedimentary rocks of Stuhini Group and Hazelton Group. The tested hydraulic conductivities of the volcanic and intrusive bedrocks in the mining area are ranging from 2.9×10^{-10} m/s to 1.1×10^{-5} m/s (geometric mean 1.3×10^{-7} m/s), and the hydraulic conductivities of the sedimentary rocks in the mining area are ranging from 2.8×10^{-9} m/s to 6.1×10^{-6} m/s (geometric mean 1.1×10^{-7} m/s). The plots show that there is a trend of decreasing hydraulic conductivities with depth for the volcanic and intrusive rocks in both Mitchell and Sulphurets valleys, but the trend of decreasing K with depth for the sedimentary rocks is weaker in comparison with the volcanic and intrusive rocks (Figure 2.6-2 and 2.6-3).


RES-MW-14A - Mining Area


RES-MW-01B - TMF Area

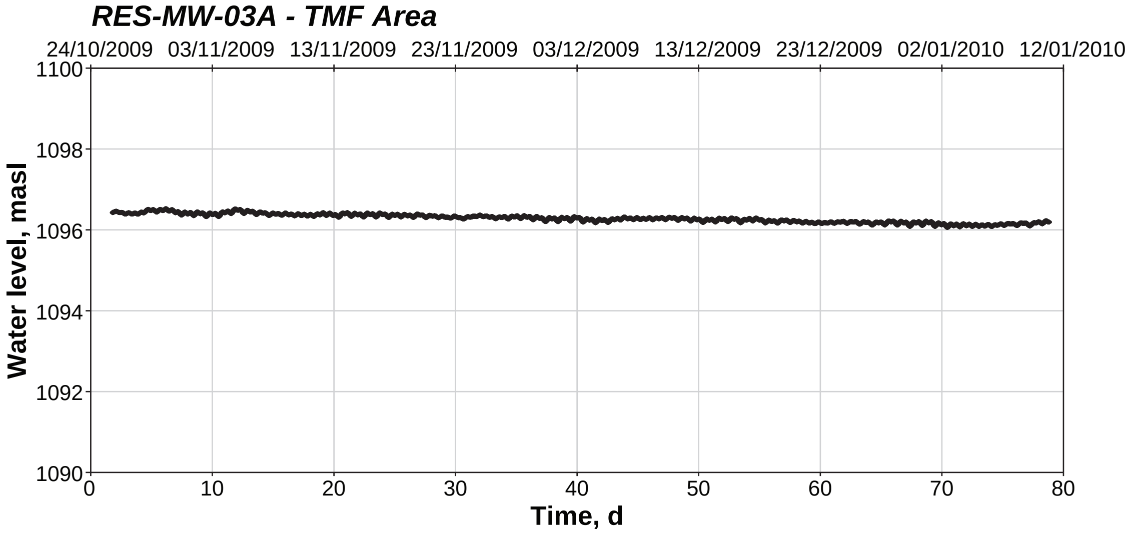

RES-MW-03A - TMF Area

FIGURE 2.5-4

KSM Project Continuous Groundwater Level Monitoring

SEABRIDGE GOLD

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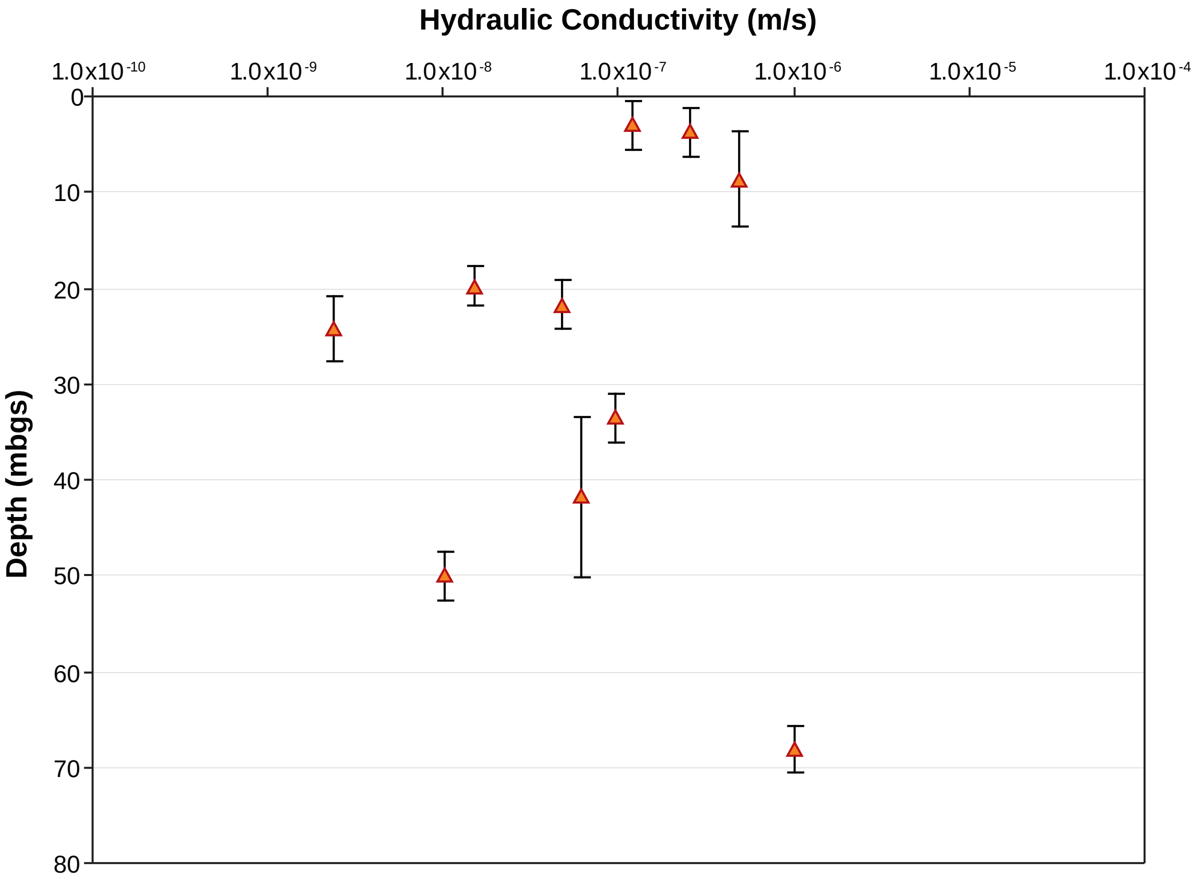
Table 2.6-1. Testing Results Summary of Overburden Hydraulic Conductivities

Hole ID	Test Type	Test Date	Test Interval From (mbgs)	Test Interval To (mbgs)	Static Water Level for Fall Head Test or Theis Recovery, Packer Test Midpoint (mbgs)	K (m/s)	Screened Lithology	Location
KC09-09	Falling Head Test	2-Sep-09	1.23	6.23	5.0	2.6E-07	Moraine	Mining Area
KC09-09	Falling Head Test	3-Sep-09	3.63	13.63	5.1	4.9E-07	Colluvium	Mining Area
KC09-09	Falling Head Test	4-Sep-09	19.20	24.2	13.0	4.8E-08	Colluvium	Mining Area
KC09-09	Falling Head Test	5-Sep-09	31.05	36.05	7.9	9.6E-08	Colluvium	Mining Area
KC09-09	Falling Head Test	6-Sep-09	47.50	52.5	14.2	1.0E-08	Colluvium	Mining Area
KC09-09	Falling Head Test	7-Sep-09	65.60	70.6	13.6	1.0E-06	Colluvium	Mining Area
KC09-10	Falling Head Test	11-Sep-09	0.50	5.5	1.7	1.2E-07	Glaciofluvial Sand	Mining Area
RES-MW-13A	Double Packer Test	15-Aug-09	33.34	50.26	41.80	6.1E-08	Overburden	Mining Area
RES-MW-02B	Theis Recovery	28-Oct-09	17.10	25.30	9.39	6.4E-05	Fluvial Sediments	TMF Area



Hydraulic Conductivities of Overburden with Depth – Mining Area

FIGURE 2.6-1

Table 2.6-2. Packer Testing Results Summary of Bedrock Hydraulic Conductivities

Hole ID		Performed by	Date	Test (mbgs)^2 From (top)	Test (mbgs)^2 To (bottom)	Midpoint	Type of Test^2	K (m/s)	Screened Lithology
RES-MW-01	A	Rescan	September 11th, 2009	12.88	31.39	22.14	Double	6.1E-07	Undifferentiated seds
		Rescan	September 12th, 2009	72.31	82.06	77.19	Triple	2.3E-07	Undifferentiated seds
		Rescan	September 12th, 2009	81.45	90.83	86.14	Double	1.2E-07	Undifferentiated seds
	B	Rescan	September 14th, 2009	13.11	20.73	16.92	Triple	6.8E-08	Undifferentiated seds
		Rescan	September 14th, 2009	20.73	26.82	23.78	Triple	1.4E-07	Undifferentiated seds
		Rescan	September 13th, 2009	31.17	42.86	37.02	Double	6.6E-07	Undifferentiated seds
RES-MW-02	A	Rescan	September 6th, 2009	42.36	49.96	46.16	Double	1.5E-07	Siltstone
		Rescan	September 7th, 2009	50.00	61.90	55.95	Double	4.7E-08	Undifferentiated seds
		Rescan	September 7th, 2009	75.60	80.20	77.90	Double	4.4E-07	Siltstone
RES-MW-03	A	Rescan	September 17th, 2009	11.84	25.56	18.70	Triple	1.5E-07	Undifferentiated seds
		Rescan	September 17th, 2009	25.60	39.32	32.46	Triple	1.2E-06	Siltstone
		Rescan	September 17th, 2009	39.32	53.04	46.18	Triple	2.8E-07	Siltstone
		Rescan	September 17th, 2009	51.51	65.23	58.37	Triple	2.7E-07	Siltstone
		Rescan	September 17th, 2009	66.75	69.80	68.28	Triple	4.7E-06	Late Quartz Veins
		Rescan	September 16th, 2009	69.58	89.61	79.60	Double	1.2E-06	Undifferentiated seds
RES-MW-04	A	Rescan	June 18th, 2009	25.34	42.20	33.77	Double	7.2E-06	Volcanic, unknown protolith (intensely altered)
		Rescan	June 19th, 2009	47.72	66.20	56.96	Double	7.6E-06	Volcanic, unknown protolith (intensely altered)
		Rescan	June 19th, 2009	63.25	78.54	70.90	Double	1.1E-05	Volcanic, unknown protolith (intensely altered)
RES-MW-05	A'	Rescan	July 14th, 2009	16.54	31.27	23.91	Double	1.2E-06	Porhyritic Andesite Intrusive
		Rescan	July 15th, 2009	41.23	53.86	47.55	Double	3.9E-07	Intermediate Volcanics, Massive Flows/Tuffs
		Rescan	July 15th, 2009	51.27	66.02	58.65	Double	6.7E-07	Intermediate Volcanics, Massive Flows/Tuffs
RES-MW-07	A	Rescan	July 31st, 2009	17.27	32.70	24.99	Double	7.9E-08	Andesite Ash Tuff
		Rescan	August 1st, 2009	44.02	66.14	55.08	Double	1.4E-08	Andesite Ash Tuff
		Rescan	August 2nd, 2009	70.43	99.58	85.01	Double	3.1E-09	Porphyritic monzonite or syenite
		Rescan	August 3rd, 2009	119.79	151.26	135.53	Double	4.6E-09	Siliceous Hydrothermal Breccia
		Rescan	August 5th, 2009	161.56	216.62	189.09	Double	8.1E-10	Porphyritic monzonite or syenite
RES-MW-09	A	Rescan	August 20th, 2009	42.07	51.41	46.74	Double - FHT	2.5E-07	Fault Zone
		Rescan	August 20th, 2009	58.78	71.17	64.98	Double - FHT	2.7E-07	Volcanic, unknown protolith (intensely altered)
		Rescan	August 21st, 2009	76.75	97.01	86.88	Double	8.5E-07	Volcanic, unknown protolith (intensely altered)
RES-MW-10	A	Rescan	August 27th, 2009	38.47	46.27	42.37	Double	1.7E-08	Unknown Tuff
		Rescan	August 28th, 2009	56.46	75.15	65.81	Double	2.7E-07	Unknown Intrusive (intensely altered)
RES-MW-11	A	Rescan	September 7th, 2009	41.06	59.82	50.44	Double	6.7E-09	Undifferentiated seds
RES-MW-12	A	Rescan	July 25th, 2009	18.70	35.62	27.16	Double	7.2E-07	Volcaniclastics/Argillites
		Rescan	July 26th, 2009	36.74	55.38	46.06	Double	8.0E-07	Siltstone
		Rescan	July 26th, 2009	58.22	69.06	63.64	Double	3.2E-08	Siltstone
RES-MW-13	A	Rescan	August 15th, 2009	62.20	76.10	69.15	Double	2.8E-08	Volcanic, unknown protolith (intensely altered)
RES-MW-14	A	Rescan	July 20th, 2009	21.34	27.62	24.48	Double	1.3E-07	Undifferentiated seds
		Rescan	July 20th, 2009	30.80	49.09	39.95	Double	1.4E-07	Undifferentiated seds
		Rescan	July, 21st, 2009	45.48	62.77	54.13	Double	3.7E-08	Undifferentiated seds
RES-MW-15	A	Rescan	September 10th, 2009	6.91	18.02	12.47	Double	1.3E-07	Fault Zone
		Rescan	September 11th, 2009	17.52	40.82	29.17	Double	8.0E-07	Feldspar Porphyry Intrusions
		Rescan	September 11th, 2009	35.76	57.54	46.65	Double	3.8E-07	Feldspar Porphyry Intrusions
		Rescan	September 12th, 2009	59.62	72.74	66.18	Double	1.9E-07	Feldspar Porphyry Intrusions
		Rescan	September 13th, 2009	73.42	100.10	86.76	Double	7.9E-09	Feldspar Porphyry Intrusions
KC09-07	-	KCB	August 28th, 2009	6.93	11.10	9.02	Double	8.6E-06	Altered Volcanics
	-	KCB	August 28th, 2009	16.10	26.90	21.50	Double	4.0E-06	Altered Volcanics
KC09-08	-	KCB	September 1st, 2009	30.00	40.70	35.35	Double	1.1E-07	Andesite Tuff and Fault Zone
	-	KCB	September 1st, 2009	40.25	49.25	44.75	Double	9.6E-08	Andesite Tuff and Fault Zone

(continued)

Table 2.6-2. Packer Testing Results Summary of Bedrock Hydraulic Conductivities (completed)

Hole ID		Performed by	Date	Test (mbgs)[2]		Midpoint	Type of Test[2]	K (m/s)	Screened Lithology
				From (top)	To (bottom)				
KC09-09	-	KCB	September 8th, 2009	95.00	113.39	104.20	Double	7.0E-08	Undifferentiated seds
	-	KCB	September 9th, 2009	113.08	126.89	119.99	Double	1.5E-07	Undifferentiated seds
	-	KCB	September 9th, 2009	102.95	126.89	114.92	Double	9.4E-08	Undifferentiated seds
KC09-10	-	KCB	September 11th, 2009	8.13	15.80	11.97	Double	1.1E-07	Undifferentiated seds and Fault zones
	-	KCB	September 11th, 2009	13.40	25.20	19.30	Double	3.1E-07	Undifferentiated seds
	-	KCB	September 11th, 2009	6.21	28.01	17.11	Double	2.3E-07	Undifferentiated seds
KC09-11	-	KCB	September 12th, 2009	4.65	14.37	9.51	Double	2.2E-08	Undifferentiated seds
	-	KCB	September 12th, 2009	16.00	30.87	23.44	Double	7.3E-08	Undifferentiated seds and Grando
KC09-12	-	KCB	September 14th, 2009	34.43	40.16	37.30	Double	7.2E-08	Undifferentiated seds
	-	KCB	September 15th, 2009	43.42	51.00	47.21	Double	3.9E-08	Undifferentiated seds and Fault zone
KC09-13	-	KCB	September 18th, 2009	13.95	23.87	18.91	Double	8.2E-08	Undifferentiated seds
	-	KCB	September 18th, 2009	36.33	54.65	45.49	Double	6.2E-07	Undifferentiated seds
M-09-095	-	BGC	N/A	92.10	118.53	105.32	Double	N/A	Volcanic, unknown protolith (intensely altered)
	-	BGC	N/A	205.84	252.32	229.08	Double	2.5E-09	Volcanic, unknown protolith (intensely altered)
	-	BGC	N/A	356.45	401.11	378.78	Double	2.1E-09	Volcanic, unknown protolith (intensely altered)
M-09-096	-	BGC	N/A	72.29	98.14	85.22	Double	1.3E-07	Intermediate Volcanics, Massive Flows/Tuffs
	-	BGC	N/A	139.44	171.72	155.58	Double	N/A	Intermediate Volcanics, Massive Flows/Tuffs
	-	BGC	N/A	191.08	215.62	203.35	Double	2.4E-09	Intermediate Volcanics, Massive Flows/Tuffs
	-	BGC	N/A	232.44	258.27	245.36	Double	1.0E-09	Intermediate Volcanics, Massive Flows/Tuffs
M-09-097	-	BGC	N/A	23.99	39.58	31.79	Double	N/A	Intermediate Volcanics, Massive Flows/Tuffs Porhyritic Monzonite Intrusive
	-	BGC	N/A	45.58	56.37	50.98	Double	6.8E-07	Porhyritic Monzonite Intrusive
	-	BGC	N/A	189.53	202.72	196.13	Double	6.4E-07	Intermediate Volcanics, Massive Flows/Tuffs
	-	BGC	N/A	260.30	272.30	266.30	Double	1.8E-08	Intermediate Volcanics, Massive Flows/Tuffs Porhyritic Monzonite Intrusive
M-09-098	-	BGC	N/A	17.70	32.26	24.98	Double	4.5E-08	Porhyritic Monzonite Intrusive
	-	BGC	N/A	94.62	119.43	107.03	Double	1.4E-07	Porhyritic Monzonite Intrusive
	-	BGC	N/A	214.96	221.16	218.06	Double	1.0E-07	Volcanic, unknown protolith (intensely altered) Porhyritic Monzonite Intrusive
	-	BGC	N/A	285.67	303.04	294.36	Double	2.2E-08	Volcanic, unknown protolith (intensely altered)
M-09-099	-	BGC	N/A	55.06	81.22	68.14	Double	1.0E-07	Volcanic, unknown protolith (intensely altered)
	-	BGC	N/A	121.23	147.29	134.26	Double	3.4E-09	Volcanic, unknown protolith (intensely altered)
	-	BGC	N/A	269.82	295.97	282.90	Double	1.7E-09	Volcanic, unknown protolith (intensely altered)
M-09-100	-	BGC	N/A	39.65	61.43	50.54	Double	1.1E-06	Intermediate Volcanics, Massive Flows/Tuffs
	-	BGC	N/A	77.72	159.95	118.84	Double	2.9E-07	Intermediate Volcanics, Massive Flows/Tuffs
	-	BGC	N/A	195.50	213.27	204.39	Double	2.9E-10	Intermediate Volcanics, Massive Flows/Tuffs
M-09-101	-	BGC	N/A	228.00	247.27	237.64	Double	2.8E-07	Andesite Ash Tuff
M-09-102a	-	BGC	N/A	286.66	298.00	292.33	Double	1.3E-07	Andesite Ash Tuff

[1] *mbgs = meters below ground surface*

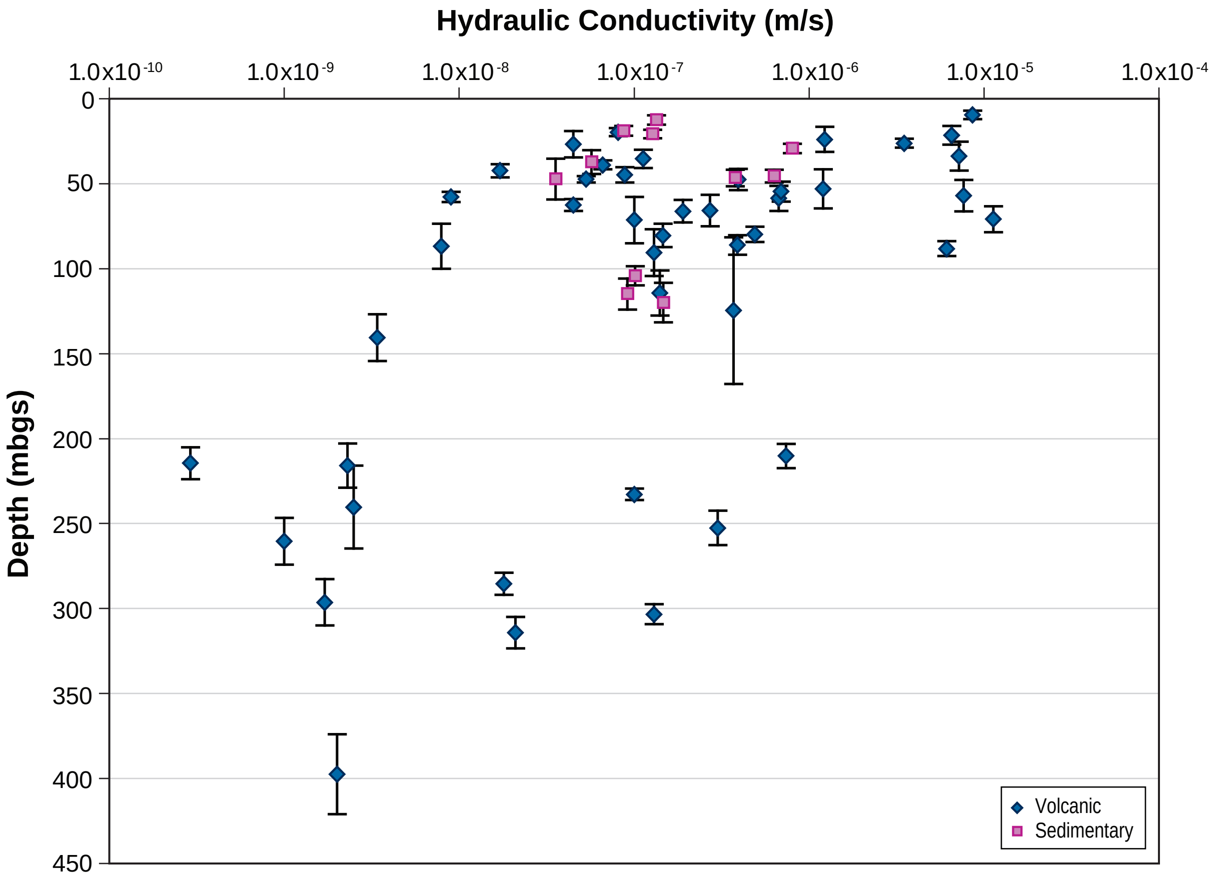
[2] *All packer tests were constant head packer tests analyzed by the Thiem (1906) method unless labelled with "FHT". FHT = Falling head packer test analyzed by Hvorslev (1951) analysis.*

N/A = Data not available

Table 2.6-3. Other Testing Results Summary of Bedrock Hydraulic Conductivities

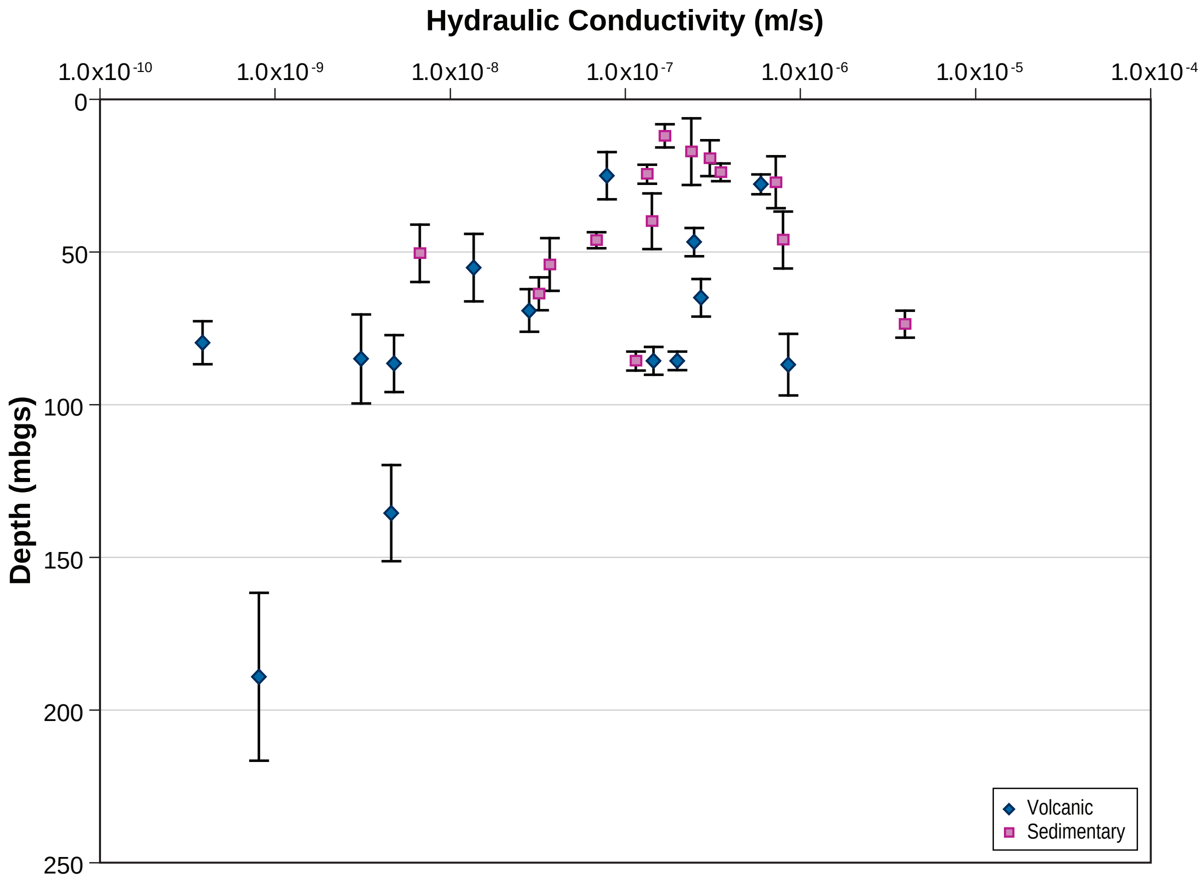
				Sand pack intervals (mbgs)		Sand pack		Initial	Hydraulic Conductivity Results (m/s)				
Well ID		Test Type	Test Date	From (top)	To (bottom)	length (m)	Static WL (mbgs)	Displacement (m)	Hvorslev	B & R	Theis Recovery	Artesian Flow Test	Screened Lithology
RES-MW-01	A	AFT	5-Oct-09	73.15	81.38	6.09	-6.01	-	-	-	-	3.7E-07	Undifferentiated seds
	B	FHT	22-Oct-09	48.16	52.73	4.57	3.68	3.03	1.1E-05	8.7E-06	-	-	Undifferentiated seds
	B	RHT	22-Oct-09	48.16	52.73	4.57	3.68	-2.21	1.4E-05	1.1E-05	-	-	Undifferentiated seds
RES-MW-02	A	FHT	28-Oct-09	70.10	76.81	6.71	6.34	2.39	1.8E-06	1.4E-06	-	-	Undifferentiated seds, siltstone
RES-MW-03	A	TR	24-Oct-09	72.57	85.04	12.47	9.53	-	-	-	3.7E-07	-	Undifferentiated seds
	B	TR	24-Oct-09	44.81	52.73	7.92	9.38	-	-	-	1.7E-07	-	Siltstone
RES-MW-04	A	AFT	21-Oct-09	83.71	92.66	8.95	-1.57	-	-	-	-	6.1E-06	Volcanic, unknown protoloith (intensely altered)
	B	FHT	21-Oct-09	17.21	22.13	4.92	1.08	2.11	8.1E-08	8.1E-08	-	-	Volcanic, quartz vein
RES-MW-05	A'	AFT	22-Sep-09	75.38	84.39	9.01	-1.44	-	-	-	-	-	Intermediate volcanic, massive flows/tuffs
	A'	RHT	7-Oct-09	75.38	84.39	9.01	-1.23	-2.21	6.2E-07	4.9E-07	-	-	Intermediate volcanic, massive flows/tuffs
	B	FHT	7-Oct-09	36.38	41.51	5.13	11.13	1.54	8.6E-08	6.6E-08	-	-	Porphyritic monzonite or syenite
	B	FHT2	7-Oct-09	36.38	41.51	5.13	11.13	1.75	1.8E-07	1.3E-07	-	-	Porphyritic monzonite or syenite
RES-MW-06	A	TR	23-Oct-09	73.66	87.40	13.74	-0.30	-	-	-	1.5E-07	-	Intermediate volcanic, massive flows/tuffs
	B	TR	23-Sep-09	23.50	28.84	5.34	-0.63	-	-	-	3.5E-06	-	Intermediate volcanic, massive flows/tuffs
	B	RHT	23-Oct-09	23.50	28.84	5.34	-0.63	-0.38	3.9E-06	3.0E-06	-	-	Intermediate volcanic, massive flows/tuffs
RES-MW-07	A	FHT	26-Oct-09	72.60	86.72	14.12	13.32	2.34	4.9E-10	3.9E-10	-	-	Andesite ash tuff
	B	RHT	24-Sep-09	24.62	31.01	6.39	8.13	-9.26	8.1E-07	6.0E-07	-	-	Andesite ash tuff
RES-MW-09	A	FHT	14-Oct-09	87.93	97.01	9.08	24.76	2.72	1.9E-07	1.5E-07	-	-	Volcanic, unknown protoloith (intensely altered)
	A	FHT2	14-Oct-09	87.93	97.01	9.08	24.76	4.05	1.9E-07	1.5E-07	-	-	Volcanic, unknown protoloith (intensely altered)
	B	FHT	14-Oct-09	48.96	55.04	6.08	26.74	1.69	2.6E-07	2.0E-07	-	-	Volcanic, fault zone
	B	FHT2	14-Oct-09	48.96	55.04	6.08	26.74	1.57	2.6E-07	2.0E-07	-	-	Volcanic, fault zone
RES-MW-10	A	FHT	15-Oct-09	80.31	91.87	11.56	60.02	2.51	4.9E-07	3.9E-07	-	-	Volcanic, unknown protoloith (intensely altered)
	A	FHT2	15-Oct-09	80.31	91.87	11.56	60.02	1.78	4.9E-07	3.9E-07	-	-	Volcanic, unknown protoloith (intensely altered)
	B	FHT**	15-Oct-09	59.00	65.93	6.93	58.89	3.37	5.7E-08	4.5E-08	-	-	Volcanic, unknown protoloith (intensely altered)
RES-MW-11	A	RHT	28-Oct-09	60.66	70.55	9.89	-1.44	-	-	-	-	-	Undifferentiated seds
	B	FHT	21-Oct-09	13.53	16.20	2.67	1.30	-	-	-	-	-	Fluvial gravel (overburden)
RES-MW-12	A	FHT	21-Oct-09	82.53	88.82	6.29	30.02	2.24	1.5E-07	1.2E-07	-	-	Siltstone
	B	FHT	21-Oct-09	21.04	26.85	5.81	12.54	2.37	4.6E-07	3.5E-07	-	-	Volcaniclastics/argillites
RES-MW-13	A	FHT	22-Oct-09	77.19	95.86	18.67	16.46	2.40	5.9E-09	4.8E-09	-	-	Volcanic, unknown protoloith (intensely altered)
	B	FHT	22-Oct-09	20.96	27.70	6.74	10.32	2.26	3.2E-09	2.4E-09	-	-	Fluvial boulders (overburden)
RES-MW-14	A	FHT	27-Oct-09	69.18	77.97	8.79	32.95	0.84	5.1E-06	4.0E-06	-	-	Undifferentiated seds
	B	FHT	28-Oct-09	43.56	48.80	5.24	28.35	2.49	8.9E-08	6.8E-08	-	-	Undifferentiated seds
RES-MW-15	A	FHT	24-Oct-09	91.30	100.10	8.80	NA	-	-	-	-	-	Feldspar porphyry intrusions
	B	FHT**	5-Oct-09	18.08	23.53	5.45	20.08	1.18	1.7E-07	1.3E-07	-	-	Undifferentiated seds
	B	FHT2**	5-Oct-09	18.08	23.53	5.45	20.08	2.47	1.2E-07	8.8E-08	-	-	Undifferentiated seds
KC08-01	-	FHT***	27-Oct-09	17.68	21.87	4.19	5.65	1.59	2.0E-08	1.5E-08	-	-	Glacial till clay (overburden)
KC08-04	-	FHT***	25-Nov-09	65.53	72.09	6.56	18.42	4.38	9.2E-09	7.1E-09	-	-	Mudstone
KC08-05	-	FHT***	26-Nov-09	15.85	23.47	7.62	5.23	3.16	4.9E-09	3.8E-09	-	-	Mudstone
KC09-08	-	FHT***	22-Oct-09	45.50	49.25	3.75	35.04	2.40	6.9E-08	5.3E-08	-	-	Unknown ash tuff
KC09-09	BDRK	FHT***	27-Oct-09	121.10	126.10	5.00	12.72	1.32	4.2E-07	3.3E-07	-	-	Undifferentiated seds
KC09-12	-	FHT***	27-Oct-09	52.00	57.50	5.50	10.28	2.48	3.6E-09	2.8E-09	-	-	Undifferentiated seds
KC09-13	-	FHT***	24-Oct-09	54.70	60.90	6.20	31.31	2.49	1.2E-08	9.0E-09	-	-	Feldspar porphyry intrusions

AFT = artesian flow test
FHT = falling head test (slug test)
RHT = rising head test (slug test)
TR = theis recovery
mbgs = meters below ground surface
BDRK = bedrock
Hvorslev = Hvorslev (1951) analysis for slug tests
B & R = Bouwer and Rice (1976) analysis for slug tests
Theis Recovery = Theis Recovery Method (Theis, 1935) for pumping tests
Artesian Flow Test = Thiem (1906) analysis for constant head tests
**Aquifer thickness taken as thickness of bottom of sandpack to water table. Taken as entire well depth for artesian wells.*
*** Static water level below top of sand pack interval. Results should be taken with caution.*
**** Wells were not developed prior to slug testing, could cause underestimation of hydraulic conductivity values*



Hydraulic Conductivities of Bedrock with Depth – Mining Area Mitchell Valley

FIGURE 2.6-2



Hydraulic Conductivities of Bedrock with Depth – Mining Area Sulphurets Valley

FIGURE 2.6-3

For bedrock within the Mitchell valley, where the proposed Mitchell Open Pit is located, there is a difference in K for rocks beneath and above the Mitchell Thrust Fault. From the plot of the hydraulic conductivities, according to the test locations relative to the Mitchell Thrust Fault, the bedrock above the Mitchell Thrust Fault is less permeable than that below the Mitchell fault within the depth of 100 mbgs (Figure 2.6-4). There is little variation in hydraulic conductivities with depth above the fault, but there is an obvious trend of decreasing permeability with depth for the bedrock below the fault, which is supported by the observation that more fractures occurred in the bedrock below the fault than above the fault. The geometric mean of the measured hydraulic conductivities is 1.0 x 10^{-7} m/s for the bedrock above the Mitchell Thrust Fault, and 3.0 x 10^{-7} m/s for the bedrock below the fault within the depth of 100 mbgs in the Mitchell valley. The geometric mean of the measured hydraulic conductivities is 3.0 x 10^{-7} m/s for the volcanic and intrusive bedrock in the Sulphurets valley.

In the TMF area, folded and faulted sedimentary rocks of Bowser Lake Group are present. The hydraulic conductivity estimates range from 3.8 x 10^{-9} m/s to 1.4 x 10^{-5} m/s with the geometric mean 3.2 x 10^{-7} m/s, and the trend of decreasing K with depth is similar to that observed in the sedimentary rocks in the mining area (Figure 2.6-5).

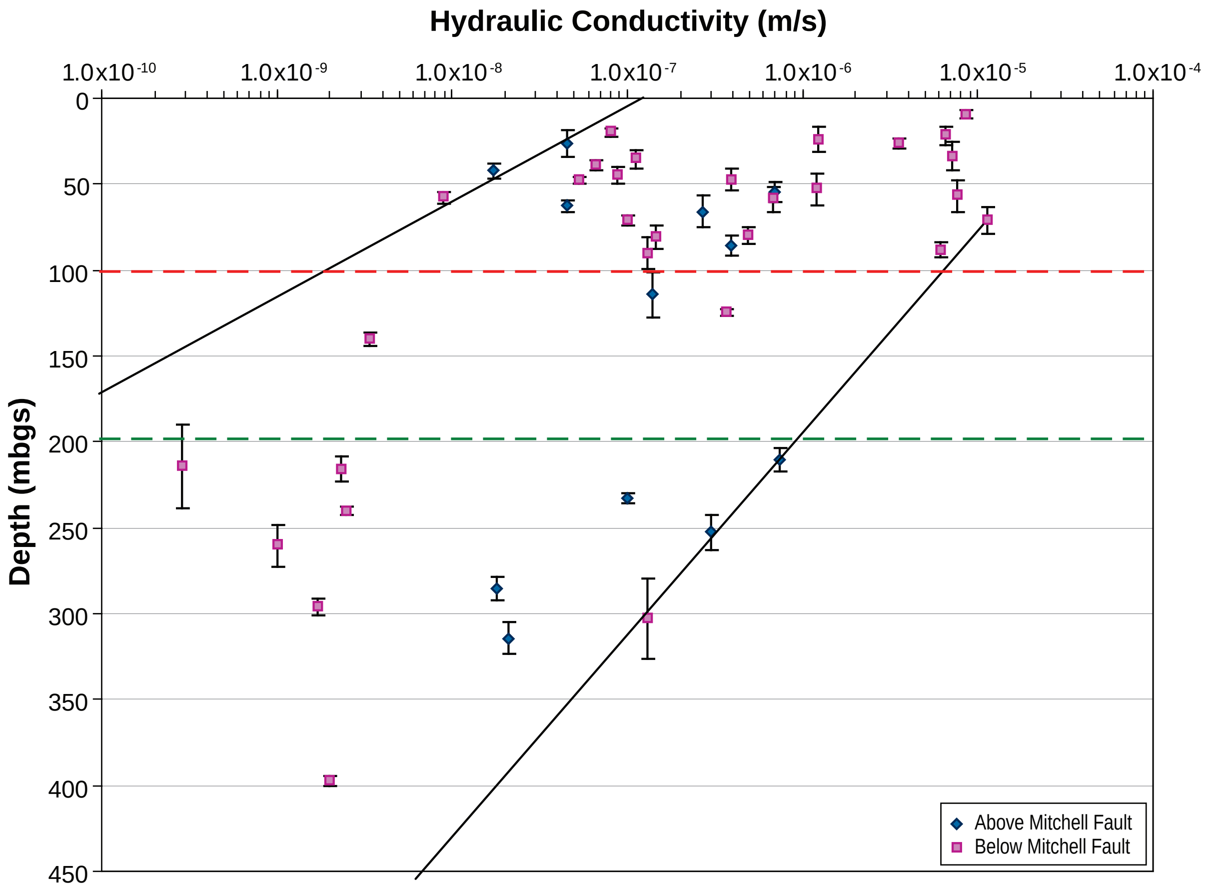
Overall in both the mining and TMF areas of the KSM Project, the borehole logs (depths up to 681.3 mbgs) show that the degree of fracturing (and therefore the K) in the bedrocks generally decreases with depth. This relationship is more evident in logs from the upper surficial materials of the ridges and slopes than the valley bases (e.g., from the boreholes drilled in the Mitchell deposit). The information suggests that the majority of groundwater flow occurs in the upper, more fractured bedrocks.

2.6.3 Hydraulic Conductivities of Faults

At the time of this modelling analysis, the information for the hydraulic conductivities of fault zones within the KSM Project site is very limited. A limited numbers of measurements of fault zone hydraulic conductivities are shown in Table 2.6-4. These zones were identified in the core logs and tested as potential faults.

Table 2.6-4. Hydraulic Conductivities of Faults

Hole ID	Fault Zone Interval (mbgs)		Lithology	Tested Interval		K (m/s)
	From (top)	To (bottom)		From (top)	To (bottom)	
RES-MW-03	66.90	67.67	Undifferentiated Sedimentary Rocks	66.75	69.8	$4.7x10^{-6}$
RES-MW-09	44.95	56.94	Undifferentiated Sedimentary Rocks (above), Volcanic unknown protolith (below)	48.96	55.04	$2.6x10^{-7}$
KC09-08	43.60	44.80	Andesite Tuff	40.25	49.25	$8.8x10^{-8}$
KC09-10	15.20	15.50	Undifferentiated Sedimentary Rocks	8.13	15.8	$1.7x10^{-7}$

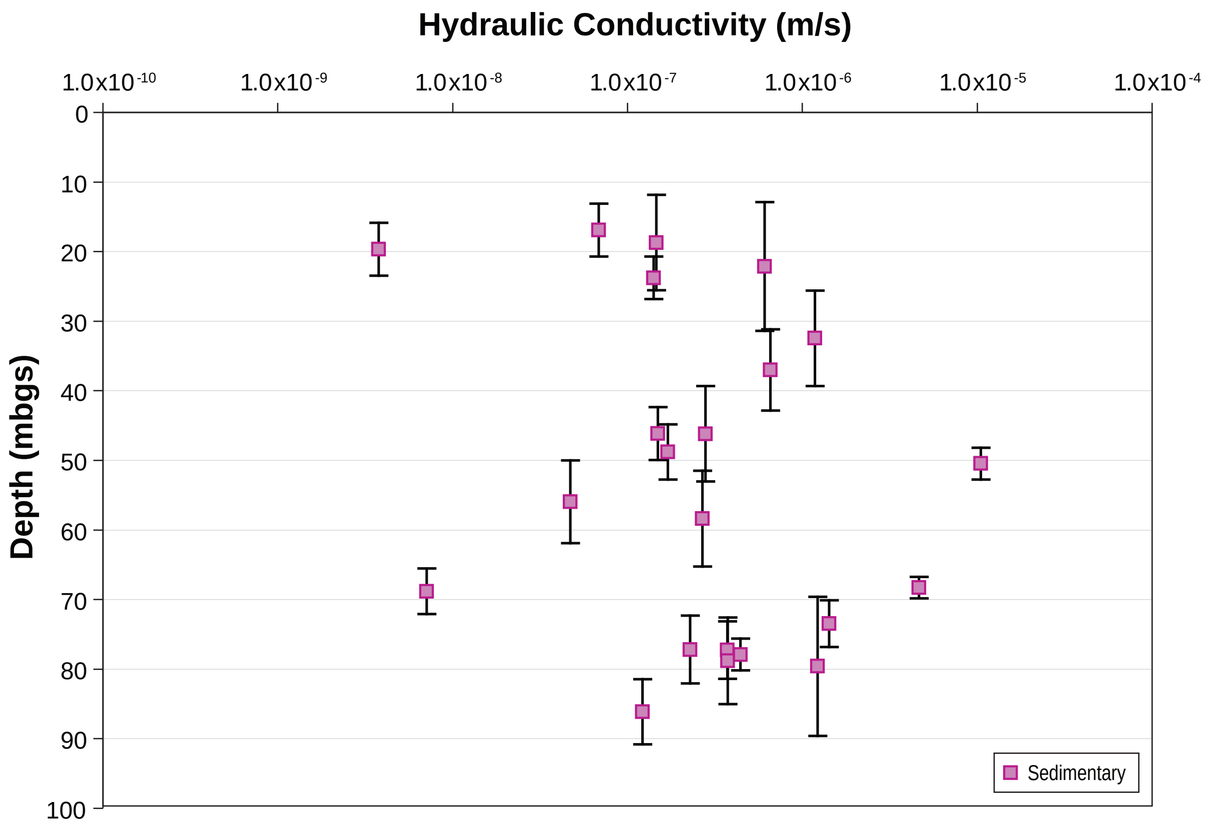


Hydraulic Conductivities of Bedrock
Above and Below Mitchell Thrust Fault

FIGURE 2.6-4

SEABRIDGE GOLD

Rescan™



Hydraulic Conductivities of Bedrock with Depth – TMF Area

FIGURE 2.6-5

SEABRIDGE GOLD

Rescan™

3. Hydrogeological Model in Mining Area

This chapter describes the hydrogeological modelling analysis for the mining area where the proposed Open Pits, Water Storage Facility and Rock Storage Facilities are located for the KSM project (Figure 1.3-1). The objectives of the modelling analysis are: 1) to develop a three-dimensional numerical baseline model to represent the pre-mining hydrogeological system in the mining area; 2) use the calibrated baseline model to characterize the regional and local groundwater flow regime including water table, flow directions, groundwater recharge and discharge zones under the pre-mining conditions; 3) use the calibrated baseline model to predict the potential impacts of the mining activities (e.g., pit dewatering and pit lake refill, seepage from Water Storage Facility and Rock Storage Facilities) on water quantity and quality; 4) provide the results for calculation of the water balance and assessment of the environmental impact due to the mining.

The pre-mining baseline model in the mining area of the KSM Project is built on the basis of the conceptual hydrogeological model, which is developed with the available information and data as of July, 2010. The inputs in the baseline model are generated from the test data for the mining project, and also collected from the literature and other MODFLOW modelling work for the same or similar mining projects including those from the USGS (Jones 2002; Lyford et al. 2007; Rescan 2009).

The baseline model is calibrated to meet a number of targets including the field measured hydraulic heads in Rescan's and KCBL's monitoring wells and BGC's piezometers, the baseflow rates observed by Rescan for the major creeks, and the groundwater levels along the surface water bodies, as well as the groundwater seep locations observed in the valleys. The calibrated baseline model is run under steady-state conditions, and the outputs from the steady-state baseline model represent the long-term average pre-mining groundwater flow regime in the mining area.

The calibrated baseline model is then used to simulate the potential changes in groundwater flow as a result of the mining activities such as pit dewatering and pit lake, and also to simulate plume migration from the key mining facilities such as the Water Storage Facility and Rock Storage Facilities. The predictive simulations of groundwater flow and solute transport are conducted for the end of operation and post-closure according to the proposed mining plan.

The details of the methodologies and approaches utilized for the hydrogeological modelling in the mining area as well as the results are described in the following sections.

3.1 CONCEPTUAL MODEL

The conceptual model for the pre-mining baseline hydrogeological flow system in the KSM Project mining area has been developed based on the available meteorological, geological, hydrological and hydrogeological information and data summarized in Chapter 2.

Groundwater enters the aquifer system as recharge from precipitation, snow and glacial melting and through infiltration from surface runoff. Groundwater leaves the system as evapotranspiration and groundwater discharge into surface waterbodies (i.e., lakes, rivers, creeks and wetlands). Recharge to groundwater in the bedrock occurs by infiltration through overburden or directly through exposed fractured bedrock. For the area without glacial coverage, it is expected that groundwater recharge increases with elevations because precipitation increases with elevation. Less recharge is thought to occur at lower elevations where temperatures are higher, vegetation is more abundant (resulting in higher evapotranspiration rates) and more runoff due to the shallow water table in the valley bottoms is expected. For the areas covered by the glaciers, the groundwater recharge is expected to be very low as the ground is believed to be generally frozen. The steep slopes connecting the mountainous areas to the valley bottoms in the mining area (approximately 2,300 m difference between the highest and lowest points), suggests that groundwater recharge occurs on the tops of the ridges and slopes at higher elevations. Groundwater discharge zones are located at lower elevations on the lower valley slopes where groundwater seeps are observed and in the valley bottoms where there are creeks, lakes and wetlands. Groundwater is thought to interact with surface water throughout the watersheds.

The proposed Open Pit in the Mitchell valley is located in both groundwater recharge and discharge zones because of the elevation difference between the high wall and base of the pit. The proposed Sulphurets and Kerr Open Pits are located in regional groundwater recharge zones. The proposed Water Storage Facility located in the Mitchell Canyon is in groundwater discharge zone. The proposed Rock Storage Facility in the Mitchell and McTagg valley bases are located in groundwater discharge areas while some of the slope areas could be considered as groundwater recharge zones, although for the reasons mentioned above, groundwater recharge on the steeper slopes is not considered to be significant. The proposed Rock Storage Facility above the Sulphurets Creek is located in a groundwater recharge zone.

Hydrostrategraphically, the groundwater aquifer is composed of fractured bedrock formations (mainly Triassic-Jurassic volcanic, intrusive and sedimentary rocks of the Stuhini Group and Hazelton Group) in the mining area with overburden (mainly glacial till and colluvium with some fluvial) distributed on the valley bases. Several large faults such as the gently dipping Mitchell and Sulphurets Thrust Faults superimpose lower older rocks on younger formations. Generally, the aquifer is unconfined in mountainous and valley slopes where the overburden is thin or doesn't exist, but could be confined on the valley bottoms where the overburden is thick and glacial till predominates.

The observed groundwater table tends to reflect topography, and the unsaturated zone thickness (the depths from ground surface to water table) increases with increasing ground elevations. Groundwater flows from higher elevations towards lower elevations in the valleys, the downward gradients predominate in higher elevations while upward gradients or artesian condition are commonly observed in lower elevations particularly on the bottom of the valleys. The groundwater flow system observed in the study area is generally in a steady-state condition.

Overburden hydraulic conductivities available are generally low for glacial till sediments and Kerr colluvium (2.4×10^{-9} m/s to 1.0×10^{-6} m/s) with a geometric mean 6.8×10^{-8} m/s. No test data is available for the hydraulic conductivities of fluvial deposits in the mining area, which are believed to be similar to the estimate 6.4×10^{-5} m/s for fluvial sediments in the TMF area. The hydraulic conductivities of the volcanic and intrusive bedrocks in the mining area range from 2.9×10^{-10} m/s to 1.1×10^{-5} m/s with the geometric mean 1.3×10^{-7} m/s, and the hydraulic conductivities of the sedimentary rocks in the area range from 2.8×10^{-9} m/s to 6.1×10^{-6} m/s with the geometric mean 1.1×10^{-7} m/s. There is a trend of decreasing hydraulic conductivities with depth for the volcanic and intrusive rocks, as well as the sedimentary rocks in both Mitchell and Sulphurets valleys.

More specifically, as indicated by the test data, the volcanic and intrusive bedrock above the Mitchell Thrust Fault are less fractured and permeable than that below the Mitchell fault within the depth of 100 mbgs in the Mitchell valley. The geometric mean of the measured K values is estimated to be 1.0×10^{-7} m/s for the bedrock above the Mitchell Thrust Fault, and 3.0×10^{-7} m/s for the bedrock below the Mitchell fault within the depth of 100 mbgs. There is little variation in hydraulic conductivities with depth above the Mitchell fault, but there is an obvious trend of decreasing permeability with depth for the bedrock below the fault. The geometric mean of the volcanic and intrusive bedrock in the Sulphurets valley is estimated to be 3.0×10^{-7} m/s. For the entire study area, the degree of fracturing in the bedrock was observed to generally decrease with depth, indicating that the majority of groundwater flow occurs in the upper, more fractured bedrocks.

3.2 BASELINE PRE-MINING MODEL

3.2.1 Model Domain and Grids

Delineation of the hydrogeological model domain requires identification of the watersheds that could be potentially affected by the proposed mine infrastructure, the model boundary conditions and the hydrostratigraphics units with hydraulic properties. The model domain for the KSM Project mining area is shown in Figure 3.2-1. The exterior boundary of the model domain follows the inferred groundwater divide based on the watershed divide along the ridge tops.

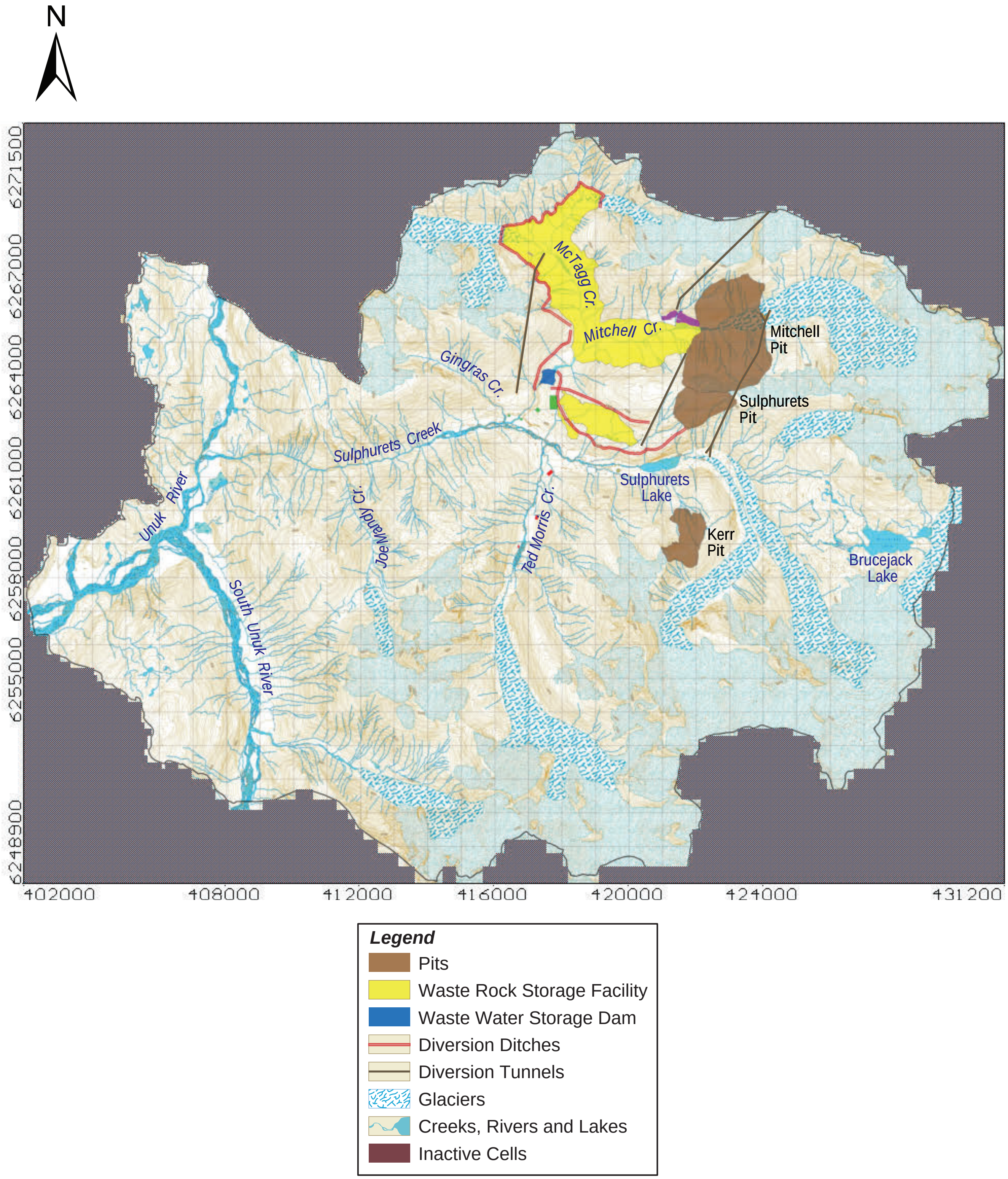
The model domain has a maximum north to south extent of 22.6 km (from 6,248,900 m N to 6,271,500 m N) and a maximum west to east extent of 29.2 km (from 402,000 m E to 431,200 m E). The surface elevation in the model domain varies from a minimum of 173.6 masl at the outlet of Unuk River in the southwestern corner of the domain to a maximum of 2,537.5 masl on the top of the mountain at the northeastern corner of the domain. The base of the model domain is set at 350 m below the sea level, which is approximately 600 m deeper than the deepest extent of the proposed Open Pits.

The model grid consists of 265 rows (north to south) and 381 columns (west to east). The model domain is spatially discretized with finer grids in the proposed mine sites and the potential impact areas, including the three Open Pits in Mitchell, Sulphurets and Kerr deposits, the Water Storage Facility, the Rock Storage Facilities, the tunnels and the Mitchell Creek valley, as well as the upper-middle reaches of Sulphurets Creek valley. The element size in the refined areas is 50 m by 50 m for more precise computations. The sizes of elements outside of the potential impact area gradually increase by the rule of thumb 1.5 times their neighbouring rows and columns to reduce the numerical instability. Figure 3.2-2 and Figure 3.2-3 show the plan view and the vertical cross-sections of the model grids with refinement in the critical mine areas (Column 309 across the three pits, Row 74 along Mitchell valley).

The model domain contains a total of twelve layers from the top to the bottom. The layers 1 to 4 represent overburden and bedrocks, while layers 5 to 12 are bedrocks only. The thickness of the top layer varies from about 14 m to 23 m along Mitchell Creek (from the confluence of Mitchell Creek and Sulphurets Creek to the upper edge of the Mitchell Pit), 16 m to 19 m along McTagg Creek (under the proposed Rock Storage Facility footprint), 14 m to 17 m along the upstream Sulphurets Creek (from the confluence of Sulphurets Creek and Mitchell Creek to the upper Sulphurets Lake), 10 m to 14 m along the downstream Sulphurets Creek, and about 9 m to 10 m along Unuk River. The thickness of the top layer in the key mining sites such as the Open Pits and Rock Storage Facilities generally varies from 16 m to 39 m (from lower valley to the ridge tops). The thickness of the deeper model layers and outside the valleys increase gradually by following the rule stated above. The bottom layer of the model is about 125 m under the confluence of Mitchell and Sulphurets Creeks.

3.2.2 Flow Boundary Conditions

Visual MODFLOW allows a variety of boundary conditions to be applied to the model to simulate the flow conditions observed. Figure 3.2-4 shows the Layer 1 flow boundary conditions applied to the pre-mining baseline hydrogeological model in the mining area of the KSM Project.



Mining Area Baseline Hydrogeological Model Domain

FIGURE 3.2-1

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Rescan™

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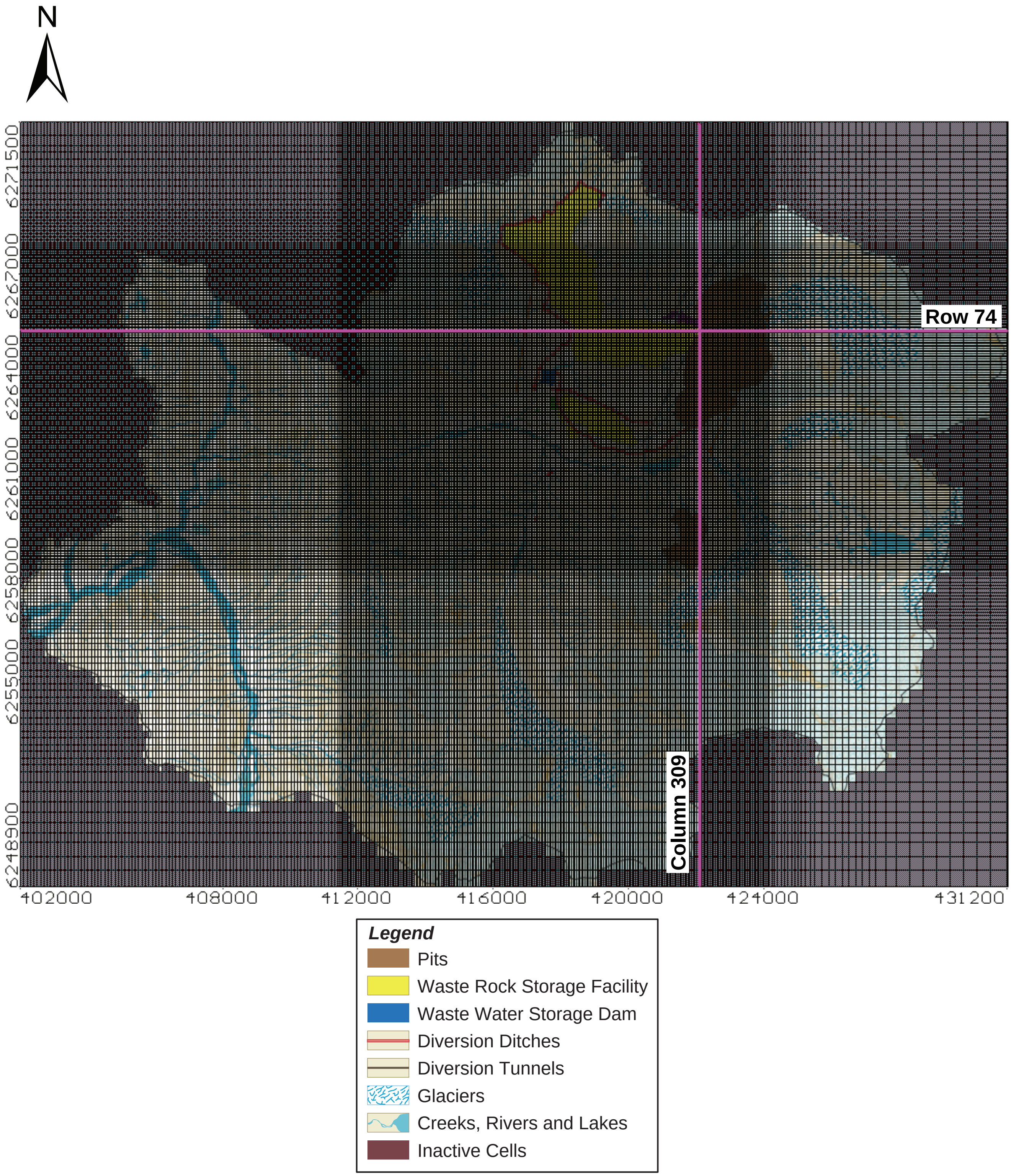


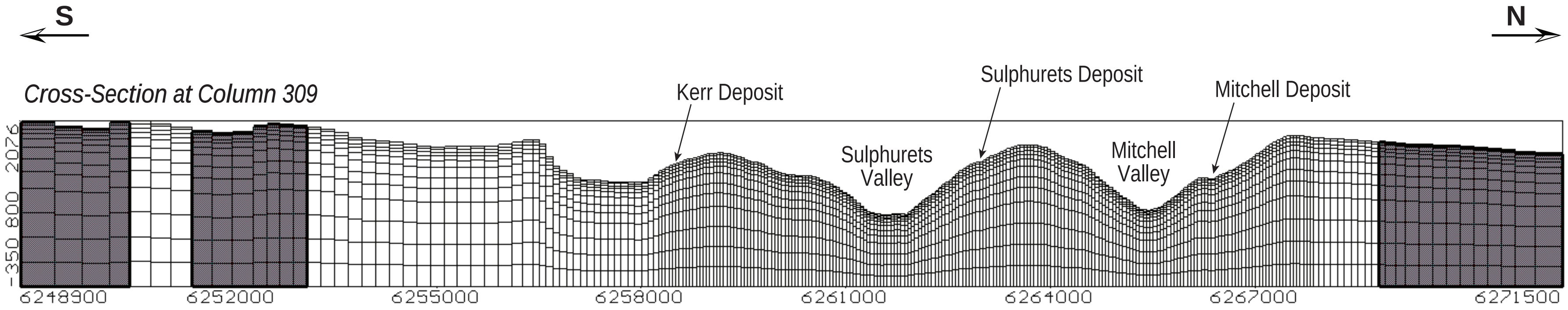
Mining Area Baseline Hydrogeological Model Grids (Plan View)

FIGURE 3.2-2

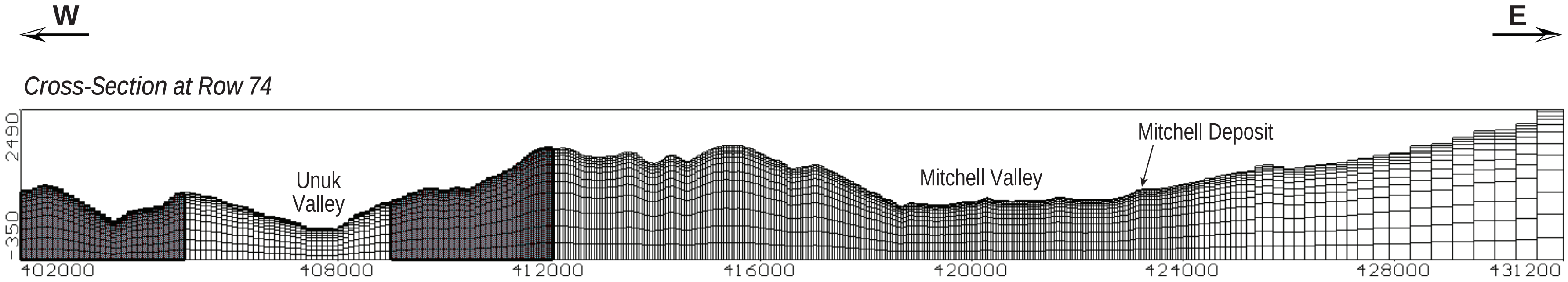
SEABRIDGE GOLD

Rescan™

Cross-Section at Column 309



Cross-Section at Row 74

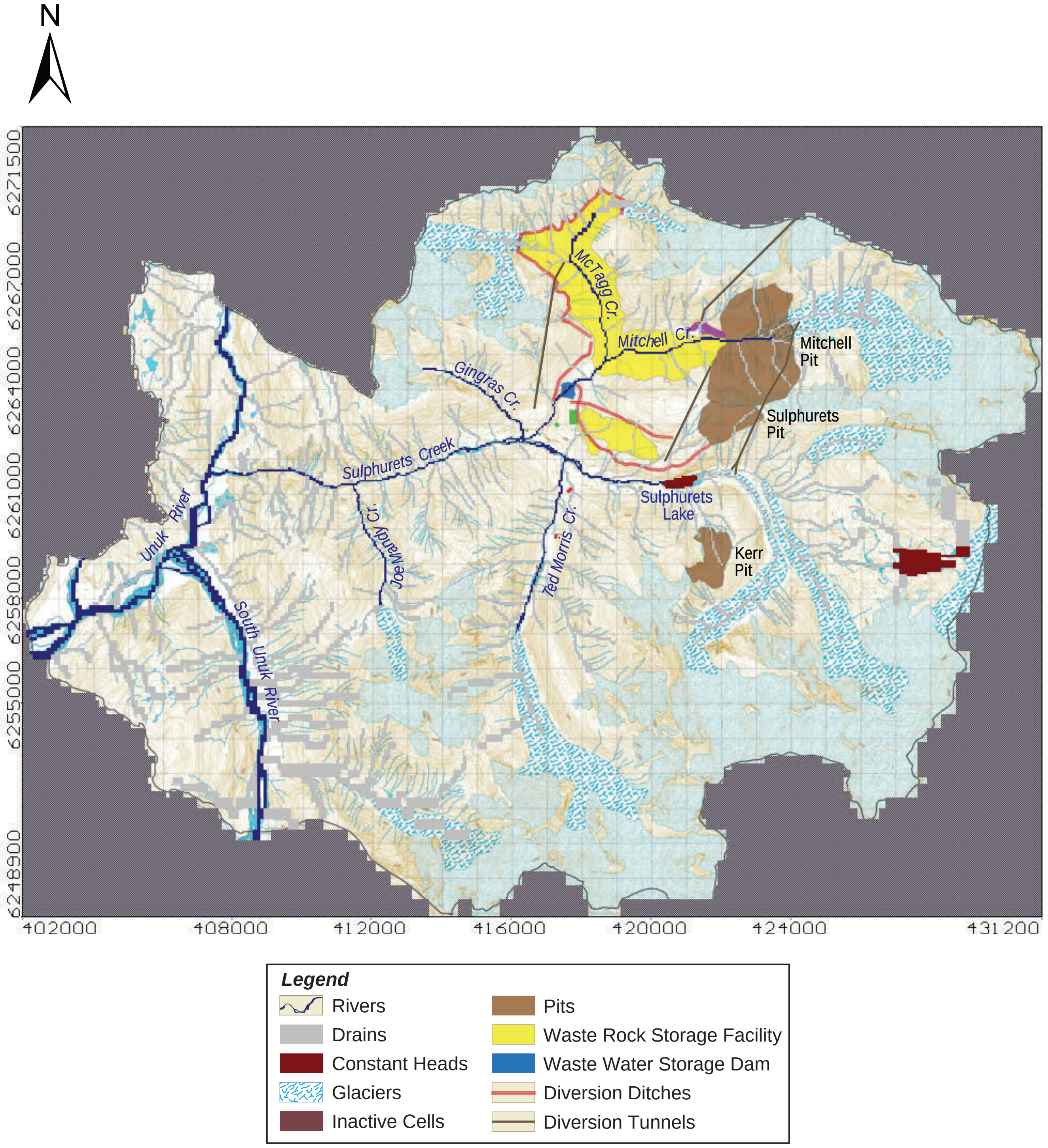


▨ Inactive Cells

Mining Area Baseline Hydrogeological Model Grids (Cross-Sections)

FIGURE 3.2-3

SEABRIDGE GOLD



Flow Boundary Conditions in Mining Area Baseline Hydrogeological Model (Layer 1)

FIGURE 3.2-4

3.2.2.1 Recharge Zones

Five recharge zones are defined in the mining area baseline pre-mining model domain based on the surface elevations and glacial coverage/permanent snow pack coverage (Figure 3.2-5). The recharge rates in mm/yr and representing the net flow into the groundwater system in these zones are shown in Table 3.2-1. For the area without glacial coverage, the recharge rates are estimated to vary from 115 mm/yr to 164 mm/yr depending on elevations. They are equivalent to 7% to 10% of the mean annual precipitation of 1,652 mm/yr observed by Rescan in 2008 at the Sulphurets meteorology station. As mentioned previously, the recharge rate applied in the valley bottoms is smaller than that in the mountainous areas with the steep orographic effect at the site resulting in less precipitation at lower elevation but more evapotranspiration due to higher temperature and more vegetation in the valleys and more surface runoff due to shallower groundwater table in the valley bottoms. For the area with glacial coverage, the recharge rate is estimated to be 40 mm/yr considering that most of the base of the glacier and underlying soil and rocks material are frozen. As no test data for the infiltration and evapotranspiration is available on the project site, and no information for the infiltration under the glaciers is available at the time of the modelling analysis, the effects of the uncertainty of the recharge rates will be examined in sensitivity analysis of the model calibration and prediction.

Table 3.2-1. Recharge Rates Applied in Baseline Hydrogeological Model – Mining Area

Recharge Zones	Recharge Rate (mm/yr)	Descriptions
1	115	<400 masl (Unuk River valley)
2	128	400 to 900 masl (other valley bottom and no glacier coverage)
3	146	900 to 1300 masl (mid-slope and no glacier coverage)
4	164	> 1300 masl (uplands and no glacier coverage)
5	40	Glacier and permanent snow pack coverage

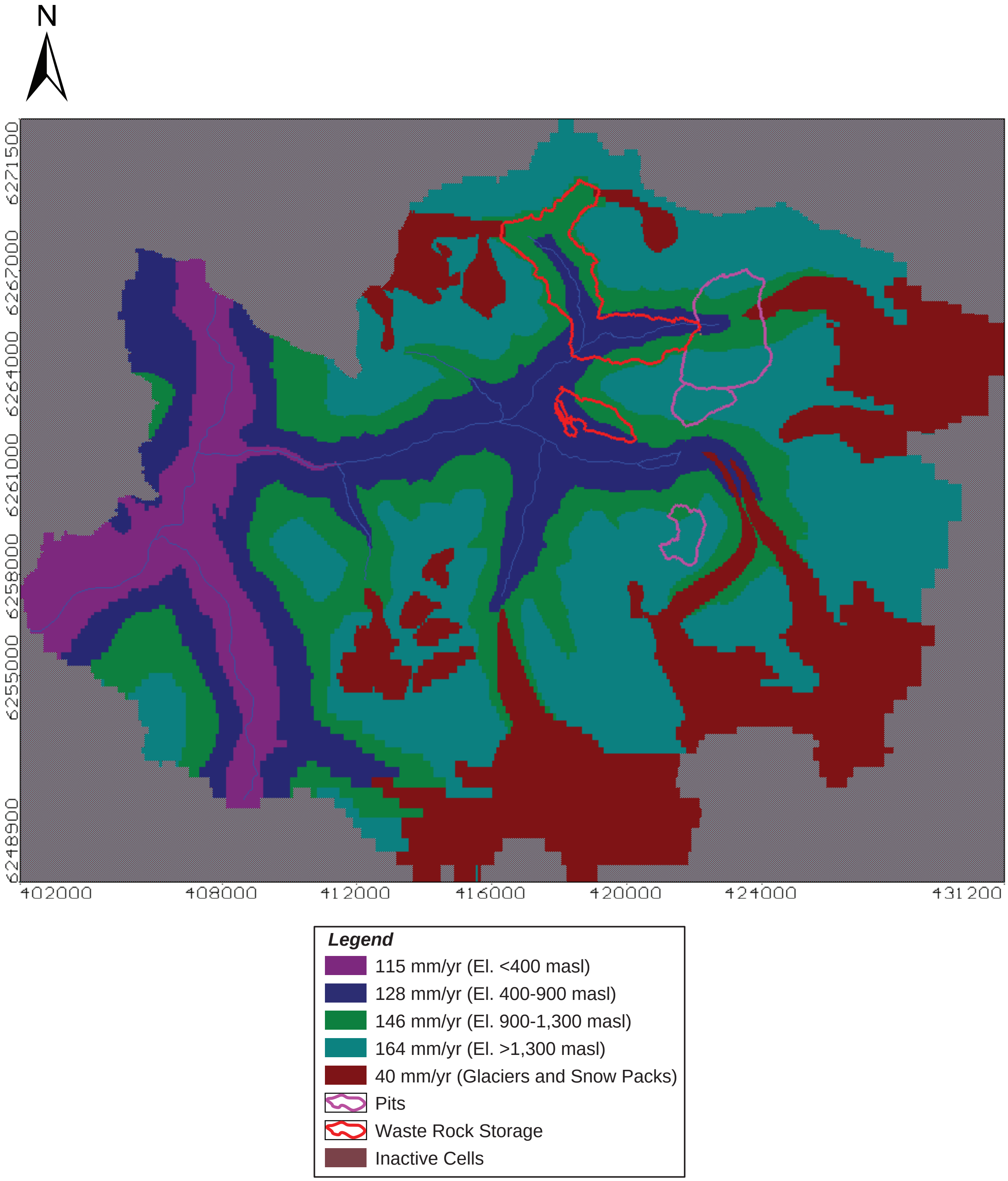
3.2.2.2 Constant Heads

Constant head boundary condition have been assigned to represent the Sulphurets Lake (590 masl) and Brucejack Lake (1,371 masl) as the water levels in these lakes are expected to remain constant or experience insignificant variation (see Figure 3.2-4).

3.2.2.3 Rivers

River boundary conditions have been assigned to represent the major surface water features in the domain: Mitchell Creek, Sulphurets Creek, McTagg Creek, Gingras Creek, Ted Morris Creek, Joe Mandy Creek, Unuk River, Unuk South River and Harrymel Creek (see Figure 3.2-4). The river boundary condition is used to characterize the groundwater and surface water interactions along the valleys and to simulate groundwater discharge (baseflow) into the surface water bodies. The modelled depths and widths of the creeks are taken from Rescan's hydrologic field observation data for the gauged stations (Rescan, 2010a) and are estimated for the ungauged stations based on the catchment areas and the aerial photography.

Based on the field observation, surface topography and riverbed elevations, the riverbed thickness are estimated to vary from 0.4 m to 0.5 m (at the headwaters of the creeks) and approximately 3.0 m (at Unuk River outlet). From the literature and experience from similar projects, the riverbed hydraulic conductivity was set at 1.0×10^{-5} m/s .



Recharge Zones in Mining Area
Baseline Hydrogeological Model

FIGURE 3.2-5

SEABRIDGE GOLD

3.2.2.4 Drains

Drain boundaries have been applied to streams in areas with steep slope (see Figure 3.2-4). The drain boundaries are assigned on ground surface and receive groundwater seepage only when the groundwater table is on or above ground surface; the conductance used for the drains is 0.1 m/d from the experience of the similar projects (Rescan, 2009; Cho 2009). A total of 202 drains were assigned in the model domain. Unlike the river boundaries, the drain boundaries do not allow recharge to the aquifer from the streams when the groundwater table is lower than the ground surface.

3.2.2.5 No Flow Boundaries

The entire exterior boundary of the model domain along the ridgelines is assumed to be the natural surface watershed and groundwater divide, and therefore it is assigned as a no flow boundary. A no flow boundary was also assigned at the bottom of the model domain at 350 m below the sea level.

3.2.3 Aquifer Properties

According to the conceptual model developed in the KSM Project mining area, the hydrogeological units in the mining area include overburden (glacial till, colluvium, fluvial), volcanic and intrusive rocks, and sedimentary rocks. To build the baseline model, initial inputs of hydrogeological parameters are required to be applied for these units in both unsaturated and saturated zones. The baseline model can then be calibrated by varying some of the key parameters, within reasonable bounds, to meet the calibration targets such as the match between the modelled and observed hydraulic heads and the modelled and observed baseflow rates. Some of the aquifer parameters are bounded by the available hydrogeological data, while other parameters were assumed due to a lack of data.

3.2.3.1 Unsaturated Zone Properties

The sharp surface topography relief with the steep slopes at the KSM Project site creates a challenge for numerical solutions of highly non-linear variably saturated groundwater flow in the large vadose zone present at high elevations, especially with the inherent problems of dry cells in Visual MODFLOW. Considering the fact that there is no test data available for the unsaturated flow properties of the overburden and bedrock materials at the Project site, and the difficulty and complexity in obtaining such data, the default experimental pseudo-soil function of relative permeability and pressure head versus soil moisture in the software MODFLOW-Surfact flow package version 3.0 (HydroGeologic, 1996) was utilized to characterize the unsaturated flow for overburden and bedrocks in the vadose zone in the simulations.

3.2.3.2 Saturated Hydraulic Conductivity

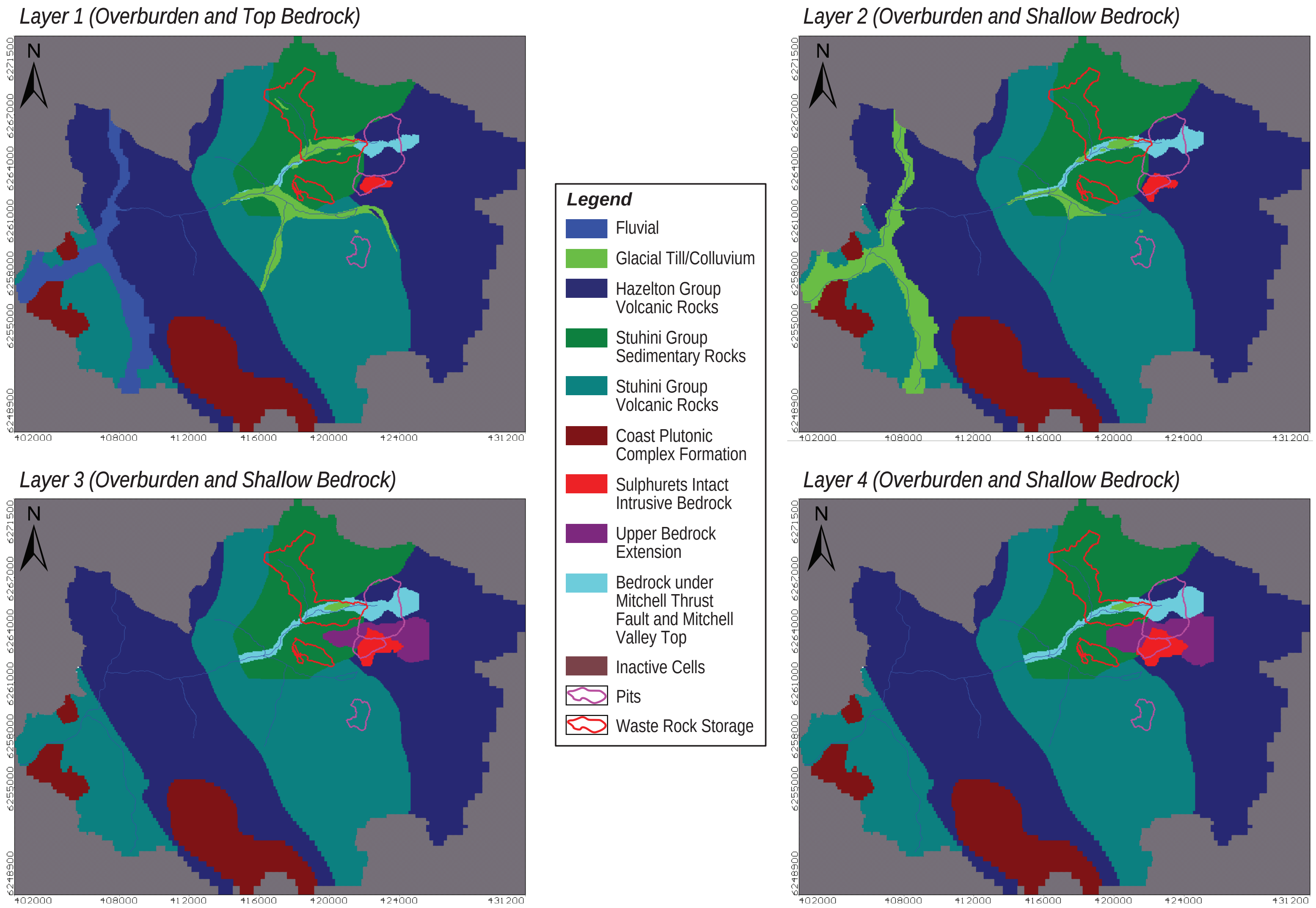
The overburden assigned in the mining area baseline model is basically classified into two hydraulic conductivity zones: 1) glacial till and colluvium on the bottoms of the Mitchell, Sulphurets, McTagg and Ted Morris valleys, and the initial input of hydraulic conductivity for this zone is 6.8×10^{-8} m/s (the geometric mean of the limited field estimates); and 2) fluvial and alluvial sediments on Unuk River and South Unuk River valley bases, and the initial input of hydraulic conductivity is 6.4×10^{-5} m/s (taken from the estimate for fluvial sediments in the TMF area of the KSM Project). In Unuk and South Unuk watersheds, the overburden materials (fluvial sediments in Layer 1 with thickness varying between 9 m and 15 m, and glacial till materials in Layer 2 with thickness varying between 13 m and 22 m) are assigned on the valley bottoms based on the overburden classification map developed by Rescan (see Figure 2.3-4a, 2.3-4b). In Mitchell-Sulphurets watersheds, while the overburden materials are assigned dominantly in Layer 1 (about 14 m to 20 m thick) and Layer 2 (20 m to 29 m thick) on the Mitchell, Sulphurets, McTagg and Tedd Morris valley bottoms based on the surficial geology map developed by KCBL (see Figure 2.3-3), the overburden materials near the well KC09-09 in the Mitchell valley (downstream of the glacial toe) are assigned into Layer 3, 4 and 5 as the overburden depth was estimated much deeper (over 140 m) at this location. In addition, some overburden materials (glacial till) were also assigned on the top layer of the model (about 20 m thick) in the upper Sulphurets valley from the Sulphurets Lake inlet to the area in between the two glacier toes based on the field observation.

The bedrock in the baseline model was divided vertically into five zones: Top/Shallow Bedrock (Layer 1 to 4), Upper Bedrock (Layer 5 to 6), Middle Bedrock (Layer 7 to 8), Lower Bedrock (Layer 9 to 10) and Bottom Bedrock (Layer 11 to 12); the thickness of the layers in the bedrock zones in the key mining area was described in the previous section 3.2.1. Within the Mitchell and Sulphurets valleys where the proposed Open Pits, Water Storage Facility and Rock Storage Facilities are located, the bedrock zones are assigned according to the conceptual model summarized in the beginning of this chapter, in which the bedrock above the Mitchell Thrust Fault is less permeable than the bedrock under the fault. The bedrock K relative to this fault are assigned with the assumptions that the hydraulic conductivity decreases with depth below the fault but there is no such trend above the fault as indicated by the field data. Outside the Mitchell and Sulphurets valleys where there is generally limited or no test data available except at the Kerr deposit, the bedrock zones in the top/shallow layers are assigned according to the sedimentary and intrusive/volcanic bedrock formations shown on the regional geological map (see Figure 2.3-5), and the upper, middle, lower and bottom bedrock layers are assigned with assumption made in the conceptual model of decreasing hydraulic conductivities with depth.

During calibration of the model, in order to match the simulated and field observed water levels, the Upper Bedrock zone was extended into Layer 3 and 4 under the ridge between Mitchell and Sulphurets valleys. In addition, two distinct bedrock zones were assigned in the model: 1) the top/shallow bedrock on the Mitchell valley bottom from downstream of the Mitchell Pit to the confluence of Mitchell and Sulphurets creeks, where the hydraulic tests in Rescan's and KCBL's wells such as RES-MW-04 and RES-MW-06 and at the proposed Water Storage Facility show that the bedrock has relatively high hydraulic conductivities, similar to that for the top/shallow bedrock under the Mitchell Thrust Fault; and 2) the top/shallow, upper and middle intact intrusive bedrock layers at the Sulphurets deposit around well RES-MW-07 location, where the measured bedrock hydraulic conductivities are extremely low (with a geometric mean 8.4×10^{-9} m/s) and the water table is close to surface. The presence of cliffs and also interpretation from aerial photos suggest the intrusive bedrock is intact and less fractured.

The representative layers and vertical cross-sections of the hydraulic conductivity zones in the baseline model are shown in Figure 3.2-6a, 3.2-6b and 3.2-7. The initial inputs of the hydraulic conductivities of all the overburden and bedrock property zones are listed in Table 3.2-2 for the baseline model before the calibration. The hydraulic conductivity values for the top/shallow and upper bedrock are specified generally with the field tested geometric means for different types of rocks; the values for middle, lower and bottom bedrock zones are assumed to decrease with a factor of 5 in each zone. For the intrusive intact bedrock at the Sulphurets deposit near the well RES-MW-07, while the top/shallow bedrock is specified with the tested geometric mean of hydraulic conductivities, the conductivities for the upper and middle bedrock are assumed to decrease by a factor of 2.

Due to the limited information, no fault zones are explicitly represented in the baseline model. Also because there is insufficient test data available for characterization of the overburden and bedrock heterogeneity and stochasticity, the overburden materials are assumed to be homogeneous and anisotropic (with the ratio 5:1 for horizontal/vertical hydraulic conductivities), and the bedrock formations are assumed to be homogeneous and isotropic. The uncertainties associated with the overburden and bedrock anisotropy will be investigated in the sensitivity analyses.


Layer 1 (Overburden and Top Bedrock)

Layer 2 (Overburden and Shallow Bedrock)

Layer 3 (Overburden and Shallow Bedrock)

Layer 4 (Overburden and Shallow Bedrock)

FIGURE 3.2-6a

Hydraulic Conductivity Zones in Mining Area Baseline Model (Layers 1 to 4)

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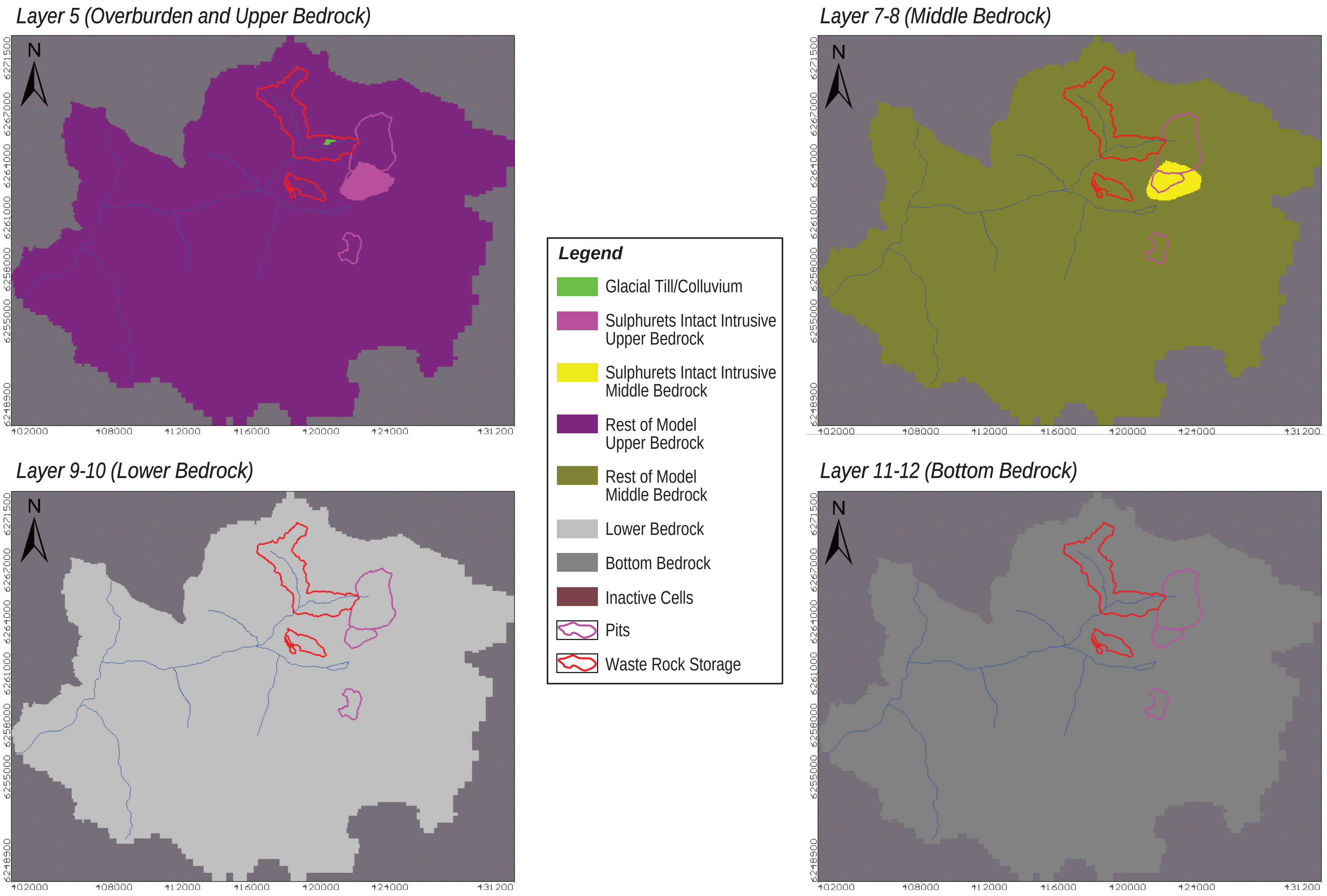
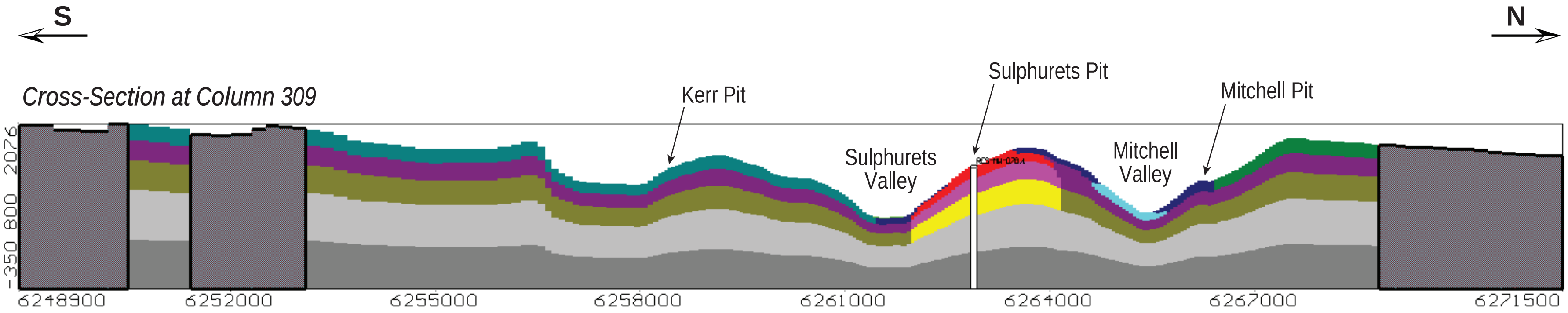


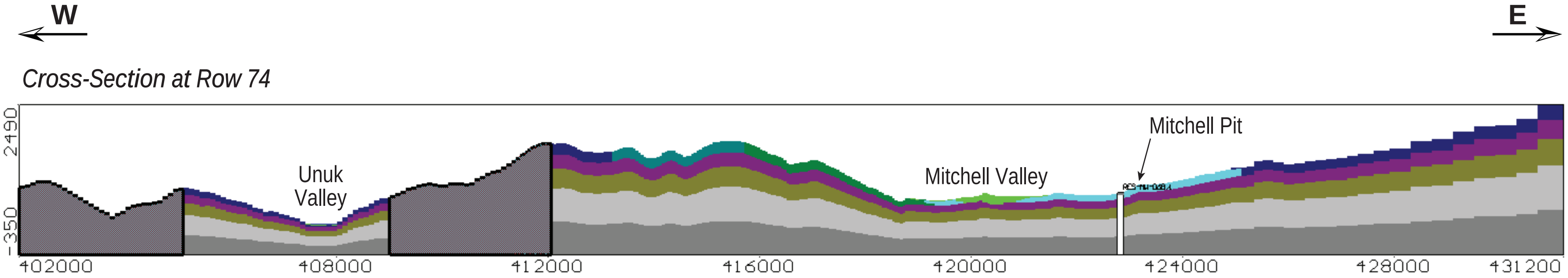
FIGURE 3.2-6b

Hydraulic Conductivity Zones in Mining Area Baseline Model (Layers 5 to 12)

Cross-Section at Column 309



Cross-Section at Row 74



Legend

🟩	Glacial Till/Colluvium
🟦	Hazelton Group Volcanic Rocks
🟩	Stuhini Group Sedimentary Rocks
🟦	Stuhini Group Volcanic Rocks
🟦	Bedrock under Mitchell Thrust Fault and Mitchell Valley Top
🟪	Upper Bedrock
🟫	Middle Bedrock
⬜	Lower Bedrock
⬛	Bottom Bedrock
🟥	Sulphurets Intact Intrusive Top Bedrock
🟪	Sulphurets Intact Intrusive Upper Bedrock
🟨	Sulphurets Intact Intrusive Middle Bedrock
🟫	Inactive Cells

Hydraulic Conductivity Zones in Mining Area Baseline Model (Cross-Sections)

FIGURE 3.2-7

SEABRIDGE GOLD

Rescan™

Table 3.2-2. Hydraulic Conductivities in Mining Area Baseline Model before Calibration

Material Type	Property Zone		Hydraulic Conductivity (K_h, m/s)	Anisotropy (K_h/K_v)	Model Layers
Overburden	Glacial Till/Colluvium		6.8×10^{-8}	5:1	1 to 5 (Mitchell-Sulphurets Watershed); 2 (Unuk Watershed)
	Fluvial Sediments		6.4×10^{-5}	5:1	1 (Unuk Watershed)
Bedrock	Top & Shallow Bedrock	Hazelton Group Volcanic Rocks Above Mitchell Thrust Fault	1.0×10^{-7}	1:1	1 to 4
		Stuhini Group Sedimentary Rocks	2.0×10^{-7}	1:1	
		Stuhini Group Volcanic Rocks	1.5×10^{-7}	1:1	
		Coast Plutonic Complex Formation	9.0×10^{-8}	1:1	
		Sulphurets Intact Intrusive Bedrock	1.0×10^{-8}	1:1	
		Bedrocks Under Mitchell Thrust Fault and Mitchell Valley Top	3.0×10^{-7}	1:1	
	Upper Bedrock	Sulphurets Intact Intrusive Bedrock	5.0×10^{-9}	1:1	5 to 6 (extending up to Layer 2 under the ridge between Mitchell and Sulphurets valleys)
		Rest of Model Layers	3.0×10^{-8}	1:1	
	Middle Bedrock	Sulphurets Intact Intrusive Bedrock	2.5×10^{-9}	1:1	7 to 8
		Rest of Model Layers	6.0×10^{-9}	1:1	
	Lower Bedrock		1.2×10^{-9}	1:1	9 to 10
	Bottom Bedrock		2.4×10^{-10}	1:1	11 to 12

3.2.3.3 Specific Storage, Specific Yield and Porosity

Table 3.2-3 lists other input parameters assumed for the aquifer property zones in the baseline model, including specific storage, specific yield, total and effective porosities. The specific storage is used in the model to calculate the volume of water that a unit of aquifer releases from storage under a unit decline in hydraulic head due to aquifer compaction and water expansion when the aquifer is confined. The specific yield is used to calculate the volume of water released from storage per unit surface area per unit decline in the water table when the aquifer is unconfined. The total and effective porosities are used to determine the average linear groundwater flow velocities in the particle tracking solution schemes and in solute transport modelling.

These parameters are assigned for the geological materials from the estimation by referring to similar groundwater modelling projects and the literature values, such as from the USGS and other mining-related groundwater modelling reports (Freeze and Cherry 1979; Fetter 1980; Dorsch and Katsube 1996; Stone and Fontaine 1998; Jones 2002; Malkki 2003; Lyford et al. 2007; Cho 2009; Rescan 2009).

3.2.4 Flow Budget Zones

Nine flow budget zones have been assigned along the major creeks. The budget zones allow for calculation of the groundwater discharge (baseflow) to the surface water system for model calibration, in the pre-mining scenario, and to predict the groundwater flows in the mining zones such as the seepage from the proposed Rock Storage Facilities during the mining operation and closure / post-closure. The names and locations of the flow budget zones in Layer 1 are shown in Figure 3.2-8.

3.2.5 Initial Heads, Flow Solver Parameters and Convergence Criteria

The initial head for the steady-state baseline flow model in the mining area is assumed to be equal to the midpoint of ground surface elevation, which is 1,355.6 masl. The initial head is used to compute the steady-state flow solutions with the output time set to 100 years, which is considered to be reasonable based on the previous experience and the mining life of 37 years for the KSM Project.

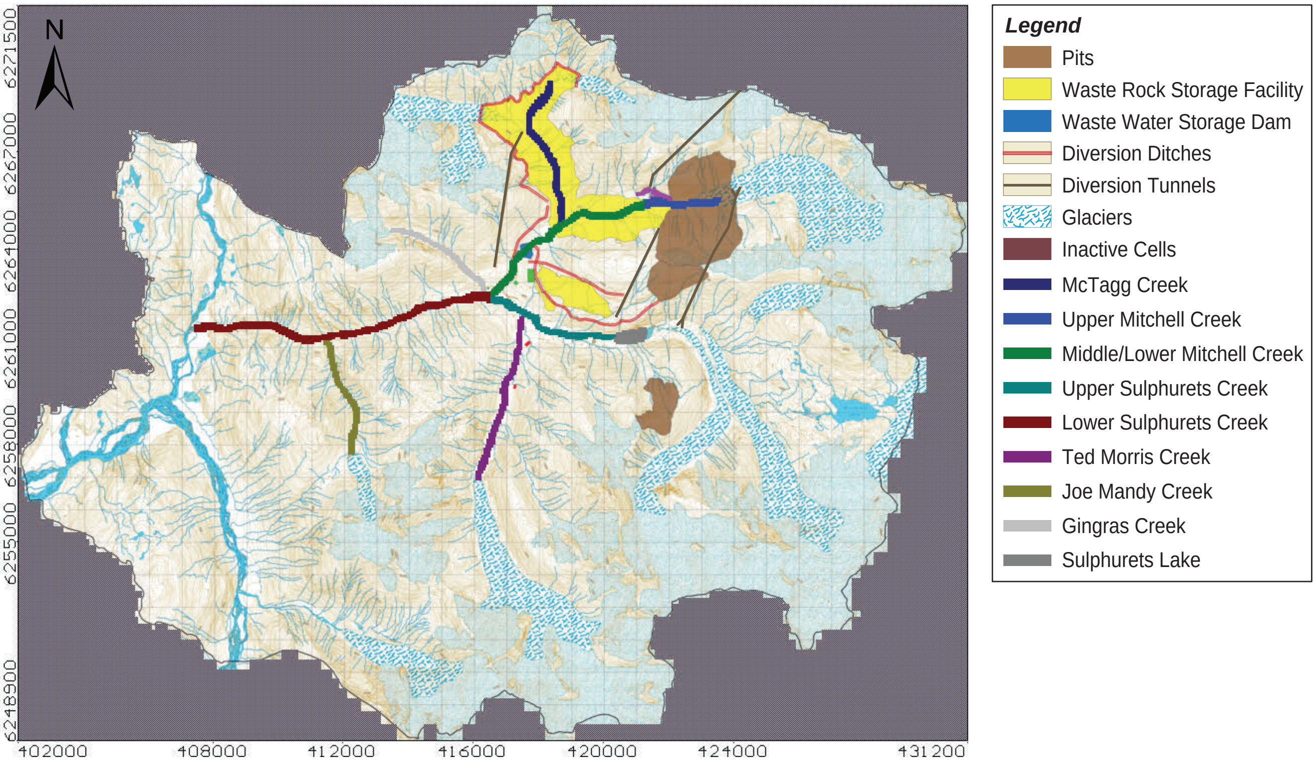
The pre-conditioned conjugate gradient (PCG4) solver in the MODFLOW-Surfact flow package version 3.0 is used for simulations of variably-saturated flow in the aquifer system, and the solver uses the efficient and rigorous Newton-Raphson linearization approach in solving the non-linear governing equations for unsaturated flow (HydroGeologic, 1996). The flow solver parameters and the convergence criteria include:

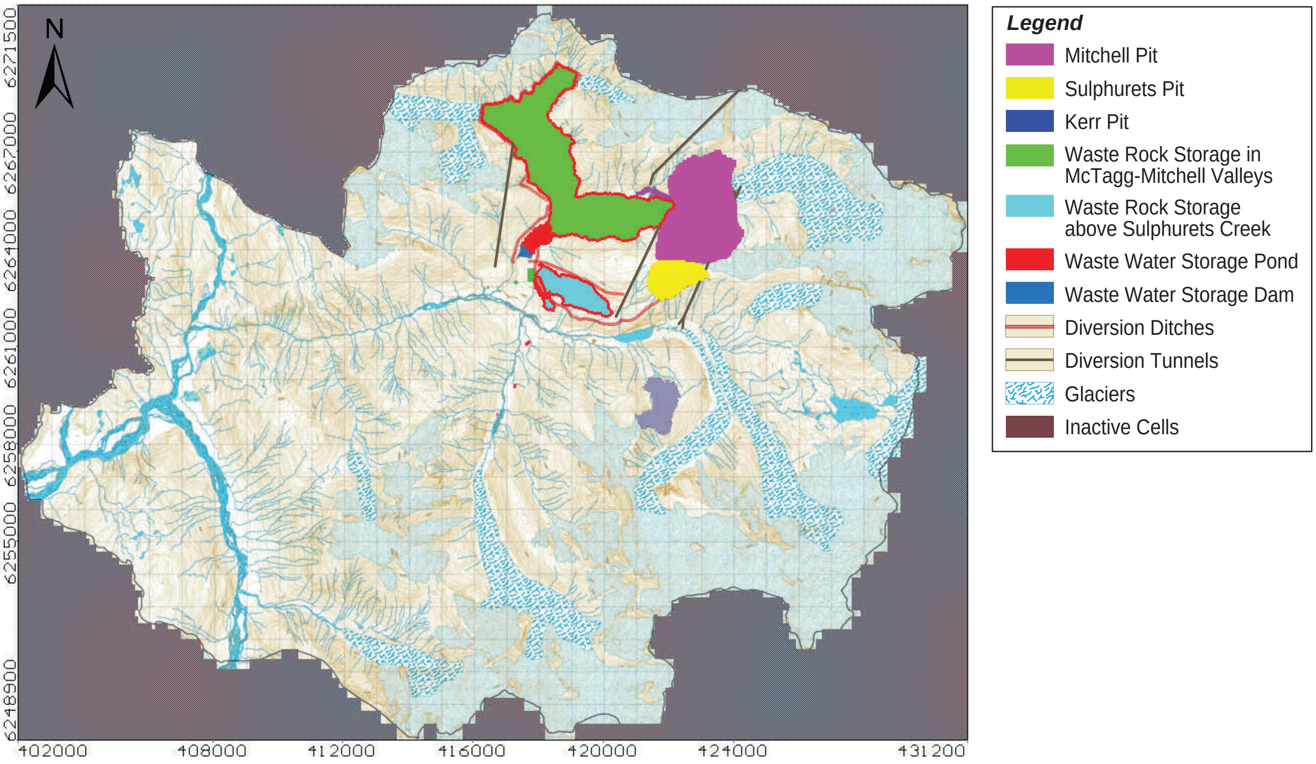
- the maximum outer iterations: 250
- the maximum inner iterations: 150
- the head change criterion: 0.01 m
- the residual criterion: 0.01 m^3/d

The other parameters of the solver such as the damping factor are kept at their default values from the numerical code (HydroGeologic 1996; Schlumberger 2008). The small absolute head change and residual criteria are used to ensure the accuracy in the flow solutions, and the damping factor applied is to make the solver work more easily for solving the problem in the domain with steep terrains.

Table 3.2-3. Specific Storage, Specific Yield and Porosities in Mining Area Baseline Model

Material Type	Property Zone		Specific Storage (S_s, 1/m)	Specific Yield (S_y)	Effective Porosity (n_e)	Total Porosity (n)
Overburden	Glacial Till/Colluvium		$1.0\text{x}10^{-5}$	0.10	0.15	0.20
	Fluvial Sediments		$5.0\text{x}10^{-5}$	0.25	0.25	0.30
Bedrock	Top & Shallow Bedrock	Hazelton Group Volcanic Rocks Above Mitchell Thrust Fault	$5.0\text{x}10^{-6}$	0.02	0.05	0.07
		Stuhini Group Sedimentary Rocks	$5.0\text{x}10^{-6}$	0.02	0.05	0.07
		Stuhini Group Volcanic Rocks	$5.0\text{x}10^{-6}$	0.02	0.05	0.07
		Coast Plutonic Complex Formation	$5.0\text{x}10^{-6}$	0.02	0.05	0.07
		Sulphurets Intact Intrusive Bedrock	$1.0\text{x}10^{-6}$	0.01	0.02	0.05
		Bedrocks Under Mitchell Thrust Fault and Mitchell Valley Top	$5.0\text{x}10^{-6}$	0.02	0.05	0.07
	Upper Bedrock	Sulphurets Intact Intrusive Bedrock	$1.0\text{x}10^{-6}$	0.01	0.02	0.05
		Rest of Model Layers	$1.0\text{x}10^{-6}$	0.01	0.02	0.05
	Middle Bedrock	Sulphurets Intact Intrusive Bedrock	$1.0\text{x}10^{-6}$	0.01	0.02	0.05
		Rest of Model Layers	$1.0\text{x}10^{-6}$	0.01	0.02	0.05
	Lower Bedrock		$1.0\text{x}10^{-6}$	0.01	0.02	0.05
	Bottom Bedrock		$1.0\text{x}10^{-6}$	0.01	0.02	0.05


Creeks


Mine Zones

Flow Budget Zones in Mining Area Baseline Model (Layer 1)

FIGURE 3.2-8

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3.2.6 Model Calibration

3.2.6.1 Calibration Targets

The baseline mining area model is run at steady state with the parameters and properties described in the previous sections and calibrated with the PEST (a popular parameter estimation program) in MODFLOW package and manual adjustment of the aquifer parameters within the reasonable ranges of the field tested and estimated data. The model calibration is aimed at maintaining the conceptualized hydrogeological system and flow regime (such as low permeable overburden overlying slightly higher permeable bedrock on the valley bases, decreasing hydraulic conductivities with depth for bedrocks under the Mitchell Thrust Fault along the Mitchell valley, groundwater flow from upper elevations towards the creeks and rivers in the lower elevations, etc.) while making alterations to the overburden and bedrock hydraulic conductivities to get the best fits between the field observation and the model simulation. During the calibration, modelled geologic materials are still assumed to be homogeneous in each of the geological property zones, and the initial inputs of overburden and bedrock anisotropy ratios, as well as the recharge rates are kept unchanged (they will be investigated in calibration sensitivity analysis). The targets for calibration of the baseline model include:

- Comparison of the simulated hydraulic heads to the measured hydraulic heads in Rescan, KCBL and BGC's monitoring wells and piezometers in mining area;
- Comparison of the simulated baseflows in major creeks to the field observed in mining area hydrological studies;
- Examination of the simulated water table adjacent to creeks, rivers and lakes in mining area;
- Verification of the simulated water table with the observed groundwater seep locations in Mitchell, Sulphurets and McTagg valleys.

The final step of the model calibration is to assess the validity of the calibrated and measured hydraulic properties of geologic materials against the conceptual model in the mining area.

3.2.6.2 Calibration Results

The KSM mining area baseline model was calibrated to meet the targets above, including the most recently measured water levels in the monitoring wells and stream flow data available for the Project. Table 3.2-4 lists the final hydraulic conductivities for overburden materials and bedrocks in the calibrated baseline model, which shows that the calibrated hydraulic conductivities are close to the initial inputs shown in Table 3.2-2, and they are therefore considered representative of the field measured values. Figure 3.2-9 shows the plot of the calculated and observed hydraulic heads in the monitoring wells. The result demonstrates that the calculated and observed hydraulic heads match very well, and the normalized root mean squared (NRMS) is 1.4%, and the residual mean is 2.7 m. Normally, a model calibration with the NRMS of 10% or less is considered acceptable.

The comparison of the simulated and observed baseflow rates in the creeks is shown in Table 3.2-5. These rates are the simulated long-term, average, steady-state stream baseflows in the major streams where Rescan hydrometric stations are located. The results shows that the simulated baseflow rates are fairly close to the field observed values, which demonstrates that the groundwater model calibration to measured surface water flows is good considering the data limitations.

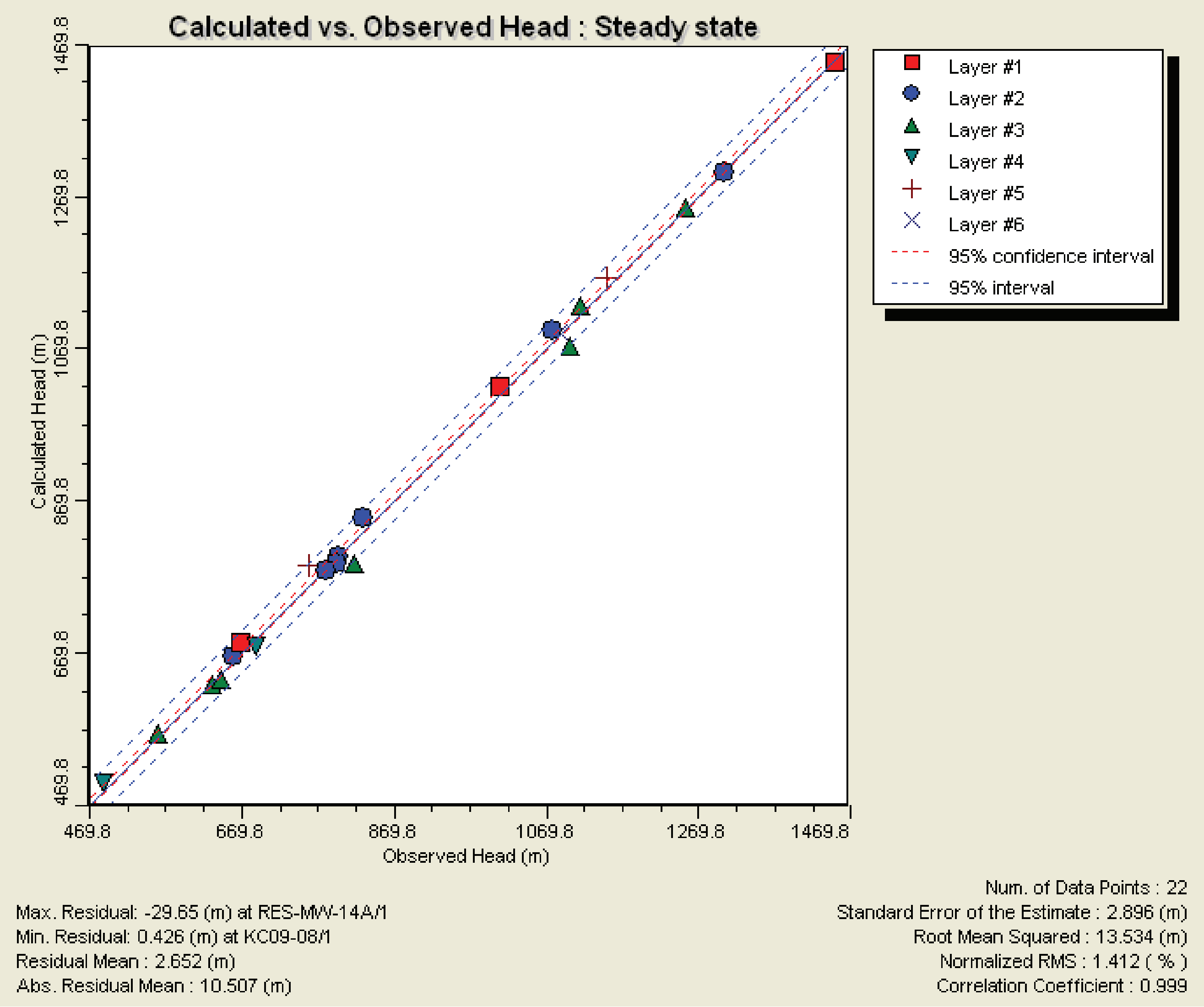
Table 3.2-4. Hydraulic Conductivities in Calibrated Mining Area Baseline Model

Material Type	Property Zone		Hydraulic Conductivity (K_h, m/s)	Anisotropy (K_h/K_v)
Overburden	Glacial Till/Colluvium		8.0×10^{-7}	5:1
	Fluvial Sediments		6.0×10^{-5}	5:1
Bedrock	Top & Shallow Bedrock	Hazelton Group Volcanic Rocks Above Mitchell Thrust Fault	8.0×10^{-8}	1:1
		Stuhini Group Sedimentary Rocks	9.0×10^{-8}	1:1
		Stuhini Group Volcanic Rocks	1.0×10^{-7}	1:1
		Coast Plutonic Complex Formation	9.0×10^{-8}	1:1
		Sulphurets Intact Intrusive Bedrock	1.35×10^{-8}	1:1
		Bedrocks Under Mitchell Thrust Fault and Mitchell Valley Top	3.7×10^{-6}	1:1
	Upper Bedrock	Sulphurets Intact Intrusive Bedrock	8.0×10^{-9}	1:1
		Rest of Model Layers	5.0×10^{-8}	1:1
	Middle Bedrock	Sulphurets Intact Intrusive Bedrock	5.0×10^{-9}	1:1
		Rest of Model Layers	8.0×10^{-9}	1:1
	Lower Bedrock		2.4×10^{-9}	1:1
	Bottom Bedrock		4.8×10^{-10}	1:1

Table 3.2-5. Simulated and Field Estimated Pre-mining Low Flows in Mining Area

Creeks	Estimated Annual Low Flows from Field Observation (m^3/s)		Simulated Baseflow in Calibrated Baseline Model (m^3/s)
	7-day	7-day Q10[1]	
Sulphurets Creek Outlet at Unuk River (Station SC-H1)	1.09	0.63	0.57
Mitchell Creek Upper Reach (Station MC-H1)	0.14	0.07	0.11
McTagg Creek (Station MCT-H1)	0.10	0.05	0.05
Ted Morris Creek (Station TMC-H1)	0.19	0.10	0.06

[1] *Q10 represents estimated low flows at an occurrence of once every 10 years.*



Num. of Data Points : 22
Standard Error of the Estimate : 2.896 (m)
Root Mean Squared : 13.534 (m)
Normalized RMS : 1.412 (%)
Correlation Coefficient : 0.999

Max. Residual: -29.65 (m) at RES-MW-14A/1
Min. Residual: 0.426 (m) at KC09-08/1
Residual Mean : 2.652 (m)
Abs. Residual Mean : 10.507 (m)

Observed vs. Calculated Hydraulic Heads in Monitoring Wells in Calibrated Mining Area Pre-mining Baseline Model

FIGURE 3.2-9

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In addition, Figure 3.2-10 shows that the simulated head equipotential contours match the manually interpolated potentiometric surface head contours from the field observation (Rescan 2010c, Appendix 11-B of the EA Chapter 11), and the simulated head contours generally mimic the surface topography (same as being described in the conceptual model). The visual examination of simulated water table depths along the creeks and lakes and along the Mitchell and Sulphurets valleys (where the groundwater seeps were observed in the field) also indicate that the model is well calibrated. Overall, the results demonstrate clearly that the conceptual model constructed from the available information for the KSM Project mining area is valid. The baseline model is well calibrated and reliable for predictive simulations.

3.2.7 Calibrated Baseline Pre-mining Model Results and Sensitivities

3.2.7.1 Baseline Model Results

The calibrated baseline model is run under steady-state and the output results from the model represent the current and also the long-term average of the pre-mining flow conditions. The results will be used to compare with the outputs from the scenarios to be simulated for the end of mine operation and post-closure to assess the largest effects of the mining activities on water quantity in the hydrogeological system.

Figures 3.2-11 shows the simulated head equipotentials (100 m interval) and flow velocity vectors in plan view (Layer 1 variably-saturated and Layer 6 fully-saturated). Figure 3.2-12 shows the simulated head equipotentials (100 m interval) and water table at the cross-sections (Column 309 crossing the Mitchell and Sulphurets valleys at well RES-MW-07 location and the pits; Row 74 along Mitchell valley at well RES-MW-06). The results clearly show that the regional groundwater flows from the high elevations towards the lower elevations and towards the surface water bodies (creeks and lakes) on the valley bottoms. These results consolidate the flow system described in the conceptual model. More specifically, in the proposed mining sites, the Mitchell Pit is located in both groundwater recharge and discharge zones (recharge from the upstream aquifer in the upper part of the Mitchell valley and steep slopes, discharge into the downstream aquifer along the valley and on the valley bottom). The Sulphurets and Kerr Pits are located in the regional groundwater recharge zones at high elevations. The proposed Rock Storage Facility in the Mitchell and McTagg valleys is located in the groundwater discharge zone, but the Rock Storage Facility above the Sulphurets Creek is located in groundwater recharge and discharge transition zone. The proposed waste Water Storage Facility in the Mitchell valley is located in groundwater discharge zone.

The flow budget zone results from the calibrated baseline model show that at pre-mining, groundwater discharge into the creeks and lake as baseflow varies from 0.03 m^3/s to 0.57 m^3/s (Table 3.2-6), and the baseflow rate is estimated to be 0.57 m^3/s at the mouth of Sulphurets Creek flowing into the Unuk River and 0.51 m^3/s at the confluence of Mitchell and Sulphurets Creeks near the well RES-MW-11. The total groundwater flow through the areas of the proposed ultimate Mitchell, Sulphurets and Kerr Pits at pre-mining is estimated to be approximately 10,158.0 m^3/d (117.6 L/s), 758.5 m^3/d (8.8 L/s) and 708.3 m^3/d (8.2 L/s), respectively. The total flow through the areas of the proposed Rock Storage Facilities in Mitchell-McTagg valleys and above the Sulphurets Creek is about 16,843.0 m^3/d (194.9 L/s), and 726.4 m^3/d (8.4 L/s), respectively. The flow into the proposed water storage area is 2,545.0 m^3/d (29.5 L/s) at the normal low operational water level and 4366.0 m^3/d (50.5 L/s) at the normal high operational water level.

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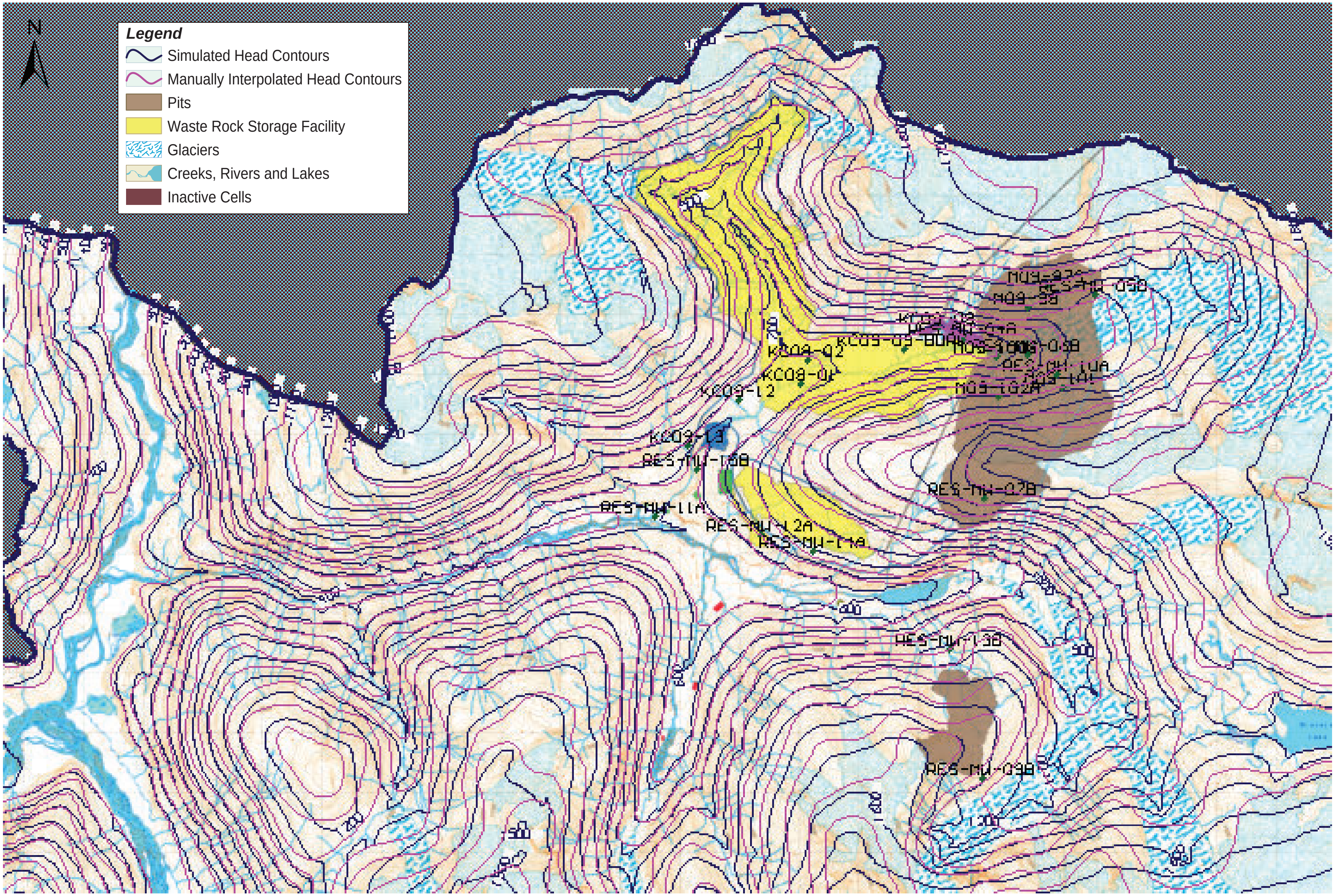

FIGURE 3.2-10

Simulated and Interpolated Pre-mining Hydraulic Head Contours in Mining Area

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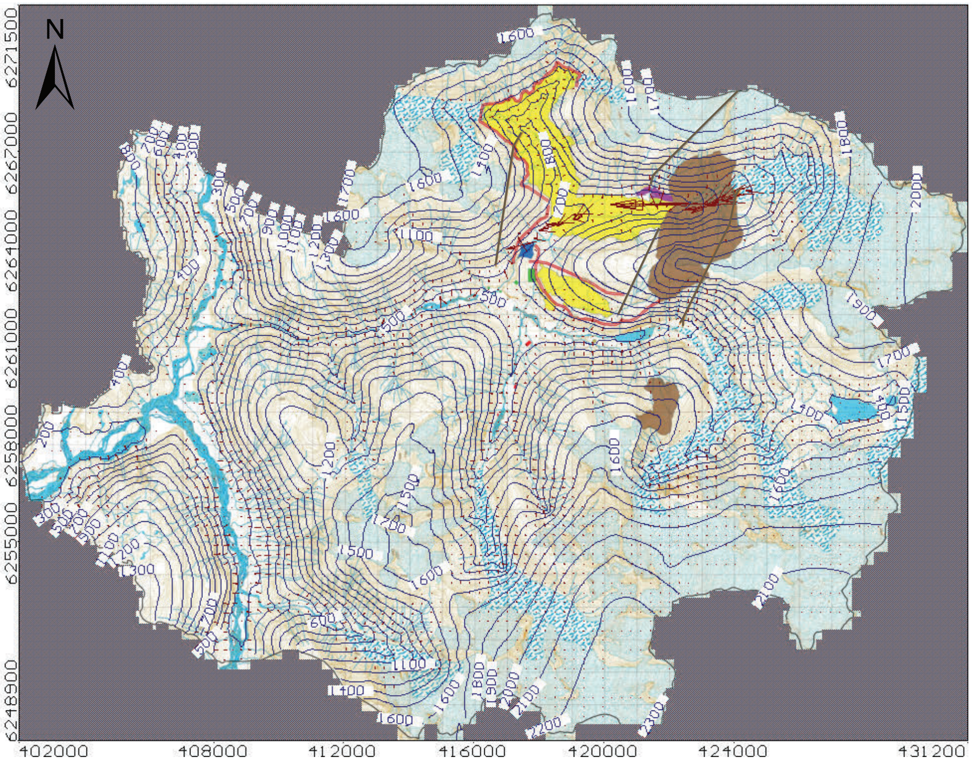
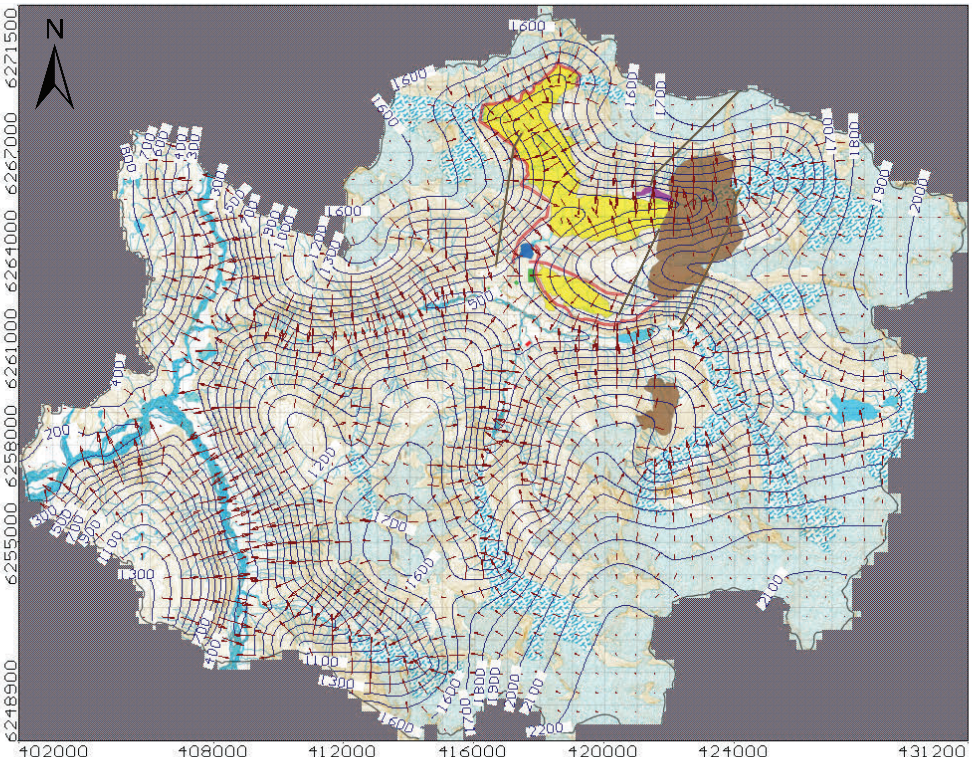
Layer 2 (Variably-Saturated)



Layer 6 (Saturated)



Legend

- 🟫 Pits
- 🟨 Waste Rock Storage Facility
- 🟦 Waste Water Storage Dam
- ▭ Diversion Ditches
- ▭ Diversion Tunnels
- ▨ Glaciers
- ▨ Creeks, Rivers and Lakes
- ■ Inactive Cells

Simulated Pre-mining Hydraulic Head Contours and Flow Directions in Mining Area Baseline Model (Plan Views)

FIGURE 3.2-11

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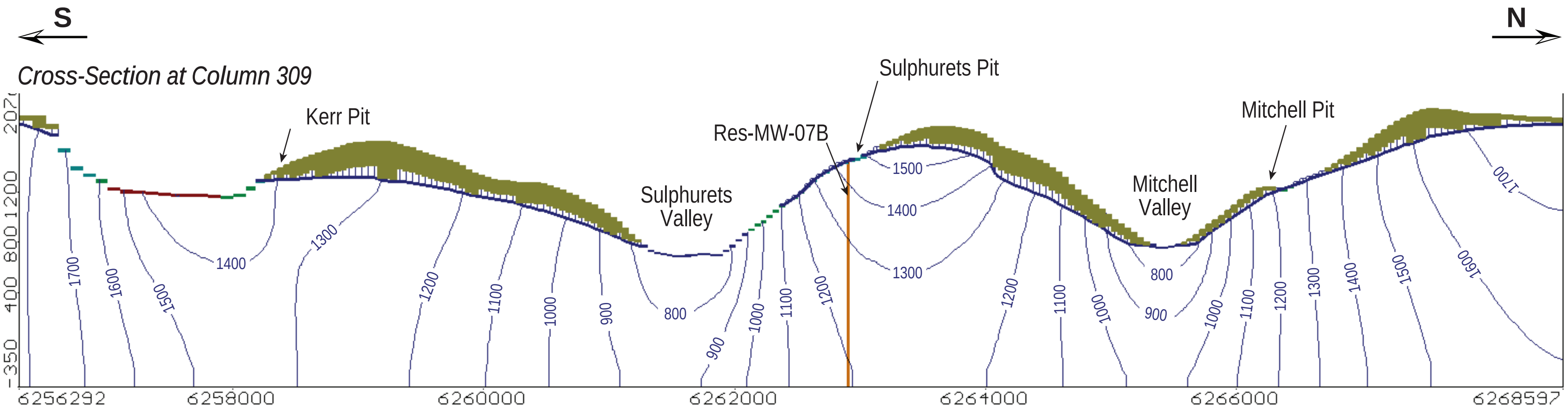
Cross-Section at Column 309

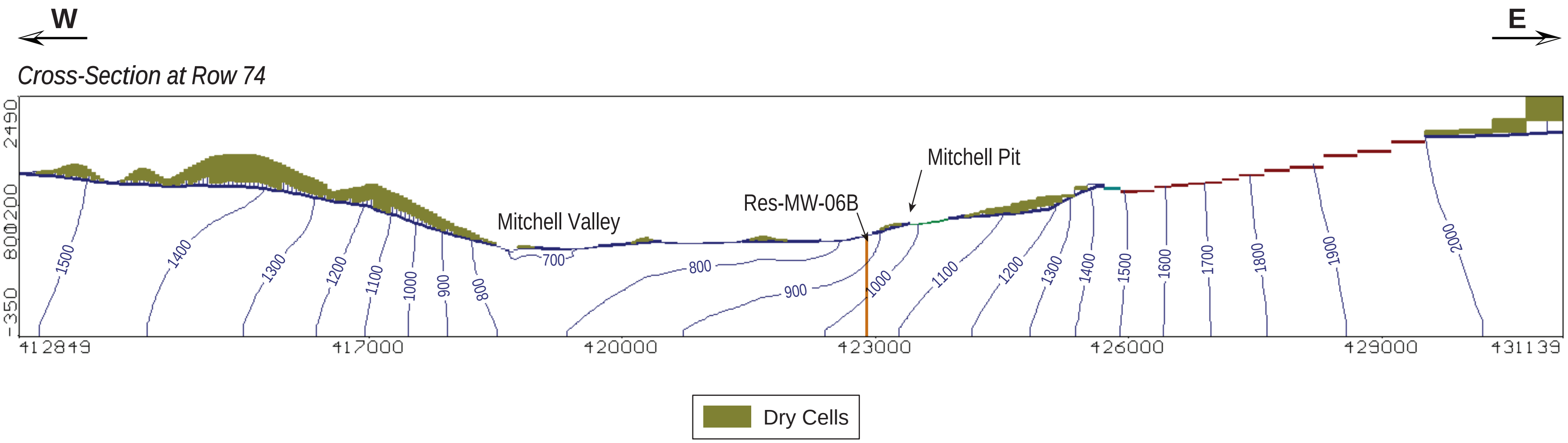
Cross-Section at Row 74

FIGURE 3.2-12

Simulated Hydraulic Head Contours and Water Table in Mining Area Baseline Model (Cross-sections)

SEABRIDGE GOLD

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Table 3.2-6. Predicted Range of Baseflows in Mining Area before Mining

Creek	Base Case (m^3/s)	Range of Baseflow (m^3/s)	
		Lower	Upper
Sulphurets Creek Outlet at Unuk River (Station SC-H1)	0.57	0.12	1.49
Sulphurets Creek Upper Reach (Between Sulphurets Lake and Confluence at Mitchell Creek)	0.03	0.01	0.15
Sulphurets Creek Lower Reach (From Confluence at Mitchell Creek to Unuk River)	0.09	0.02	0.37
Sulphurets Lake	0.02	0.01	0.03
Mitchell Creek Upper Reach (Station MC-H1)	0.11	0.02	0.13
Mitchell Creek Middle/Lower Reach (Between Station MC-H1 and Confluence at Sulphurets Creek)	0.15	0.02	0.46
McTagg Creek (Station MCT-H1)	0.05	0.01	0.10
Ted Morris Creek (Station TMC-H1)	0.06	0.01	0.15
Joe Mandy Creek	0.03	0.01	0.05
Gingras Creek (Station GC-H1)	0.03	0.01	0.05

3.2.7.2 Baseline Model Sensitivities

Sensitivity analyses were performed to identify which input parameter(s) in the mining area model are most sensitive and have the most significant influence on the simulated groundwater flow results by comparing the change of calculated groundwater discharge (baseflow) rates into the creeks and lake to the pre-mining baseline results. The parameters altered in the sensitivity analysis include the hydraulic conductivities for all the overburden and bedrock materials (one order of magnitude higher and lower in relative to the base case), the anisotropy ratios of the materials (1:10, 1:1 , 10:1 for overburden, 1:10 and 10:1 for bedrock), and the recharge rates (1/2 and 2 times of the base case). Table 3.2-7 shows the details of sensitivity analysis with the parameters altered and the calculated baseflow rates into the creeks in comparison with the base case. The results show that the recharge rates, the hydraulic conductivities of glacial till, the top bedrock zone (including Hazelton group volcanic rock and Stuhini group volcanic and sedimentary rocks and the bedrocks under the Mitchell Thrust Fault in the Mitchell valley), the upper and middle bedrock zones (excluding the intrusive intact bedrock at the Sulphurets deposit), as well as the overburden and bedrock anisotropy are the most sensitive to the results.

Incorporating these most sensitive parameters with the same order of magnitude change for each of the parameters, the mining area baseline model was run to calculate the potential ranges of baseflows in the creeks and lake. The results (see Table 3.2-6) are generally close to the field measurements: the simulated baseflow varies from 0.12 m^3/s to 1.49 m^3/s at the mouth of Sulphurets Creek entering Unuk River, from 0.01 m^3/s to 0.10 m^3/s at the McTagg Creek mouth, from 0.01 m^3/s to 0.15 m^3/s at Ted Morris Creek mouth, and from 0.01 m^3/s to 0.03 m^3/s to the Sulphurets Lake. The baseflow rate at the confluence of Mitchell and Sulphurets Creeks is calculated to be from 0.10 m^3/s to 1.39 m^3/s.

3.2.8 Summary

Based on the conceptual model developed, the 3D baseline pre-mining hydrogeological model has been constructed to represent the long-term average pre-mining surface water and groundwater flow conditions in the KSM Project mining area. The baseline model is developed using all relevant information and data available for the Project at the time of this analysis and also using data from similar mining-related groundwater modelling projects and the literature.

The model is well calibrated with the multiple targets including the measured hydraulic heads, stream baseflow and the water table adjacent to surface waterbodies. The final calibrated hydraulic parameters were compared with the initial inputs from the available hydrogeological field test data. The calculated hydraulic heads and baseflows match the field measurements. The calibration results demonstrate that the conceptual model of the hydrogeological system is valid and representative.

The steady-state simulation of the calibrated baseline model shows that the regional groundwater flows from the recharge zone in the high lands towards the valley bases where the surface water bodies (creeks and lake) are located. The proposed Mitchell Pit is located in the groundwater recharge zone of the downstream aquifer but in the groundwater discharge zone of the upstream aquifer, the Sulphurets and Kerr Pits are located in the regional groundwater recharge zones at high elevations. The McTagg/Mitchell Rock Storage Facility is located in groundwater discharge zone, but the Sulphurets Rock Storage Facility is located in groundwater recharge and discharge transition zone. The Water Storage Facility in Mitchell valley is located in groundwater discharge zone.

Table 3.2-7. KSM Project Mining Area Baseline Hydrogeology Model Sensitivity Analysis Results

Property and Parameter			Base Case Value	Lower and Upper Limits of Uncertainty	Calibration		Simulated Baseflow Rates in Creeks and Lake							
					NRMS (%)	Residual Mean (m)	McTagg Creek (m^3/s)	Change from Base Case (%)	Mitchell Creek at MC-H1 (m^3/s)	Change from Base Case (%)	Mitchell Creek Lower (m^3/s)	Change from Base Case (%)	Sulphurets Creek Upper (m^3/s)	Change from Base Case (%)
Overburden	Glacial Till/Colluvium (K_h)		8.0E-07	8.0E-08	2.8	13.9	0.05	1.1	0.11	5.2	**0.13**	**-9.6**	**0.02**	**-33.6**
				8.0E-06	1.4	-1.3	0.05	6.7	0.11	0.1	**0.20**	**36.2**	**0.09**	**204.5**
	Fluvial (K_h)		6.0E-05	6.0E-06	1.4	2.7	0.05	0.0	0.11	0.0	0.15	0.0	0.03	0.0
				6.0E-04	1.4	2.7	0.05	0.0	0.11	0.0	0.15	0.0	0.03	0.0
Bedrock	Top/Shallow Bedrock (K_h)	Hazelton Group Volcanic Rocks Above Mitchell Thrust Fault	8.0E-08	8.0E-09	5.1	22.4	0.05	0.3	0.10	-0.1	0.15	0.3	0.03	0.4
				8.0E-07	2.4	-5.7	0.05	-0.1	0.11	7.5	0.15	-0.3	0.03	-0.3
		Stuhini Group Sedimentary Rocks	9.0E-08	9.0E-09	2.4	12.3	**0.02**	**-48.1**	0.11	0.4	0.14	-1.4	0.03	-7.8
				9.0E-07	2.8	-5.4	**0.09**	**86.6**	0.10	-2.1	0.15	3.3	0.04	12.8
		Stuhini Group Volcanic Rocks	1.0E-07	1.0E-08	8.8	22.6	0.05	2.2	0.11	0.1	0.15	0.6	0.03	-3.5
				1.0E-06	3.3	-6.8	0.05	-1.0	0.10	0.0	0.15	-0.3	0.03	12.5
		Coast Plutonic Complex Formation	9.0E-08	9.0E-09	1.4	2.7	0.05	0.0	0.11	0.0	0.15	0.0	0.03	0.0
				9.0E-07	1.4	2.6	0.05	0.0	0.11	0.0	0.15	0.0	0.03	0.0
		Sulphuret Intact Intrusive Bedrock	1.35E-08	1.35E-09	10.8	24.8	0.05	0.0	0.11	0.4	0.15	0.0	0.03	0.0
				1.35E-07	3.3	-3.8	0.05	0.0	0.10	-0.4	0.15	-0.1	0.03	-0.2
		Bedrocks Under Mitchell Thrust Fault and Mitchell Valley Top	3.7E-06	3.7E-07	4.0	24.4	0.05	-0.4	**0.05**	**-56.5**	**0.07**	**-54.9**	0.03	-0.9
				3.7E-05	3.1	-13.0	0.05	3.9	**0.14**	**37.3**	**0.25**	**68.9**	0.03	3.9
	Upper Bedrock (K_h)	Sulphuret Intact Intrusive Bedrock	8.0E-09	8.0E-10	1.8	5.0	0.05	0.0	0.11	0.0	0.15	0.0	0.03	0.0
				8.0E-08	3.9	-5.5	0.05	0.0	0.10	-1.2	0.15	-0.3	0.03	-0.5
		Rest of Model Layers	5.0E-08	5.0E-09	2.9	16.7	**0.04**	**-14.0**	**0.09**	**-10.5**	0.14	-4.5	0.03	-13.0
				5.0E-07	8.7	-47.5	**0.07**	**37.7**	**0.13**	**22.7**	0.16	6.2	0.04	37.2
	Middle Bedrock (K_h)	Sulphuret Intact Intrusive Bedrock	5.0E-09	5.0E-10	1.5	3.7	0.05	0.0	0.11	0.1	0.15	0.0	0.03	0.0
				5.0E-08	1.9	-0.7	0.05	0.0	0.10	-1.3	0.15	-0.2	0.03	-0.2
		Rest of Model Layers	8.0E-09	8.0E-10	1.4	5.0	0.05	-2.9	0.10	-1.6	0.15	-0.7	0.03	-2.5
				8.0E-08	3.2	-12.2	0.05	16.1	0.11	8.3	0.16	5.9	0.04	17.6
	Lower Bedrock (K_h)		2.4E-09	2.4E-10	1.4	3.6	0.05	-1.2	0.10	-0.4	0.15	-0.3	0.03	-1.2
				2.4E-08	1.7	-1.3	0.05	7.1	0.11	2.6	0.15	3.2	0.03	10.9
	Bottom Bedrock (K_h)		4.8E-10	4.8E-11	1.4	2.7	0.05	-0.2	0.10	-0.1	0.15	-0.1	0.03	-0.2
				4.8E-09	1.4	2.4	0.05	1.2	0.11	0.4	0.15	0.6	0.03	2.3
Anisotrophy of Overburden (K_h/K_v)			5:1	1:10	1.3	0.5	0.05	3.3	0.11	1.0	0.17	18.2	0.03	11.2
				1:1	1.3	1.2	0.05	1.3	0.11	0.6	0.16	7.9	0.03	5.8
				10:1	1.5	3.7	0.05	0.1	0.11	0.1	0.14	-2.2	0.03	-2.2
Anisotrophy of Bedrock (K_h/K_v)			1:1	1:10	2.6	-8.8	0.05	11.6	0.11	7.8	**0.19**	**29.8**	0.03	-4.7
				10:1	4.8	28.7	0.04	-18.7	0.09	-10.8	**0.11**	**-23.4**	0.03	3.2
Recharge Rates			115 mm/yr in Zone 1 128 mm/yr in Zone 2 146 mm/yr in Zone 3 164 mm/yr in Zone 4 40 mm/yr in Zone 5	1/2 of Base Case	5.4	-33.3	**0.03**	**-36.7**	**0.08**	**-28.5**	**0.12**	**-16.3**	**0.02**	**-34.9**
				2 times Base Case	6.1	39.5	**0.07**	**49.5**	**0.14**	**38.0**	**0.18**	**22.9**	**0.05**	**47.6**
Base Case Calibration and Baseflow Rates:					***1.4***	***2.7***	***0.05***		***0.11***		***0.15***		***0.03***	

(continued)

Table 3.2-7. KSM Project Mining Area Baseline Hydrogeology Model Sensitivity Analysis Results (completed)

Property and Parameter			Base Case Value	Simulated Baseflow Rates in Creeks and Lake										Overall Sensitivity
				Sulphurets Creek Lower (m^3/s)	Change from Base Case (%)	Sulphurets Lake (m^3/s)	Change from Base Case (%)	Ted Morris Creek (m^3/s)	Change from Base Case (%)	Joe Mandy Creek (m^3/s)	Change from Base Case (%)	Gingras Creek (m^3/s)	Change from Base Case (%)	
Overburden	Glacial Till/Colluvium (K_h)		8.0E-07	**0.08**	**-18.2**	0.01	-23.2	**0.03**	**-38.1**	0.03	0.0	0.03	7.8	High
				0.13	**44.5**	0.02	28.8	**0.10**	**82.8**	0.03	0.0	0.03	-2.6	
	Fluvial (K_h)		6.0E-05	0.09	-6.5	0.02	0.0	0.06	0.0	0.03	0.0	0.03	0.0	Low
				0.11	14.4	0.02	0.0	0.06	0.0	0.03	0.0	0.03	0.0	
Bedrock	Top/Shallow Bedrock (K_h)	Hazelton Group Volcanic Rocks Above Mitchell Thrust Fault	8.0E-08	**0.07**	**-21.6**	0.02	1.7	0.06	8.3	**0.01**	**-50.5**	0.03	0.1	High
				0.13	**40.9**	0.02	-1.6	0.05	-2.8	**0.05**	**74.9**	0.03	-0.3	
		Stuhini Group Sedimentary Rocks	9.0E-08	0.09	-1.4	0.02	0.9	0.06	0.4	0.03	0.0	0.02	-13.7	High
				0.10	8.9	0.02	-5.5	0.06	-0.8	0.03	0.0	0.03	16.2	
		Stuhini Group Volcanic Rocks	1.0E-07	0.09	-6.2	0.01	-37.0	**0.04**	**-25.7**	0.03	2.4	0.02	-27.7	High
				0.11	19.6	0.03	70.4	**0.08**	**48.1**	0.03	-1.9	0.04	38.1	
		Coast Plutonic Complex Formation	9.0E-08	0.09	0.0	0.02	0.0	0.06	0.2	0.03	0.1	0.03	0.0	Low
				0.09	0.0	0.02	0.0	0.06	-0.1	0.03	0.0	0.03	0.0	
		Sulphuret Intact Intrusive Bedrock	1.35E-08	0.09	0.0	0.02	0.1	0.06	0.0	0.03	0.0	0.03	0.0	Low
				0.09	0.0	0.02	-0.8	0.06	0.0	0.03	0.0	0.03	0.0	
		Bedrocks Under Mitchell Thrust Fault and Mitchell Valley Top	3.7E-06	0.09	-3.4	0.02	0.1	0.06	0.0	0.03	0.0	0.03	3.1	High
				0.11	14.6	0.02	0.0	0.06	0.0	0.03	0.0	0.03	4.5	
	Upper Bedrock (K_h)	Sulphuret Intact Intrusive Bedrock	8.0E-09	0.09	0.0	0.02	0.0	0.06	0.0	0.03	0.0	0.03	0.0	Low
				0.09	0.0	0.02	0.2	0.06	0.0	0.03	0.0	0.03	0.0	
		Rest of Model Layers	5.0E-08	**0.08**	**-15.3**	0.01	-21.2	**0.05**	**-17.8**	0.03	-12.5	0.03	1.5	High
				0.13	**43.6**	0.03	64.2	**0.08**	**52.2**	0.03	-10.0	0.01	-61.4	
	Middle Bedrock (K_h)	Sulphuret Intact Intrusive Bedrock	5.0E-09	0.09	0.0	0.02	-0.2	0.06	0.0	0.03	0.0	0.03	0.0	Low
				0.09	0.0	0.02	1.9	0.06	0.0	0.03	0.0	0.03	0.0	
		Rest of Model Layers	8.0E-09	0.09	-3.1	0.02	-3.5	0.05	-3.6	0.03	-1.6	0.03	2.3	Low
				0.11	20.0	0.02	20.5	0.07	20.4	0.03	-5.1	0.02	-31.7	
	Lower Bedrock (K_h)		2.4E-09	0.09	-1.3	0.02	-1.3	0.05	-1.4	0.03	-0.2	0.03	1.3	Low
				0.10	8.8	0.02	9.3	0.06	8.7	0.03	-3.3	0.02	-12.6	
	Bottom Bedrock (K_h)		4.8E-10	0.09	-0.2	0.02	-0.2	0.06	-0.2	0.03	0.0	0.03	0.2	Low
				0.09	1.5	0.02	1.6	0.06	1.5	0.03	-0.8	0.03	-2.0	
Anisotrophy of Overburden (K_h/K_v)			5:1	0.11	16.5	0.02	0.4	0.06	2.9	0.03	0.0	0.03	-1.2	Low
				0.10	5.2	0.02	0.4	0.06	1.7	0.03	0.0	0.03	-1.0	
				0.09	-2.2	0.02	-0.5	0.05	-1.0	0.03	0.0	0.03	1.4	
Anisotrophy of Bedrock (K_h/K_v)			1:1	0.10	8.4	0.02	-0.2	0.06	-0.2	0.04	21.2	0.03	22.1	Low
				0.08	-10.9	0.02	-13.0	0.05	-5.3	0.02	-21.7	0.02	-21.8	
Recharge Rates			115 mm/yr in Zone 1 128 mm/yr in Zone 2 146 mm/yr in Zone 3	**0.07**	**-27.2**	0.01	-31.4	**0.04**	**-34.5**	**0.02**	**-40.5**	**0.01**	**-52.4**	High
			164 mm/yr in Zone 4 40 mm/yr in Zone 5	**0.12**	**32.3**	0.02	28.2	**0.08**	**40.7**	**0.05**	**58.3**	**0.05**	**74.6**	
Base Case Calibration and Baseflow Rates:				***0.09***		***0.02***		***0.06***		***0.03***		***0.03***		

The steady-state baseline pre-mining model results also show that simulated head equipotential contours generally mimic the surface topography. The groundwater table is shallow or artesian on the valley bottoms. The simulated flow budget results show that for the baseline pre-mining conditions, the baseflow varies from 0.12 to 1.49 at the mouth of Sulphurets Creek entering Unuk River, 0.1 m^3/s to 1.39 m^3/s at the confluence of Mitchell and Sulphurets Creeks, and from 0.01 m^3/s to 0.1 m^3/s at the McTagg Creek outlet. The total groundwater flow through the proposed ultimate Mitchell, Sulphurets and Kerr Pit areas at pre-mining is estimated to be approximately 10,158.0 m^3/d (117.6 L/s), 758.5 m^3/d (8.8 L/s), 708.3 m^3/d (8.2 L/s), respectively; the total flow through the areas of the proposed Rock Storage Facilities in Mitchell-McTagg valleys and above the Sulphurets Creek is about 16,843.0 m^3/d (194.9 L/s), and 726.4 m^3/d (8.4 L/s), respectively; the flow into the proposed water storage area is 2,545.0 m^3/d (29.5 L/s) at the operational low water level and 4366.0 m^3/d (50.5 L/s) at the operational high water level.

The sensitivity analysis identify that the estimated groundwater flow results are highly sensitive to the recharge rates, the hydraulic conductivities of glacial till materials and the bedrock formations in the top/shallow, upper and middle zones in the mining area, as well as their anisotropy ratios.

Based on the available information, the results demonstrate that the calibrated baseline model is a reasonable representation of the hydrogeological system of the baseline pre-mining conditions, and it is reliable for predictive modelling to assess the effects of the proposed mining activities of the KSM Project for water quantity and quality.

3.3 PREDICTIVE SIMULATIONS OF GROUNDWATER FLOW

3.3.1 Overview

According to the KSM Project mine design plan in the prefeasibility study (Wardrop 2010), the proposed pits (Mitchell, Sulphurets and Kerr) in the mining area are to be fully mined and dewatered by the end of mine life in 37 years, then the pits will be refilled at post-closure as artificial lakes. The major components in the mining area also include Water Storage Facility, Rock Storage Facilities and Diversion Tunnels, and they will be developed to their maximum extent at the end of mine operation and post-closure. For the purpose of environmental impact assessment, the end of operation and post-closure scenarios represent the largest effects that the mining activities will have on the groundwater regime in comparison with the mine construction and operational years.

This chapter describes the methodologies for predictive modelling of potential changes to groundwater flow in the mining area at the end of operation and post-closure, and presents the key results for qualitative and quantitative assessment of the potential impact of the mining activities on groundwater flow, and the data for calculation of the water balance and environmental effect analysis. The results include:

1. The predicted change of regional/local groundwater levels and flow patterns at the end of the mine operation when the ultimate pits are dewatered, together with the full capacities of the Water Storage Facility, Rock Storage Facilities and tunnels.
2. The predicted change of regional/local groundwater levels and flow patterns at the mine post-closure when the pits are refilled, together with the full capacities of the Water Storage Facility, Rock Storage Facilities and tunnels.
3. The predicted change of groundwater discharge (baseflow) into the major creeks at the end of mine operation and post-closure.
4. The predicted groundwater flows in and out of the mine facilities, including the seepage from the Water Storage Facility and the Rock Storage Facilities at the end of mine operation and post-closure.

The Visual MODFLOW Surfact flow package was used to predict the maximum change in groundwater flows at the end of mine operation and post-closure (Base Case flows under steady-state conditions), and compared to the pre-mining conditions. Sensitivity analyses were carried out with reasonable assumptions, for example, order-of-magnitude variation of the hydrogeological properties (such as hydraulic conductivities) and climatic conditions to estimate the possible ranges (average, upper and lower, wet and dry) of the predictions. Sensitivities are also carried out to examine the effect of reclamation with soil cover on the Rock Storage Facilities.

3.3.2 Approaches

3.3.2.1 Flow Boundary Conditions

End of Operation

Figure 3.3-1 shows the flow boundary conditions for Base Case simulation of groundwater flow at the end of mine operation. The modifications to the flow boundary conditions used in the pre-mining model include the removal of McTagg Creek and Mitchell Creek above the Water Storage Facility and the Seepage Collection Dam, the small streams (drains) under the footprints of the Proposed Open Pits and Rock Storage Facility to represent the effect of the mining on the surface water bodies.

The boundary conditions for the Open Pits (Mitchell, Sulphurets and Kerr) are similar to those in BGC's pit dewatering model (BGC 2010a; Appendix 11-I of the EA Chapter 11). Pit dewatering was simulated by assigning drain boundary condition for vertical pit dewatering wells (50 wells in Mitchell Pit and 14 in Kerr Pit) and the cells at the bottom of the pits. Groundwater levels within the drain cells are specified at the depth of mining, and the conductance of the drains is set to a high value (100 m^2/d) to allow water to freely flow into the simulated Open Pits and dewatering wells.

For the Rock Storage Facilities, a higher net recharge 330.4 mm/yr (equivalent to 20% of the observed mean annual precipitation 1,652 mm/yr at the mine site) was assigned to the footprints to represent the effect of increased infiltration from precipitation through uncovered rock piles. The increased net recharge rate through the RSF is from reference to similar studies (McCreadie and Smith 1993; Kampf et al. 2002; Wels 2009). The uncertainty associated with the recharge in Rock Storage Facilities is examined in the sensitivity analysis.

The Water Storage Facility (pond) and the Seepage Collection Pond are assigned as constant heads. The water levels are taken from the prefeasibility study: 670 masl in Water Storage Pond (the operational high level) and 536 masl in Seepage Collection Pond to examine the maximum potential seepage.

The tunnels are assigned as drains to calculate potential groundwater flow into the tunnels. The drain elevations are, respectively, from 860 masl (McTagg valley) to 800 masl (Sulphurets valley) in McTagg Diversion Tunnel, from 858 masl (Mitchell valley) to 811 masl (Sulphurets valley) in Mitchell Pit East Diversion Tunnel, from 960 masl (Mitchell valley) to 940 masl (Sulphurets valley) in Mitchell Pit West Diversion Tunnel, and from 925 masl (Mine area study boundary) to 900 masl (Mitchell valley) in Mitchell-Teigen Ore Transport Tunnel. The conductance of the drains is set to a high value (100 m^2/d) to allow water to freely flow into the tunnels.

In addition, a wall boundary (horizontal flow barrier) is assigned to represent the grout curtain under the Water Storage Dam., The wall (grount curtain or equivalent cut-off) is about 100 m deep (Layer 1 to 4 in the model) and 10 m wide with a hydraulic conductivity assumed 1.0×10^{-8} m/s, two orders of magnitude higher than the sedimentary bedrock under the dam.

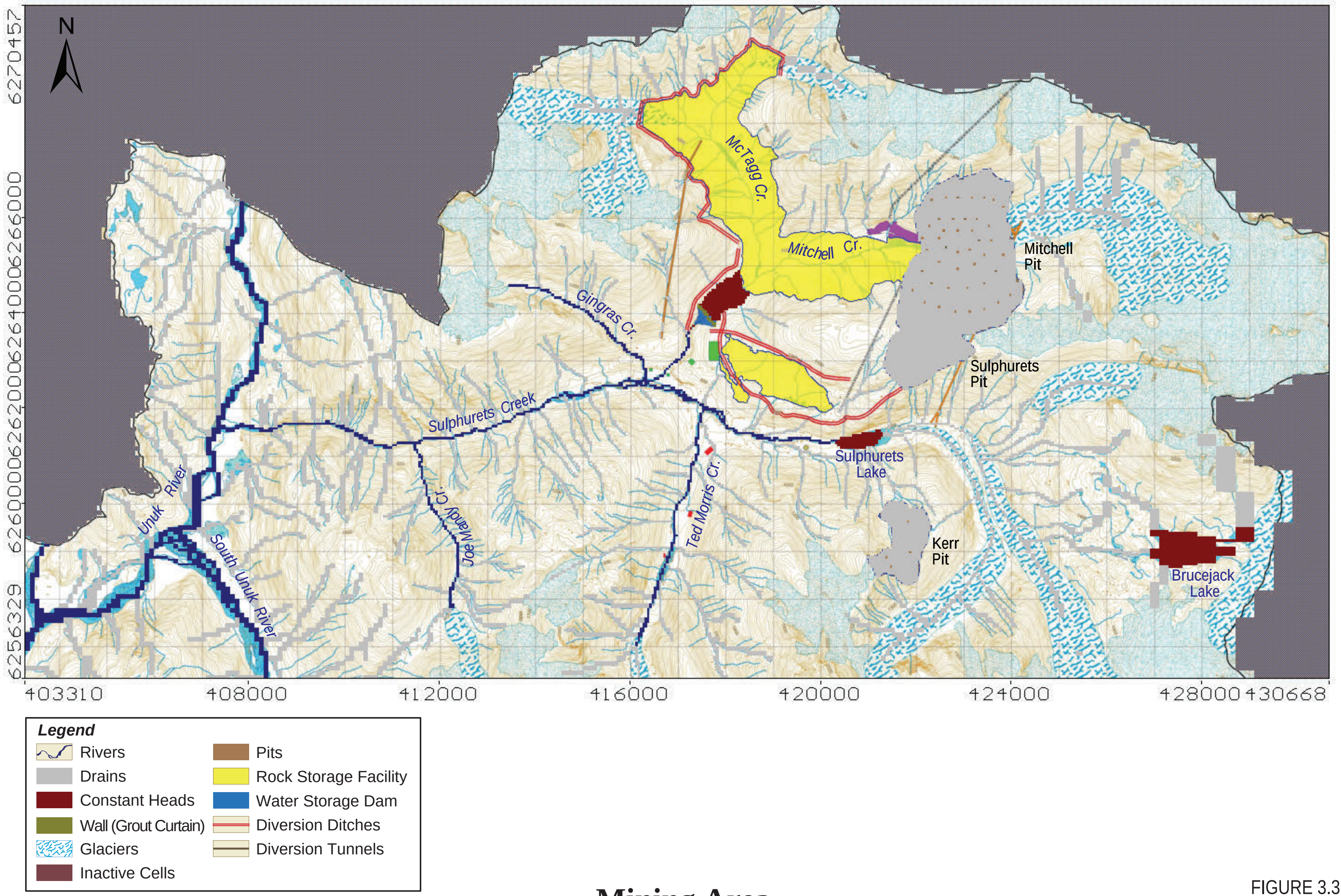

FIGURE 3.3-1

Mining Area
End of Operation Flow Boundaries (Layer 1)

Post-closure

Figure 3.3-2 shows the flow boundary conditions for Base Case simulation of groundwater flow at post-closure. The boundary conditions are the same as those for the end of mine operation, except for the pits in which constant head boundaries were assigned to represent the refilled artificial pit lakes at post-closure. According to the prefeasibility study (Wardrop 2010), the Mitchell Pit will be flooded to 840 masl post-closure, the Sulphurets Pit lake will be refilled to the spill elevation at 1,206 masl, and the south and north Kerr Pit lakes will also be refilled to their spill elevations at 1,458 masl and 1,080 masl, respectively. These elevations are the maximum levels in the pit lakes and therefore predict the largest seepage rates for the EA.

3.3.2.2 Hydraulic Conductivities

The hydraulic conductivities in the Base Case models for the end of operation and the post-closure are the same as those used in the baseline pre-mining model. The exception is that an elevated hydraulic conductivity (1.0×10^{-5} m/s) is assigned in the pit dewatering wells above the drains together with the high drain conductance to allow water to freely flow into the wells for the end of operation scenario. Similarly, an elevated hydraulic conductivity (1.0×10^{-5} m/s) is assigned in the cells within the pit shells to represent the ultimate mined pits at post-closure.

3.3.2.3 Flow Budget Zones

Figures 3.3-3 and 3.3-4 show the budget zones that were assigned to calculate baseflows to the creeks and groundwater flows in the mine facilities (e.g., to calculate seepage from the facilities that mixes with regional groundwater) at the end of mine operation and post-closure. In both scenarios, the budget zones for calculation of baseflow in the creeks and Sulphurets Lake are assigned in the top model layer only. The budget zones for the pits are assigned from the top layer into deeper layers to represent the pit geometries (i.e., Layers 1 to 9 in Mitchell Pit, Layers 1 to 6 in Sulphurets Pit and Layers 1 to 5 in Kerr Pits). The budget zones in Rock Storage Facilities, Water Storage Facility and Seepage Collection Area were assigned from the top layer to Layer 8 based on the results of solute plume migration from the facilities (see Section 3.4.3 for solute plumes). The budget zones for the tunnels are assigned in various layers along the drain cells of the tunnels. The only difference between the two scenarios is that budget zones were assigned for the pit dewatering wells at the end of operation scenario (as shown in Figure 3.3-3) but not in the post-closure scenario.

3.3.2.4 Flow Solver Parameters

The PCG4 flow solver in the MODFLOW-Surfact flow package version 3.0 (as in the baseline pre-mining model) was used to simulate steady-state variably-saturated groundwater flow at the Base Case end of mine operation scenario (with pit dewatering) and at the Base Case post-closure scenario (with pit lake refill) and to predict the maximum impact of mining on groundwater flow.

The solver parameters and the convergence criteria used for the post-closure Base Case flow simulations and sensitivities are the same as being used in the baseline pre-mining model:

- the maximum outer iterations: 250
- the maximum inner iterations: 150
- the head change criterion: 0.01 m
- the residual criterion: 0.01 m^3/d

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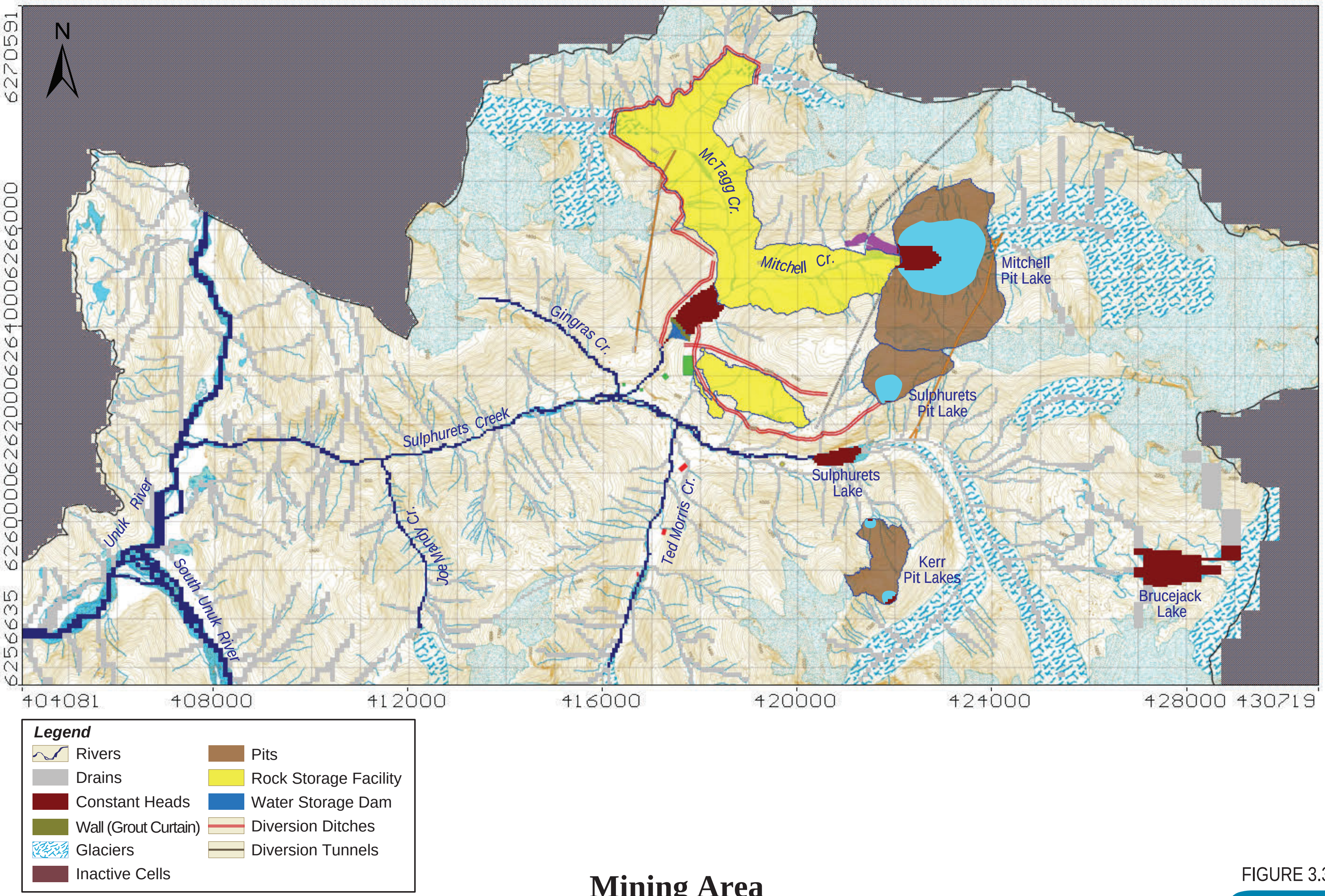

Mining Area
Post-closure Flow Boundaries (Layer 1)

FIGURE 3.3-2

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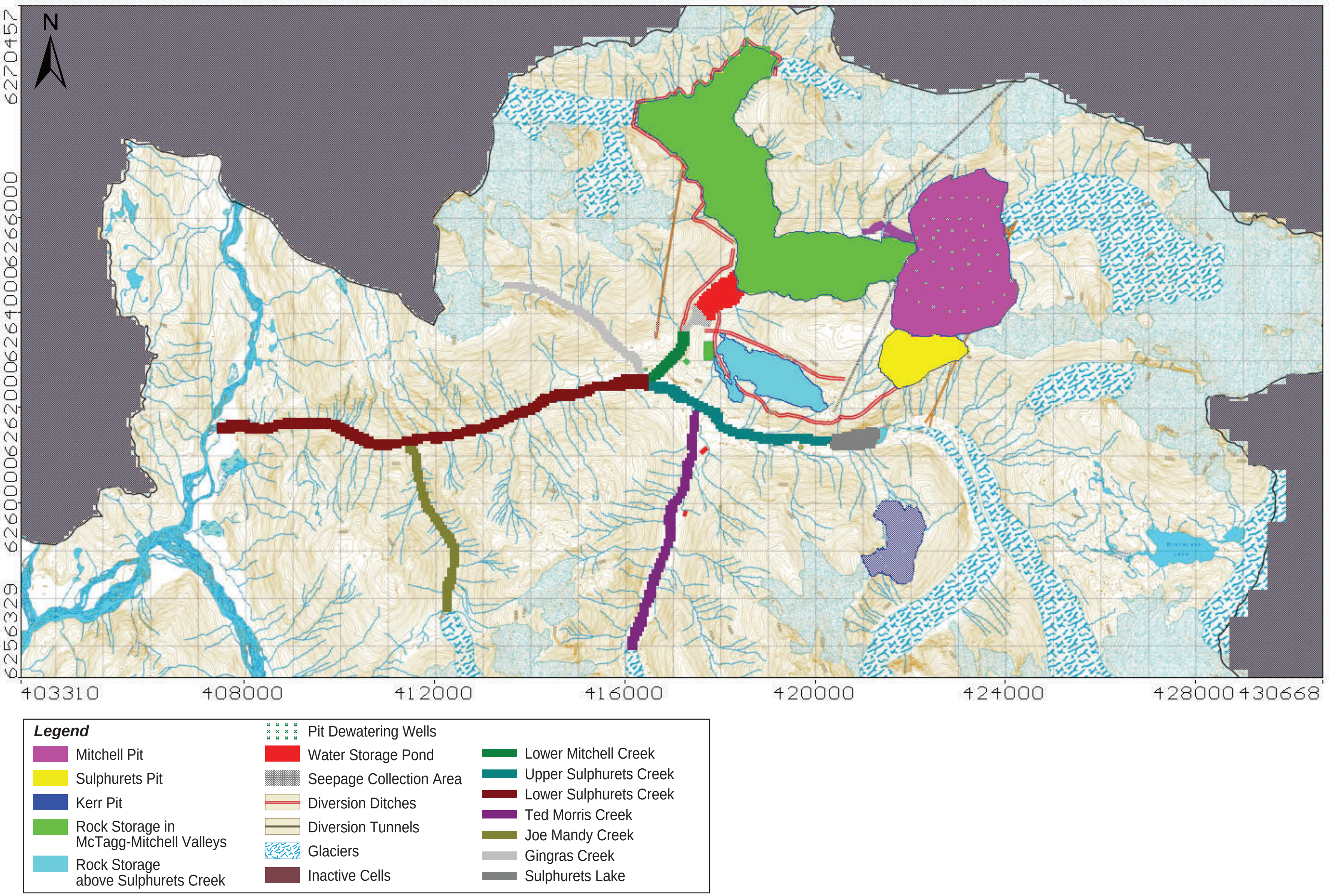

FIGURE 3.3-3

Mining Area
End of Operation Budget Zones (Layer 1)

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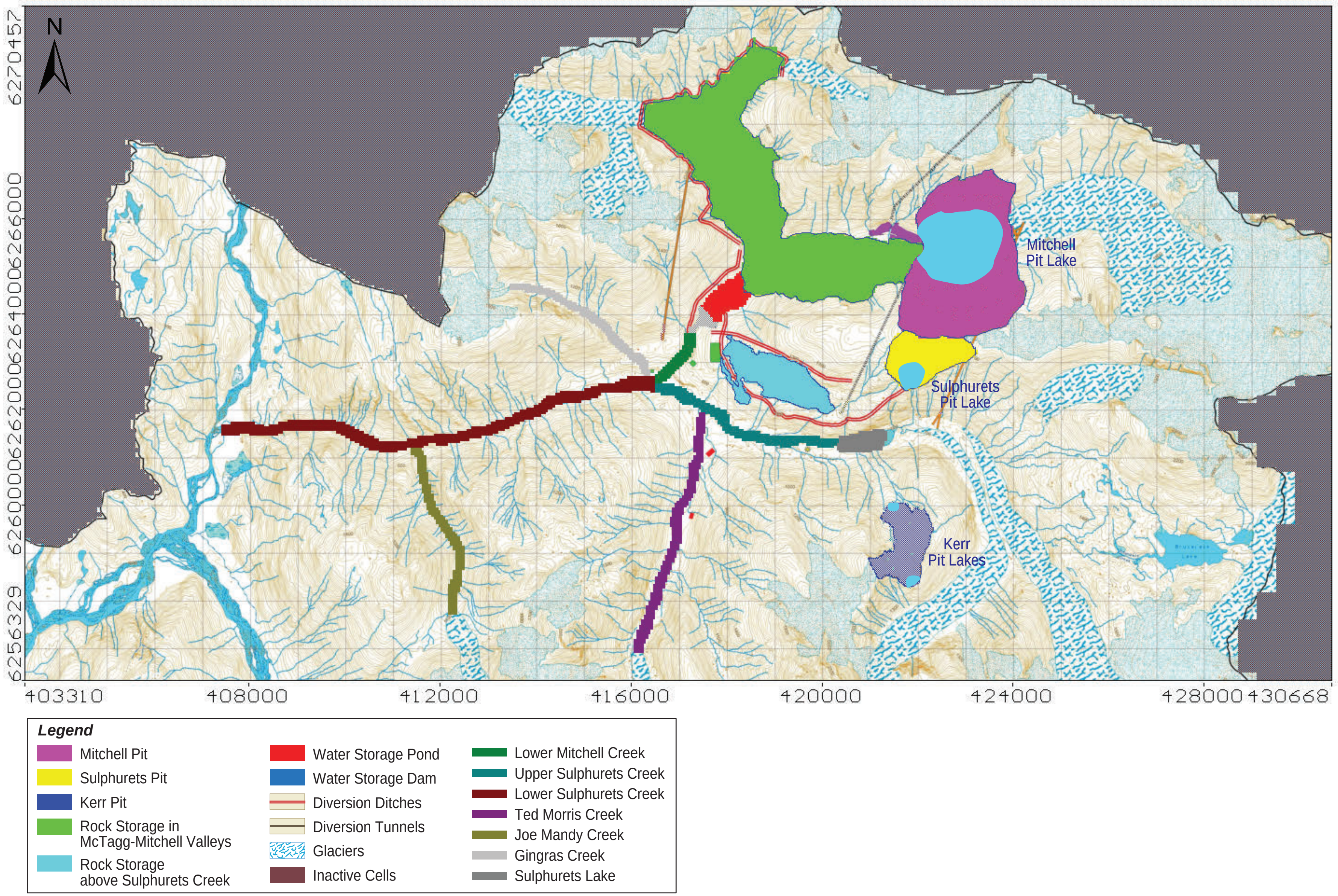

FIGURE 3.3-4

Mining Area
Post-closure Budget Zones (Layer 1)

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For the end of operation flow simulations, in order to obtain the numerical solutions in facing the great challenge of pit dewatering (e.g., over 1,000 m drawdown is required in Mitchell Pit), the maximum outer iterations are increased to 500, and the head convergence criteria are relaxed to 0.1 m for Base Case and up to 1.0 m for sensitivities. The criteria relaxation is considered to be appropriate for the KSM project mining study area with the maximum topography relief of over 2,300 m and the maximum head difference of over 2,100 m.

The other parameters of the solver for Base Case and sensitivities such as the damping factor are kept at their default values from the numerical code, same as the baseline pre-mining model. The small absolute head change and residual criteria used are to ensure the accuracy in the flow solutions, and the damping factor applied is to make the solver work more easily for solving the problem in the domain with steep terrains.

3.3.3 Base Case Flow Patterns and Pathlines

Base Case steady-state flow simulations were run for the end of operation scenario and the post-closure scenario using particles assigned inside the major mine components (the pits and pit lakes, the Rock Storage Facilities, the Water Storage Facility) to simulate the flow patterns from these facilities. This section presents the flow patterns and particle-tracking pathlines.

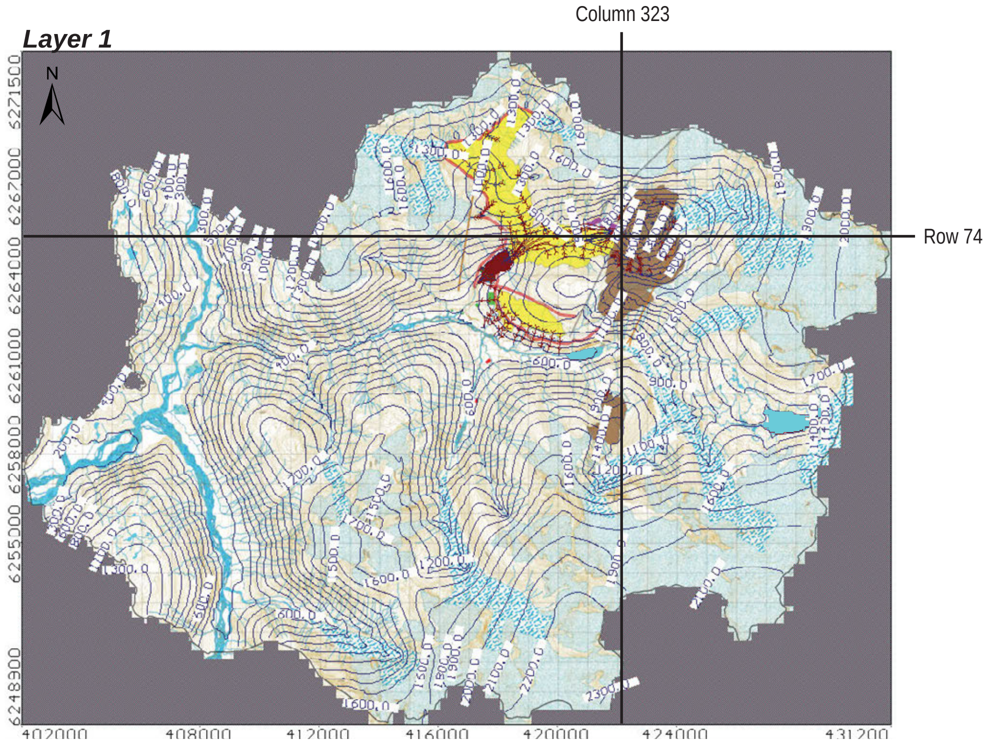
3.3.3.1 End of Operation

Figure 3.3-5 shows the end of operation flow patterns with the equipotential lines within the entire model domain (Layer 1). The figure inset shows details of the particle-tracking pathlines on the mine site (each marker represents the flow distance in 10 years). Figure 3.3-6 shows the flow patterns in cross-sections at the end of operations. The figures illustrate that groundwater recharge zones are on the highlands and the discharge zones are at lower elevations and in the valley bottoms (rivers, creeks and lakes), similar to the pre-mining. The change of flow patterns outside the mining zones and the Mitchell-Sulphurets watersheds are insignificant.

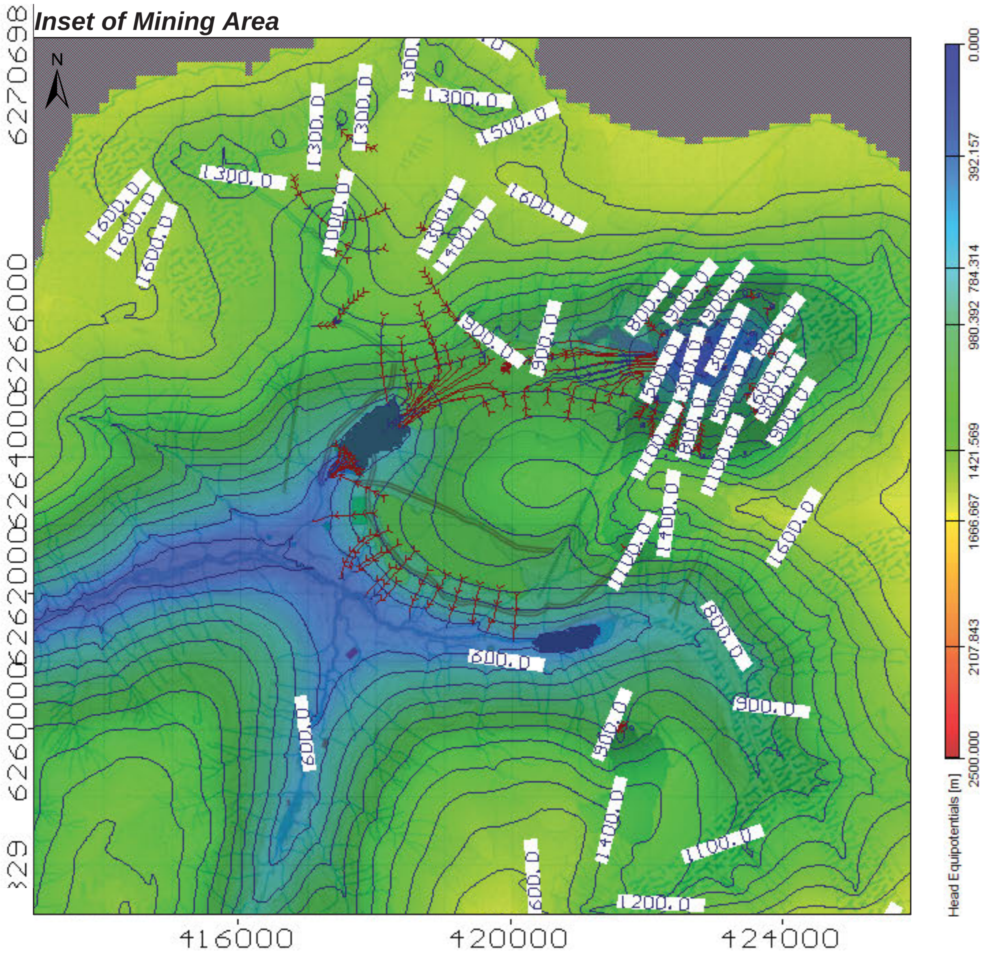
However, within the mining zones the results indicate that, in comparison with the pre-mining, the local groundwater flow patterns at the end of mine operation change significantly in the Mitchell Pit area because of the dewatering. At pre-mining, groundwater from upstream Mitchell valley flows through the Mitchell Pit footprint and flows downstream along the valley toward the confluence of Mitchell and Sulphurets Creeks. However, as shown by the particle-tracking pathlines, groundwater flows into the Mitchell Pit from all directions and the pit becomes a groundwater sink at the end of mine operation, influencing groundwater flow direction to a distance of about 4 km along Mitchell valley. The groundwater flow direction in the valley downstream of the Mitchell Pit is reversed: instead of flowing toward the Water Storage Facility area (as in the pre-mining scenario), the groundwater flows toward the pit as a result of the dewatering. Compared to the Mitchell Pit, the Sulphurets and Kerr Pits have relative smaller effect on the overall flow patterns due to their small sizes, especially the Kerr Pits.

In the proposed McTagg-Mitchell Rock Storage Facility area, the particle pathlines show that there is a groundwater divide under the Mitchell Rock Storage Facility: groundwater flows toward the Mitchell Pit in eastern section of the Mitchell RSF and flows to the Water Storage Facility in the western section of the Mitchell RSF. This indicates that the water infiltrating into the eastern section of the RSF (with potentially poor water quality) will discharge into the pit and mix with the water inside the pit. Similarly, water infiltrating into and leaching out of the west of the Mitchell and the McTagg RSFs with potentially poor quality will discharge into the Water Storage Facility. The particle-tracking pathlines also show that some seepage from McTagg RSF could flow into the proposed McTagg tunnel.

Layer 1



Inset of Mining Area



Legend

- *- 600 -* Equipotential Line
- → Particle Pathline
- ■ Inactive Cells
- ■ Pits
- ■ Rock Storage Facility
- ■ Water Storage Pond

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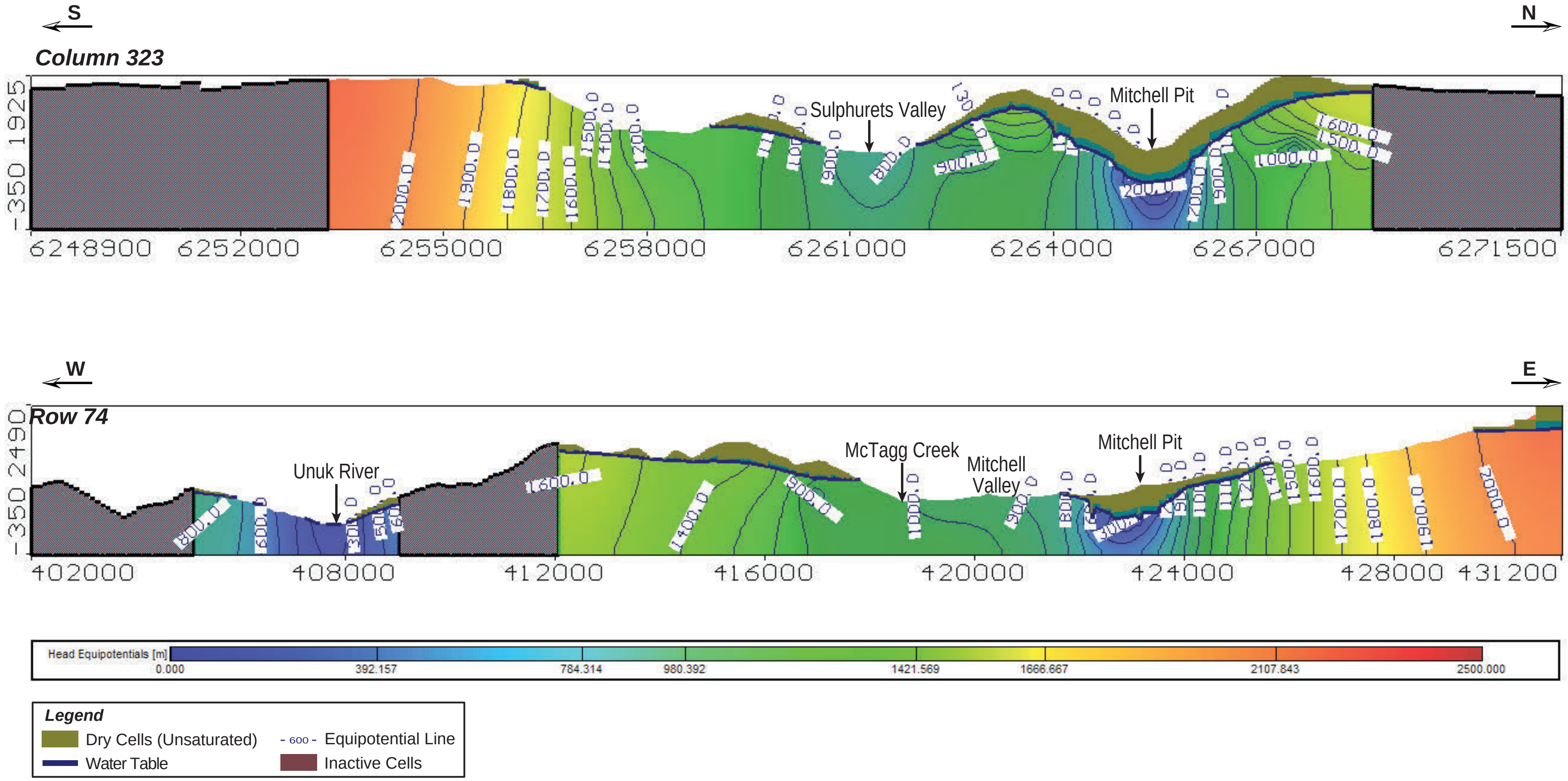
Mining Area End of Operation Steady-state Flow Patterns (Base Case, Plan View)

FIGURE 3.3-5



Mining Area End of Operation
Steady-state Flow Patterns
(Base Case, Cross-sections)

FIGURE 3.3-6

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For the proposed Sulphurets RSF, the particle pathlines show that the RSF is located in a groundwater recharge zone, and that most of the seepage out of the RSF will discharge to the Sulphurets Creek in about 20 to 30 years in the Base Case. The travel time could be as short as 2 to 3 years if highly permeable fracture networks and faults are present between the RSF and the creek. Less than 10% of the seepage from the Sulphurets RSF will report to the Water Storage Facility and Seepage Collection System. This suggests that the Sulphurets Rock Storage Facility could affect the water quality in the Sulphurets Creek, although this creek has naturally elevated solute mass load. The groundwater flux from the RSF should be assessed against the total load in the creek to determine whether any groundwater management is warranted at the RSF.

The particle-tracking pathlines in the proposed Water Storage Facility and Seepage Collection System area (located in the deep canyon of downstream Mitchell valley), show that the seepage out of the Water Storage Pond will be captured by the Seepage Collection System, and therefore is unlikely to cause a significant effect to the downstream surface water receptor. This result indicates that provided the foundations of Water Storage and Seep Collection Dams are effectively grouted and sealed to the appropriate depths, there should be minimal concern for environmental impact in this area.

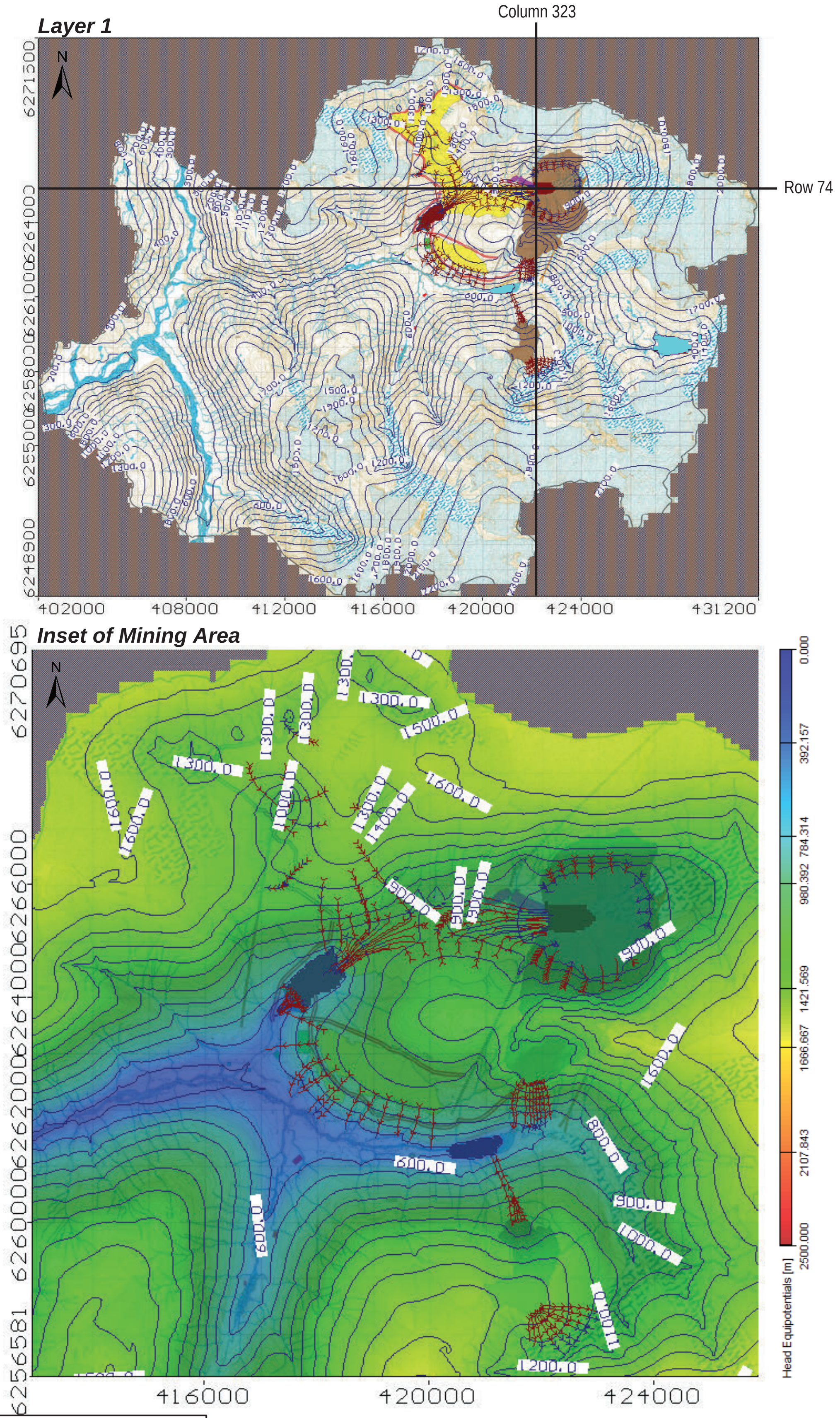
3.3.3.2 Post-closure

Figure 3.3-7 shows the mining area post-closure Base Case steady-state flow patterns with the equipotential lines in the entire model domain (Layer 1). The inset shows the details of the particle-tracking pathlines on the mine site (each marker represents the flow distance in 10 years). Figure 3.3-8 shows cross-sections of steady-state flow patterns in the mining area for the post-clousre scenario. Similar to the pre-mining and the end of operation scenarios, regional groundwater is recharged predominantly in high elevations and discharges at lower elevations and to surface water bodies on the valley bottoms. The change in flow patterns is limited to the major mine zones in the Mitchell-Sulphurets watersheds.

Within the pit lakes, the flow patterns and particle-tracking pathlines indicate that the Mitchell Pit will continue to be a groundwater sink receiving groundwater discharge from the surrounding aquifer and groundwater leaching from the Mitchell RSF. The influence on the downstream flow in the Mitchell valley has diminished because there is no pit dewatering post closure; the groundwater has moved closer to the Mitchell Pit. However, the pathlines show that the groundwater from the Sulphurets Pit Lake and the Kerr Pit South/North Lakes will continue discharging into the downstream Sulphurets Lake and the upstream Sulphurets valley (under the glacier).

Outside of the influence from the pit lakes, as shown by the equipotential lines and the particle pathlines, the flow patterns at post-closure in the areas of McTagg Rock Storage Facility, Sulphurets Rock Storage Facility, the Water Storage Facility and the Seepage Collection System are basically the same as those in the end of operation scenario. Most seepage from the Sulphurets RSF will discharge to Sulphurets Creek and take around approximately 20 to 30 years to reach the creek. A small portion of seepage from the Sulpurets RSF will discharge to the Water Storage Facility and Seepage Collection System. Most of the seepage from the Water Storage Facility will be captured in the Seepage Collection System.

The post-closure results demonstrate that the effects of pit dewatering or refill on the groundwater regime in the mining area will be limited to the local pit areas only. These localized effects do not affect the groundwater flow in the downstream of Mitchell Valley (under the Water Storage and Seepage Collection Dams) and to the downstream of Sulphurets Creek, as well as the flow to the McTagg Diversion Tunnel.



Legend

- 600 -	Equipotential Line	▨	Pits
→	Particle Pathline	🟨	Rock Storage Facility
▨	Inactive Cells	🟥	Water Storage Pond

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Mining Area Post-closure Steady-state Flow Patterns
(Base Case, Plan View)

FIGURE 3.3-7

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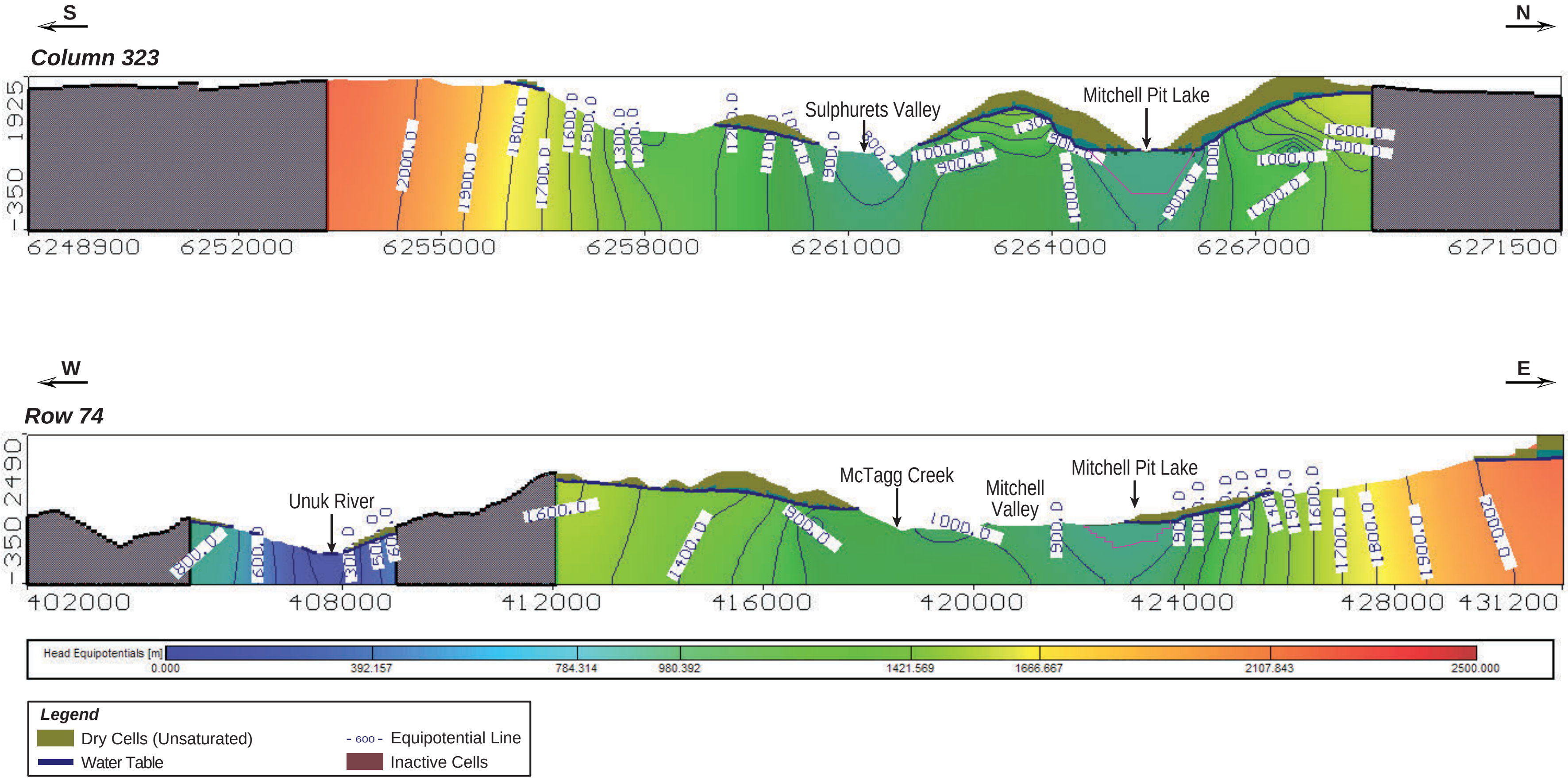

FIGURE 3.3-8

Mining Area Post-closure Steady-state Flow Patterns
(Base Case, Cross-sections)

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3.3.4 Groundwater Flow Rates and Sensitivities

To provide the groundwater inputs for the site water balance and for quantitative assessment of mining effects, groundwater flows including baseflows into the creeks and flows in the major mine zones have been calculated for the end of operation scenario and post-closure scenarios (Base Cases) using the budget zones assigned and discussed in Section 3.3.2.3. In addition, sensitivity analyses have been carried out by varying the most significant parameters identified in the baseline pre-mining scenario and by the same orders of magnitude as in the baseline model sensitivities. The sensitivity scenarios and the parameters are shown in Table 3.3-1.

3.3.4.1 Stream Baseflow

Table 3.3-2 summarizes the predicted baseflows and shows that in comparison with the baseflows in the pre-mining scenario (see Table 3.2-7), the baseflows to Sulphurets Lake, Sulphurets Creek upper reach (from Sulphurets Lake to Mitchell confluence), Sulphurets Creek lower reach (from Mitchell confluence to Unuk River, Ted Morris, Gingras Creek and Joe Mandy Creek) do not change significantly in the end of operation and post-closure scenarios. However, as the McTagg Creek and most of the Mitchell Creek will disappear under the McTagg-Mitchell Rock Storage Facility, Water Storage Facility and seepage collection area, the total baseflow at the outlet of Sulphurets Creek entering Unuk River (hydrometric station SC-H1) is reduced from 0.57 m^3/s at the pre-mining stage to 0.28 m^3/s at the end of mine operation and post-closure; about 50% reduction in total baseflow.

The Base Case results demonstrate that as groundwater flows to the Mitchell Pit during dewatering and to the Pit Lake at the post-closure, and to the Water Storage Facility from the McTagg and Mitchell valleys, the contribution of Mitchell Creek (above the Water Storage Facility) and McTagg Creek to the baseflow in the downstream Sulphurets Creek is lost. However, the total runoff the downstream Sulphurets Creek is unlikely to change significantly because, according to the mine plan, a large portion of surface water flow in the McTagg and Mitchell valleys will be diverted through tunnels to the Sulphurets Creek, and groundwater from dewatering the pits and from the Water Storage Facility will be discharged into Sulphurets Creek. Therefore, it can be concluded that the mining activities will have limited effect on the water quantity in downstream creeks outside of the mining area, including the Mitchell/Sulphurets confluence.

The results of the sensitivity analysis show that the baseflows will be higher when the overburden (glacial till) and bedrocks are more permeable, and lower when the geological materials are less permeable; the baseflows will increase in wet years and decrease in dry years. In addition, the results show that there is no change in the baseflows in the downstream surface water bodies when the Rock Storage Facilities are covered (the recharge is reduced by half to 165.2 mm/yr, 10% of mean annual precipitation 1,652 mm/yr). Covering the RSF will reduce the infiltration into the Rock Storage Facilities and the seepage of potentially poor water quality out of the facility.

3.3.4.2 Water Storage Facility

Table 3.3-3 lists the groundwater flows in the proposed Water Storage Facility at the end of mine operation and post-closure in the Base Case and for the upper and lower cases (sensitivity analysis). The results show that at the Base Case end of operation, the inflow from McTagg-Mitchell Rock Storage Facility into the water storage pond is estimated at 2,867 m^3/d (33 L/s), inflow of non-contact groundwater at 1,609 m^3/d (19 L/s), and the seepage from the water storage pond and collection dam basin is estimated at 295 m^3/d (3 L/s). The difference between inflow and seepage represents the groundwater discharging into the surrounding aquifer and leaving the pond on the surface (e.g., through evaporation and removal for treatment to maintain the water level). The results indicate that the seepage out of Water Storage Facility is very small due to the fact that the facility is located in the deep Mitchell Canyon and therefore groundwater seepage out of the facility is minimized because of steep hydraulic gradients.

Table 3.3-1. Parameters for Sensitivity Analysis of Groundwater Flows at Mining Area End of Operation and Post-closure

Parameter	Base Case	Upper Case	Lower Case	Wet Year	Dry Year	Cover on Rock Storage Facilities
Glacial till K (m/s)	8.0 x 10^{-7}	x10	x0.1	Same as Base Case	Same as Base Case	Same as Base Case
Top/Shallow Bedrock K (m/s)	8.0 x 10^{-8} (Hazelton Group Volcanic Rocks Above Mitchell Thrust Fault) 9.0 x 10^{-8} (Stuhini Group Sedimentary Rocks) 1.0 x 10^{-7} (Stuhini Group Volcanic Rocks)	x10	x0.1			
Upper Bedrock (m/s)	5.0 x 10^{-8}	x10	x0.1			
Bedrock under Mitchell Thrust Fault and Mitchell valley top (m/s)	3.7 x 10^{-6}	x10	x0.1			
Net Recharge (mm/yr)	115 (<400 masl in Unuk River valley) 128 (400 to 900 masl in other valley bottom) 146 (900 to 1,300 masl on mid-slope) 164 (>1,300 masl on uplands) 40 (Glacier and permanent snow packs) 330.4 (Rock Storage Facilities)	Same as Base Case	Same as Base Case	x2	x0.5	Same as Base Case, but x0.5 for RSF

Table 3.3-2. Baseflows and Sensitivities in Mining Area End of Operation and Post-closure

	Base Case		Upper Case (Kx10)		Lower Case (K/10)		Wet Year (recharge x2)		Dry Year (recharge x0.5)		Cover on RSF	
Baseflow to Creeks (m^3/s)	**End of Operation**	**Post Closure**	**End of Operation**	**Post Closure**	**End of Operation**	**Post Closure**	**End of Operation**	**Post Closure**	**End of Operation**	**Post Closure**	**End of Operation**	**Post Closure**
Mitchell Creek to Sulphurets Confluence	0.03	0.03	0.07	0.07	0.01	0.01	0.03	0.03	0.03	0.03	0.03	0.03
Sulphurets Lake	0.02	0.02	0.04	0.07	0.01	0.01	0.02	0.02	0.01	0.01	0.02	0.02
Sulphurets to Mitchell confluence	0.03	0.03	0.12	0.12	0.02	0.02	0.05	0.05	0.02	0.02	0.03	0.03
Ted Morris Creek	0.06	0.06	0.15	0.15	0.02	0.02	0.08	0.08	0.04	0.04	0.06	0.06
Gringas Creek	0.03	0.03	0.04	0.04	0.02	0.02	0.05	0.05	0.01	0.01	0.03	0.03
Joe Mandy Creek	0.03	0.03	0.04	0.04	0.01	0.01	0.05	0.05	0.02	0.02	0.03	0.03
Sulphurets/Mitchell confluence to Unuk River	0.09	0.09	0.24	0.24	0.04	0.04	0.12	0.12	0.07	0.07	0.09	0.09
Total Baseflow at Unuk River Confluence	**0.28**	**0.28**	**0.70**	**0.73**	**0.12**	**0.12**	**0.40**	**0.40**	**0.19**	**0.20**	**0.28**	**0.28**

Table 3.3-3. Wastewater Storage Facility - Groundwater Flows (Base Case and Sensitivity Analysis)

	End of Operation		Post-Closure	
	m^3/day	**L/s**	**m^3/day**	**L/s**
Base Case				
Inflow from McTagg/Mitchell RSF	2,867	33	2,992	35
Inflow of non-contact groundwater	1,609	19	1,630	19
Outflow from WSF and Collection Dam Basin	295	3	295	3
Upper Case - Increase hydraulic conductivity 10x				
Inflow from McTagg/Mitchell RSF	6,382	74	9,476	110
Inflow of non-contact groundwater	1,593	18	2,014	23
Outflow from WSF and Collection Dam Basin	1,892	22	1,890	22
Lower Case - Decrease hydraulic conducvity 10x				
Inflow from McTagg/Mitchell RSF	1,430	17	1,441	17
Inflow of non-contact groundwater	910	11	913	11
Outflow from WSF and Collection Dam Basin	29	0.3	29	0.3
Wet Year - Increase Recharge 100%				
Inflow from McTagg/Mitchell RSF	4,521	52	4,625	54
Inflow of non-contact groundwater	2,613	30	2,626	30
Outflow from WSF and Collection Dam Basin	251	3	251	3
Dry Year - Decrease Recharge 50%				
Inflow from McTagg/Mitchell RSF	1,857	21	2,028	23
Inflow of non-contact groundwater	868	10	902	10
Outflow from WSF and Collection Dam Basin	327	4	327	4
Cover on McTagg/Mitchell WRF				
Inflow from McTagg/Mitchell RSF	2,159	25	2,299	27
Inflow of non-contact groundwater	1,317	15	1,341	16
Outflow from WSF and Collection Dam Basin	300	3	300	3

The results of sensitivities show that the inflows and seepage rate are going to increase when the geological materials are hydraulically more conductive and decrease when the materials are less conductive. The results show that the inflows into the Water Storage Facility from McTagg-Mitchell Rock Storage Facility and the surrounding aquifer will increase in wet years, and decrease in dry years or if the Rock Storage Facility is covered.

The predicted seepage out of Water Storage Facility is slightly higher in dry years than in wet years because a lower water table in the regional aquifer in the dry years will result in a lower hydraulic gradient between the aquifer and the Water Storage Pond (constant head) and therefore more seepage. Conversely, the water table in the aquifer is going to be higher in wet years with higher hydraulic gradients and less seepage out of the Water Storage Pond. The cover option on Rock Storage Facilities has no effect on the seepage out of the Water Storage Facility. The small seepage rates align with the results of the particle-tracking that show most of the seepage will be captured by the Seepage Collection System as shown in Section 3.3.3.

By comparing the results of Base Case end of operation and sensitivities, it is clear that the inflows into and seepage from the Water Storage Facility are largely controlled by the hydraulic conductivities of the geological materials especially the bedrock in the foundation. Therefore, it is expected that with appropriate seepage control measures such as grout curtains under the storage and seepage collection dams and in the abutments, the seepage will be significantly reduced and the concern of the seepage effect to the downstream surface water receptor will be minimal.

The results in Table 3.3.3 show that the seepage rates from Water Storage Facility for the post-closure Base Case and sensitivities are similar to those at the end of operation, although the estimated inflows at post-closure are slightly higher than at the end of operation because the water levels in the Mitchell and Sulphurets Pits are recovered at post-closure and less water is flowing into the pits compared to during pit dewatering (the Kerr Pit has no effect on the Water Storage Facility). This information demonstrates again that the pits have negligible effect on the flow in the surface water receptors in the downstream of the Water Storage Facility and near the Mitchell/Sulphurets confluence.

3.3.4.3 Rock Storage Facilities

The groundwater inflows and outflows from the McTagg-Mitchell and Sulphurets Rock Storage Facilities, at the end of mine operation and post-closure for Base Case and sensitivities are presented in Tables 3.3-4 and 3.3-5 respectively. For the McTagg-Mitchell Rock Storage Facility, the results show that at Base Case end of operation, the inflow of non-contact groundwater into the rock storage (including recharge from precipitation and discharge from regional aquifer) is estimated to be 13,000 m^3/d (150 L/s), the outflow to the downstream Water Storage Facility will be 2,867 m^3/d (33 L/s) and the outflow to the Mitchell Pit will be 2,019 m^3/d (23 L/s). The post-closure inflow of non-contact groundwater into the rock storage will decrease slightly to 12,565 m^3/d (145 L/s), the outflow to the downstream Water Storage Facility will increase slightly to 2,992 m^3/d (35 L/s) and the outflow to the Mitchell Pit will reduce slightly to 1,932 m^3/d (22 L/s). Although the differences between the end of operation and post-closure are small (less than 6%), it appears that Mitchell Pit dewatering draws more non-contact groundwater into the pit and thereby reduce the outflow into Water Storage Facility.

The results of sensitivity analyses for the inflow and outflow in McTagg-Mitchell Rock Storage Facility show that the inflow of non-contact groundwater will increase when the geological materials are more permeable and decrease when the materials are less permeable, and increase when the climate is wet (more recharge) and decrease when the climate is dry (less recharge) in dry years. In Upper Case (with more permeable geological materials), groundwater flow to the Water Storage Facility at the post-closure is significantly higher than that at the end of operation because more groundwater will flow from Mitchell Pit lake through the preferential flow paths in the highly permeable overburden and bedrock on the valley surface to the Water Storage Pond. Similarly, the outflow from Mitchell Rock Storage Facility to the pit lake is much smaller at the post-closure in the case of highly permeable materials on the valley bottom.

Table 3.3-4. McTagg/Mitchell Rock Storage Facility - End of Operation and Post-closure Groundwater Flows (Base Case and Sensitivities)

	End of Operation		Post-Closure	
	m^3/day	L/s	m^3/day	L/s
Base Case				
Inflow of non-contact groundwater	13,000	150	12,565	145
Outflow to Water Storage Facility	2,867	33	2,992	35
Outflow to Mitchell Pit	2,019	23	1,932	22
Upper Case - Kx10				
Inflow of non-contact groundwater	24,371	282	23,776	275
Outflow to Water Storage Facility	6,382	74	9,476	110
Outflow to Mitchell Pit	2,836	33	153	2
Lower Case - K/10				
Inflow of non-contact groundwater	10,662	123	10,626	123
Outflow to Water Storage Facility	1,430	17	1,441	17
Outflow to Mitchell Pit	1,617	19	1,314	15
Wet Year - Recharge x2				
Inflow of non-contact groundwater	23,407	271	23,026	267
Outflow to Water Storage Facility	4,521	52	4,625	54
Outflow to Mitchell Pit	4,025	47	3,594	42
Dry Year - Recharge x0.5				
Inflow of non-contact groundwater	7,586	88	7,178	83
Outflow to Water Storage Facility	1,857	21	2,028	23
Outflow to Mitchell Pit	1,127	13	1,029	12
Cover on RSF				
Inflow of non-contact groundwater	4,030	47	8,344	97
Outflow to Water Storage Facility	2,159	25	2,299	27
Outflow to Mitchell Pit	1,482	17	1,349	16

Note: The inflow of non-contact groundwater includes both the net recharge on water table in the RSF and the discharge into the RSF from regional aquifer

Table 3.3-5. Sulphurets Rock Storage Facility - End of Operation and Post-closure Groundwater Flows (Base Case and Sensitivities)

	End of Operation		Post-Closure	
	m^3/day	L/s	m^3/day	L/s
Base Case				
Inflow/Outflow	2,798	32	2,809	33
Upper Case - Kx10				
Inflow/Outflow	3,291	38	3,314	38
Lower Case - K/10				
Inflow/Outflow	2,247	26	2,249	26
Wet Year - Recharge x2				
Inflow/Outflow	5,121	59	5,131	59
Dry Year - Recharge x0.5				
Inflow/Outflow	1,446	17	1,457	17
Cover on RSF				
Inflow/Outflow	1,776	21	1,790	21

For the Sulphurets Rock Storage Facility, the inflow and outflow is 2,798 m^3/d (32 L/s) for the end of operation Base Case and 2,809 m^3/d (33 L/s) for the post-closure Base Case (Table 3.3.5). The sensitivity results also show that the groundwater flow through the facility will be higher if the bedrocks are more permeable (overburden is minimal at this location) and the climate is wetter (more recharge), and lower if the bedrocks are less permeable and the climate is drier (less recharge). More importantly, the results for the Base Case and sensitivities show that the flow rates (seepage) out of Sulphurets Rock Storage Facility are the same at the end of mine operation and at the post-closure, which demonstrates that they are not affected by the pits, by the Water Storage Facility or by McTagg-Mitchell Rock Storage Facility. In other words, the seepage out of Sulphurets Rock Storage Facility together the seepage from the Water Storage Facility are going to be the major factors for the potential environmental effects of the mine project on the downstream surface water receptors.

For both the McTagg-Mitchell Rock Storage Facility and Sulphurets Rock Storage Facility, the model results show that if the facilities are covered with e.g., the low permeable glacial till, then both the inflow and the outflow will be significantly reduced due to less infiltration and groundwater recharge. This demonstrates that covering the Rock Storage Facilities would benefit seepage and potentially reduce any impact on downstream water quality, especially for the Sulphurets Rock Storage Facility.

3.3.4.4 Pits and Tunnels

The flows into the pits at the end of mine operation (dewatering rates) reported here are from the calculation of BGC's pit depressurization analysis modelling for the KSM Project (BGC 2010a; Appendix 11-I of the EA Chapter 11), and the results from Rescan's regional environmental assessment (EA) model are essentially the same as BGC's predictions because the same inputs and approaches are used in the two models.

The maximum inflow to the Mitchell Pit at the start of pit dewatering is approximately 12,220 m^3/d (141.4 L/s). In the last year of mining (Year 37) this will have declined to about 5,580 m^3/d (64.6 L/s). The average dewatering rate is predicted to be approximately 7,390 m^3/d (85.5 L/s) throughout the mine life.

The average inflow to the Sulphurets Pit is predicted to be 130 m^3/d (1.5 L/s). The groundwater inflows to the Kerr Pit are predicted to vary from 410 m^3/d (4.7 L/s) to 2,750 m^3/d (31.8 L/s), and the average dewatering rate is predicted to be approximately 730 m^3/d (8.5 L/s). The water from the pits will be conveyed to the Water Storage Facility or treated before discharge to the Sulphurets Lake or Creek and therefore will not affect downstream water quality.

From a water quality and environmental assessment point of view, the long-term effect of the pit lakes after mine closure is important and therefore a more detailed examination of the post-closure groundwater flows for the pit lakes was carried out in Rescan's environmental assessment model. Table 3.3-6 shows the post-closure (Base Case and sensitivities) groundwater flows into the mine pits. The results show that in Base Case, the total inflow and outflow is estimated to be 10,794 m^3/d (125 L/s) for the Mitchell Pit; 1,096 m^3/d (13 L/s) for the Sulphurets Pit and 1,781 m^3/d (21 L/s) for the Kerr Pits (south and north). These estimates accord with the predicted pit dewatering rates from BGC, except for Sulphurets Pit. This difference is likely due to different geological conditions between Rescan's and BGC's models. At the time these models were built, there was very limited information available for the Sulphurets Pit hydrogeology. With new data soon to be available from ongoing field investigations, the uncertainty in the results should be resolved.

Table 3.3-6. Mine Pits - Post-closure Groundwater Flows (Base Case and Sensitivities)

	Post-Closure	
	m³/day	L/s
Base Case		
Inflow/Outflow - Mitchell Pit	10,794	125
Inflow/Outflow - Sulphurets Pit	1,096	13
Onflow/Outflow - Kerr Pit	1,781	21
Upper Case - Kx10		
Inflow/Outflow - Mitchell Pit	9,872	114
Inflow/Outflow - Sulphurets Pit	1,880	22
Inflow/Outflow - Kerr Pit	11,543	134
Lower Case - K/10		
Inflow/Outflow - Mitchell Pit	8,993	104
Inflow/Outflow - Sulphurets Pit	1,037	12
Inflow/Outflow - Kerr Pit	1,954	23
Wet Year - Recharge x2		
Inflow/Outflow - Mitchell Pit	21,238	246
Inflow/Outflow - Sulphurets Pit	1,942	22
Inflow/Outflow - Kerr Pit	2,717	31
Dry Year - Recharge x0.5		
Inflow/Outflow - Mitchell Pit	5,646	65
Inflow/Outflow - Sulphurets Pit	695	8
Inflow/Outflow - Kerr Pit	1,529	18
Cover on RSF		
Inflow/Outflow - Mitchell Pit	9,995	116
Inflow/Outflow - Sulphurets Pit	1,096	13
Inflow/Outflow - Kerr Pit	1,781	21

The results of sensitivities show that the hydraulic conductivities of the bedrocks are critical in estimation of the groundwater flows into all the mine pits. The Upper and Lower Cases with higher and lower bedrock hydraulic conductivities give the general ranges of the predicted flow rates, but the results are complicated by the geological uncertainties (e.g., the bedrock conductivities above and below the Mitchell Thrust Faults in Mitchell Pit). In addition, the results show that the flows into the pits are going to be much higher in wet years and much less in dry years in comparison to the Base Case, which demonstrates that the climate has a big role in the flow estimates. The groundwater flow into Mitchell Pit is also going to be affected by the reclamation option of Mitchell Rock Storage Facility. The results also show that if the Rock Storage Facility is covered (less recharge), the flow into Mitchell Pit will be smaller (Table 3.3-6). Flows into Sulphurets and Kerr Pits are not affected by cover of the RSF.

The groundwater flows into the tunnels in the mining area at the end of operation and the post-closure Base Case and sensitivities as shown in Table 3.3-7. The groundwater flow into McTagg tunnel is estimated at 1,823 m^3/d (21 L/s) at end of operation and 1,826 m^3/d (21 L/s) at post-closure. The end of operation flows into Mitchell Pit east and west tunnels are estimated at 1,466 m^3/d (17 L/s) and 838 m^3/d (10 L/s) respectively whereas the post-closure flows are greater, estimated at 1,865 m^3/d (22 L/s) and 957 m^3/d (11 L/s). The Mitchell and Sulphurets Pits and pit lakes affect the flows into the Mitchell Pit east and west tunnels and the Mitchell-Teigen tunnel near Mitchell Pit, but they have no effect on flow into McTagg tunnel. At post-closure, there will be more water flowing into the tunnels under and near the Mitchell Pit lake.

The results of the sensitivity analysis shows that there will be more water flowing into all the tunnels in wet years and less in dry years in comparison with the Base Case The cover option on McTagg-Mitchell Rock Storage Facility will reduce the flows into the tunnels. In the Upper and Lower cases, where bedrock hydraulic conductivities are varied without changing the recharge rate, the flows into the tunnels appear inconsistent. For example, with a fixed recharge rate but higher bedrock hydraulic conductivity in Upper Case, the flow into the McTagg tunnel is smaller than in the Base Case. This is because when the bedrock has higher hydraulic conductivity, the regional groundwater level decreases in the upper section of the tunnel's alignment (i.e., much of the tunnel is in the unsaturated zone), resulting in less inflow to the tunnel. In the Lower Case, with the fixed recharge and less permeable bedrocks, the regional groundwater levels increases, resulting in more inflow to the tunnel. In reality, tunnel inflow will depend on the location of water table relative to the tunnel, the geology intersected by the tunnel, especially the presence of high permeability faults and extensive fracture networks that connect to active recharge zones.

Finally, it should be also mentioned that due to the modelling limitations, the predicted groundwater flows into the tunnels represent the flows into the drain cells where the tunnels are located. As the smallest drain cell is 50 m by 50 m (greater than the dimensions of the tunnels), the groundwater flows reported above could be overestimated to some degree.

3.3.5 Summary

Steady-state flow simulations have been carried out to predict the potential impact of the proposed mining facilities at the KSM Project. The predictions have been completed for the end of operation (with dewatered pits) and the post-closure (with pit lakes) and the groundwater flow patterns and flow quantities compared to pre-mining conditions. The Base Case flow simulation was carried out with the parameters from the calibrated baseline pre-mining model, and the results are considered to represent the most realistic estimation of flow rates. The sensitivity analyses were carried out with reasonable magnitudes of variation for the most sensitive parameters identified in the baseline sensitivities, and the results represent the possible ranges of flows associated with the uncertainties in geological material properties and different climatic conditions, as well as capping of the Rock Storage Facilities.

Table 3.3-7. Tunnels - End of Operation & Post-closure Groundwater Flows (Base Case and Sensitivities)

	End of Operation		Post-Closure	
	m³/day	L/s	m³/day	L/s
Base Case				
McTagg Tunnel (from RSF to Mitchell Creek)	1,823	21	1,826	21
Mitchell Pit East Tunnel	1,466	17	1,865	22
Mitchell Pit West Tunnel	838	10	957	11
Mitchell - Teigen Tunnel (Mining Area Section)	1,735	20	2,011	23
Upper Case - Kx10				
McTagg Tunnel (from RSF to Mitchell Creek)	853	10	858	10
Mitchell Pit East Tunnel	2,596	30	4,127	48
Mitchell Pit West Tunnel	395	5	433	5
Mitchell - Teigen Tunnel (Mining Area Section)	1,027	12	1,197	14
Lower Case - K/10				
McTagg Tunnel (from RSF to Mitchell Creek)[1]	2,771	32	2,773	32
Mitchell Pit East Tunnel	1,223	14	1,459	17
Mitchell Pit West Tunnel[1]	1,599	19	1,903	22
Mitchell - Teigen Tunnel (Mining Area Section)[1]	2,268	26	2,420	28
Wet Year - Recharge x2				
McTagg Tunnel (from RSF to Mitchell Creek)	3,214	37	3,216	37
Mitchell Pit East Tunnel	1,852	21	2,278	26
Mitchell Pit West Tunnel	2,387	28	2,567	30
Mitchell - Teigen Tunnel (Mining Area Section)	2,901	34	3,250	38
Dry Year - Recharge x0.5				
McTagg Tunnel (from RSF to Mitchell Creek)	972	11	977	11
Mitchell Pit East Tunnel	1,048	12	1,427	17
Mitchell Pit West Tunnel	279	3	363	4
Mitchell - Teigen Tunnel (Mining Area Section)	1,038	12	1,192	14
Cover on RSF				
McTagg Tunnel (from RSF to Mitchell Creek)	1,630	19	1,634	19
Mitchell Pit East Tunnel	1,468	17	1,865	22
Mitchell Pit West Tunnel	727	8	826	10
Mitchell - Teigen Tunnel (Mining Area Section)	1,694	20	1,942	22

[1] *Lower Case tunnel flow is higher than Upper Case because greater gradients result in higher flows (recharge remains constant).*

Qualitative Assessment of Mine Impact on Groundwater Flow

The steady-state flow patterns and particle-tracking pathlines show that in comparison to the pre-mining, dewatering of the Mitchell Pit at the end of operation and the refilled pit lake at the post-closure will cause a significant change in the local flow field around the pit. The dewatered Mitchell Pit and the refilled pit lake will become a large groundwater sink, drawing groundwater from the surrounding aquifer into the pit. Groundwater from beneath the proposed Mitchell Rock Storage Facility will also be drawn into the pit, which means the water in the final pit lake may be impacted by potentially poor quality water leaching from the Rock Storage Facility. Groundwater flow direction along the upper Mitchell valley is going to be reversed due to the Mitchell Pit dewatering and pit lake. Groundwater that in the pre-mining scenario flows from the pit footprint area along the Mitchell valley will flow toward the pit and pit lake in the upper part of the valley during operation and post-closure (there will be a water divide between the pit and the Water Storage Facility). The Sulphurets and Kerr Pits will also become groundwater sinks during operational dewatering, and affect local flow fields, but the effects are much smaller in comparison with Mitchell Pit. At post-closure, in contrast to the Mitchell Pit lake, the Sulphurets and Kerr Pit lakes will become constant sources of aquifer recharge, and water from the lakes will recharge the deep aquifer and discharge to the Sulphutets Creek.

The particle-tracking pathlines at the end of operation and the post-closure show that while the effluent from the upper section of Mitchell Rock Storage Facility flows to the Mitchell Pit and Pit Lake, the effluent from the lower section of the rock storage will discharge into the Water Storage Facility. The effluent from the rock storage in McTagg valley will also discharge into the Water Storage Facility, but a small portion of groundwater in the upper part of valley could flow to the McTagg Diversion Tunnel.

Most of the seepage from the Sulphurets Rock Storage Facility will discharge through the aquifer to the downstream Sulphurets Creek and also to the small streams on the slopes. A small portion of the seepage will discharge to the Water Storage Facility and the Seepage Collection System, and into Mitchell Creek. The travel (residence) time of the seepage from the Sulphurets Rock Storage Facility into the receiving waters is estimated to be 20 to 30 years in average, but it could be as short as 2 to 3 years through high permeable fracture networks or faults in the bedrocks. For the Water Storage Facility, the pathlines show that the seepage from the facility will be captured by the Seepage Collection System during the mine operation and at the post-closure.

The results suggest that of all the mine facilities, the Sulphurets Rock Storage Facility may have the greatest role in affecting the downstream water receptor along Sulphurets Creek. The total load from this needs to be assessed against those of other sources, including the naturally high background solute loadings in the Sulphurets Creek. The seepage from the Water Storage Facility is not a concern as it will be largely be captured by the Seepage Collection System and provided measures such as grouting the dam foundations are carried out to minimize seepage. The seepage out of the McTagg-Mitchell Rock Storage Facility will be intercepted by the Water Storage Facility, and will be managed there. The pits will only affect local groundwater flows and they have no effect on flows under the Water Storage Facility and under the Sulphurets Rock Storage Facility.

Quantitative Assessment of Mine Impact on Groundwater Flow

The Base Case model calculation results show that at the end of operation and post-closure, the total baseflow to the Sulphurets Creek (where it joins the Unuk River) will be reduced by 50% compared to the pre-mining scenario. The baseflow reduction is a result of the mine pits and Water Storage Facility intercepting the baseflow that would normally flow to the creeks and streams. However, the loss of baseflow in the downstream Sulphurets Creek is likely to be compensated by the discharge of diverted surface runoff through the tunnels and the discharge of treated mine water. Therefore, the flow in the creek at the end of operations and post-closure is unlikely to change in comparison to the pre-mining situation. The results show that there is no change in the baseflows to the Sulphurets Lake, Sulphurets Creek upper reach, Ted Morris Creek, Joe Mandy Creek and Gingras Creek. The effects of the mining activities to the stream baseflow quantities are limited within McTagg and Mitchell valleys above the Water Storage Facility.

The seepage out of the Water Storage Facility is predicted to be fairly small (3 L/s in Base Case, less than 22 L/s as the highest) at both the end of operation and the post-closure, and it will be largely captured in the Seepage Collection System. The steep hydraulic gradients in the deep Mitchell Canyon contain the Water Storage Facility and limit the seepage out of the facility.

The seepage out of the Sulphurets Rock Storage Facility is estimated to be about 32 L/s to 33 L/s in Base Case, and varies from 17 L/s to 59 L/s in sensitivities at the end of operation and the post-closure. The seepage from this facility may affect downstream water quality in the Sulphurets Creek.

Flows into the pits and the tunnels are also predicted with the uncertainties of geology and climate. In general, there will be more flows into these facilities in wet years, less in dry years and more flow into tunnels from Mitchell and Sulphurets Pit lakes at the post-closure than at the end of operation.

In summary, it is recommended that the results of the Base Case be applied in water balance calculation and environmental effect assessment on water quantity and quality.

3.4 PREDICTIVE SIMULATIONS OF SOLUTE TRANSPORT

3.4.1 Overview

This section describes the methodology for predictive simulations of solute transport using the calibrated hydrogeological model in the mining area, and presents the results of the simulations. The objective is to predict the solute plumes and concentrations in groundwater flows from the source areas of the mine (Pit Lakes, Water Storage Facility and Rock Storage Facilities), and to provide the data as inputs to overall water balance and in assessing the potential effects of the proposed mining activities on water quality in the KSM Project mining area.

As discussed in the previous section with the results of predicted flow patterns and flow rates, there is very little difference between the end of operation and the post-closure scenarios in terms of the overall mining effects on flows to downstream receptors. The solute transport modelling has therefore been run for the post-closure scenario only. In addition, the post-closure scenario is seen as ‘worst-case’ since the pits will become pit lakes and be the sources of potentially contaminated water recharging the deep aquifer whereas during the mine operational years, the pits will be dewatered and the groundwater will be conveyed to the Water Storage Facility where it will be treated according to the mine plan. Therefore, the pits will not be potential sources of contamination during operation, and their effects on downstream water quality during the operation years will be less than post-closure.

Using the MT3DMS Version 5.2 within the Visual MODFLOW package (Zheng and Wang 1999), the Base Case solute transport for post-closure was simulated by using the previous Base Case post-closure flow solutions. The major mine zones (the Pit Lakes, the Water Storage Facility and the Rock Storage Facilities) were assigned as unit concentration, conservative contamination sources and the output time to 100 years after mine closure. The sensitivities were run by varying the same parameters to the same orders of magnitude as in the post-closure flow model sensitivities.

The predicted concentrations represent values relative to the unit concentration assigned to the source zones, and should be interpreted as the “worst” potential effects of the relevant mine components on the receiving environment as they do not incorporate any attenuation due to biogeochemical reactions or surface water dilution.

3.4.2 Approaches

3.4.2.1 Flow Boundary Conditions

The boundary conditions for flow solutions that were used in the Base Case solute transport modelling are the same as those used in the Base Case post-closure flow model (see Figure 3.3-2). The constant heads are assigned to represent the Pit Lakes with the elevation 840 masl in Mitchell Pit Lake, 1,206 masl in Sulphurets Pit Lake, 1,080 masl in North Kerr Pit Lake and 1,458 masl in South Kerr Pit Lake. The Sulphurets and Kerr Pit Lakes will be refilled to their spill elevations. The recharge rate 330.4 mm/yr assigned to the McTagg-Mitchell and Sulphurets Rock Storage Facilities is equivalent to 20% of observed mean annual precipitation of 1,652 mm/yr in the mining area, and represents the scenario of no cover on the Rock Storage Facilities.

3.4.2.2 Transport Boundary Conditions

The boundary conditions for Base Case solute transport modelling in the mining area are shown in Figure 3.4-1. The conservative contaminant sources with constant unit concentration 1.0 mg/L are assigned in the Pit Lakes (same sizes as the constant heads), the Water Storage Pond and McTagg-Mitchell and Sulphurets Rock Storage Facilities. The boundary conditions infer that these mine facilities will provide continuous sources of contamination to the aquifer. Zero mass flux boundaries are specified at all the no-flow boundaries in the model domain. The background concentration in the model domain is zero.

3.4.2.3 Aquifer Properties

The hydraulic properties used for Base Case solute transport modelling in the mining area are exactly the same as those in the previous post-closure Base Case flow modelling.

3.4.2.4 Transport Solver Parameters

The implicit Generalized Conjugate Gradient (GCG) solver with the Upstream Weighting Finite Difference solution method within the MT3DMS package is used to solve the solute transport in groundwater (Zheng and Wang 1999), and the parameters for the transport solver include:

- maximum number of outer iterations: 1
- maximum number of inner iterations: 50
- relative convergence criterion: 0.001 mg/L
- initial timestep size: zero
- maximum timestep size: 90 days
- timestep multiplier: 1.1

Both advection and dispersion are simulated for solute transport using the effective porosity, but the complex biogeochemical processes such as adsorption/absorption to the geological materials or biodegradation were not simulated (the results are considered conservative). The longitudinal dispersivity is set to be equal to 10m, which is considered to be representative for the geological materials on site and appropriate for simulation of solute transport in kilometre-scale bedrocks (Li 1995; Shapiro 2001; Schulze-Makuch 2005; Zhou et al. 2007; Niemann and Rovey 2009). The horizontal and vertical transverse dispersivities in the model are 1 m and 0.1 m, respectively.

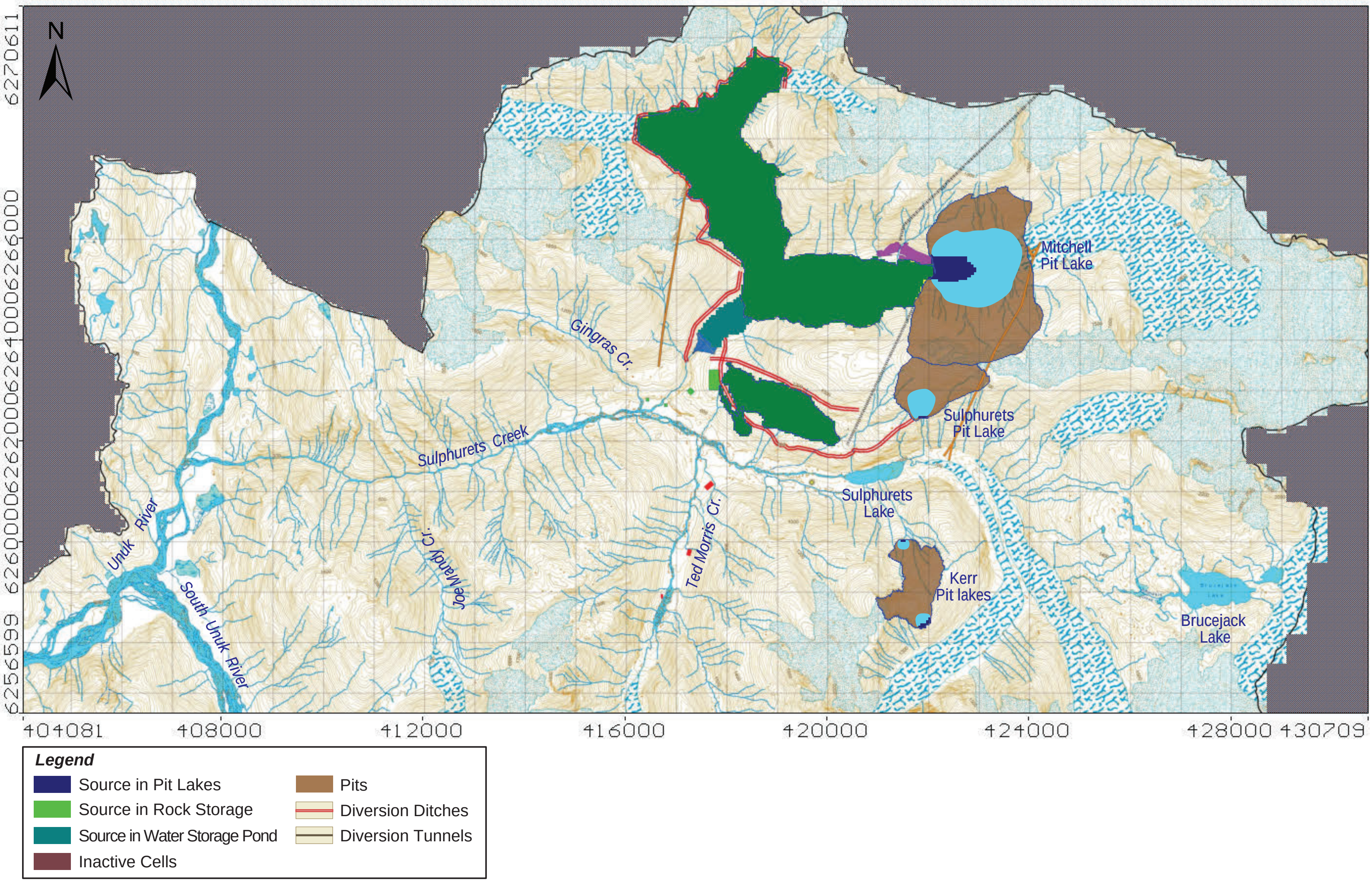

FIGURE 3.4-1

Mining Area Post-closure
Contaminant Source Zones (Layer 1)

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The transport equations are solved with the steady-state flow solutions from the Visual MODFLOW-Surfact. The strict transport convergence criterion 0.001 mg/L and small maximum timestep 90 days used in the model is to ensure the solutions are precise. The calculated Péclet number and Courant number in the dominant flow direction are small and meet the requirements for numerical solute transport simulations. Other parameters used for the transport modelling are the software defaults (Schlumberger 2008). The final output time for the solute transport simulation is 100 years after the Pit Lakes are refilled at post-closure.

3.4.3 Solute Plumes and Sensitivities

Figure 3.4-2 shows the plan view of solute plumes in different layers for the post-closure Base Case scenario with the output time of 100 years. Figure 3.4-3 shows the cross-sections of Base Case solute plumes migrating from the potential contaminant sources under the major mine zones (Pit Lakes, Water Storage Facility and Rock Storage Facilities). As stated, the plumes represent the predicted long-term “worst case”, because the prediction does not include any retardation due to biogeochemical processes such as sorption and degradation or surface water dilution. The predicted concentrations are not absolute values, but concentrations relative to the specified unit concentration of 1.0 mg/L in the source zones. The lowest concentration plotted at the plume fronts is 0.01 mg/L, representing 1% of the source concentration. In other words, if the concentration of sulphate is 1,500 mg/L in the source zone, then the concentration at the front of the plume in the “worst” case will be 15 mg/L.

For the Base Case, both the plan views and the cross-sections (Column 309 and Row 74) shows that although the Mitchell Pit Lake is the largest of the Pit Lakes, the plume from the lake only migrates within a very limited distance due to the fact that the Pit Lake is a large groundwater sink at post-closure, and that the solute mass leaving the Pit Lake is dominantly by dispersion. The results confirm the findings from the particle-tracking pathlines and demonstrate that potentially poor quality from the Pit Lake is unlikely to cause a significant effect in the deep aquifer or to downstream surface water quality near the Mitchell/Sulphurets confluence.

The plan views and the cross-section (Column 309) of Base Case show that the solute plumes from Sulphurets and Kerr Pit Lakes migrate to the deep aquifer, and into the downstream Sulphurets Lake and also the streams under the upper Sulphurets valley glacier. The results demonstrate that the Sulphurets and Kerr Pit Lakes could have considerable effects on the groundwater quality in the surrounding aquifer and potentially on the Sulphurets Lake water quality.

In contrast to the solute transport results in the Pit Lakes, the solute mass from the proposed McTagg-Mitchell Rock Storage Facility is predicted to migrate into the deep aquifer and discharge into the Water Storage Facility (as shown in the plan views and cross-section Row 74). The plume from the Sulphurets Rock Storage Facility is predicted to migrate into the Mitchell and Sulphurets Creek, and could reach as far as the Mitchell/Sulphurets confluence (i.e., proximal to monitoring well RES-MW-11 as shown in cross-section Row 129), close to the outlet of Gingras Creek and the proposed compliance point SC-2 (as shown in plan views). This illustrates, as mentioned previously, that seepage from Sulphurets Rock Storage Facility could be a factor influencing the downstream Sulphurets Creek water quality.

For the proposed Water Storage Facility, as shown in plan view Layer 1 and cross-section Row 97, there is minimal solute mass plume migration from the Water Storage Facility and the seepage collection area, as well as to the deep aquifer. This illustrates that the effect of seepage from the Water Storage Facility is limited and is not likely to be a concern.

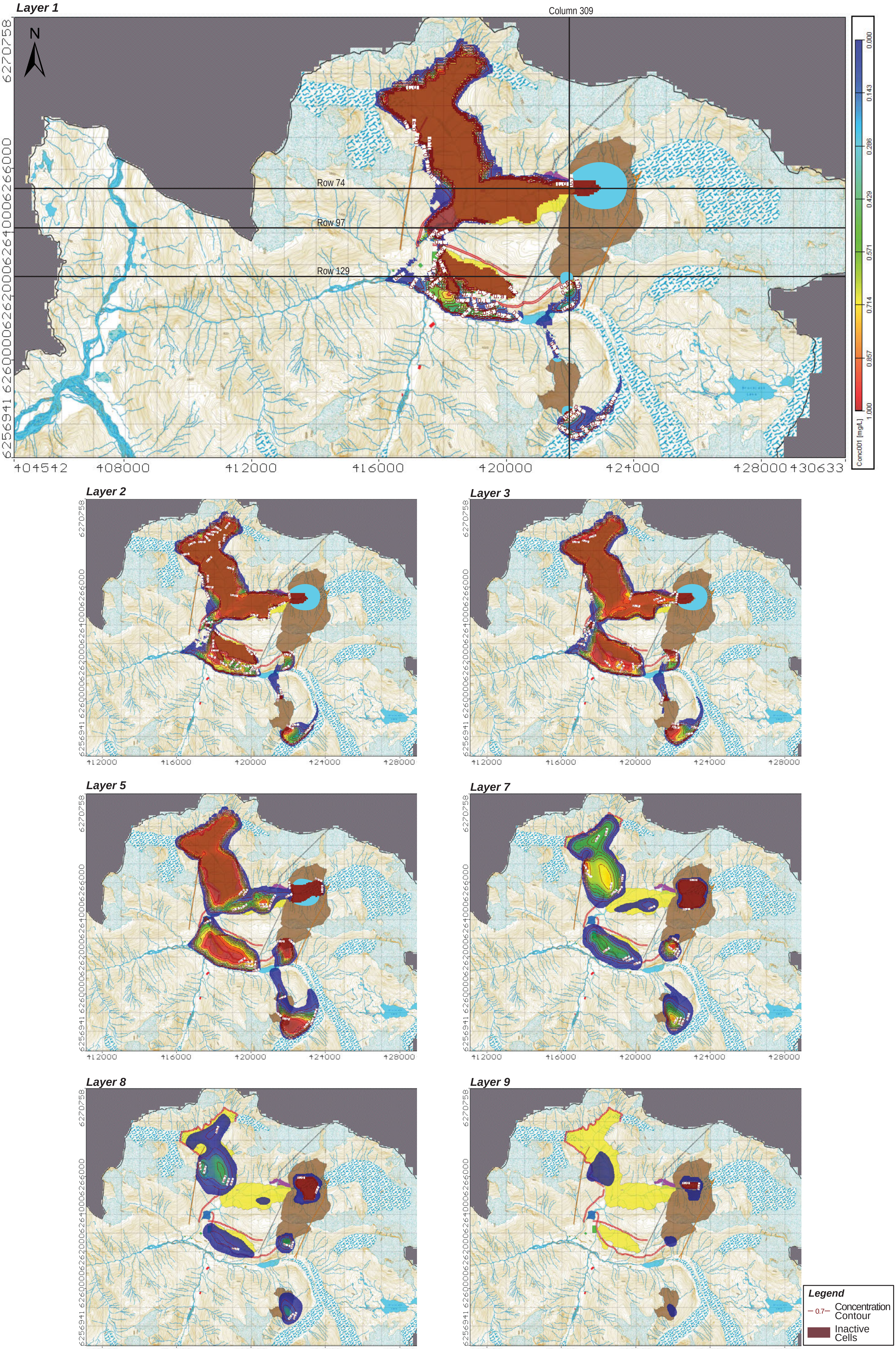

FIGURE 3.4-2

Mining Area Post-closure Solute Plumes (Base Case, Plan View, 100 Years)

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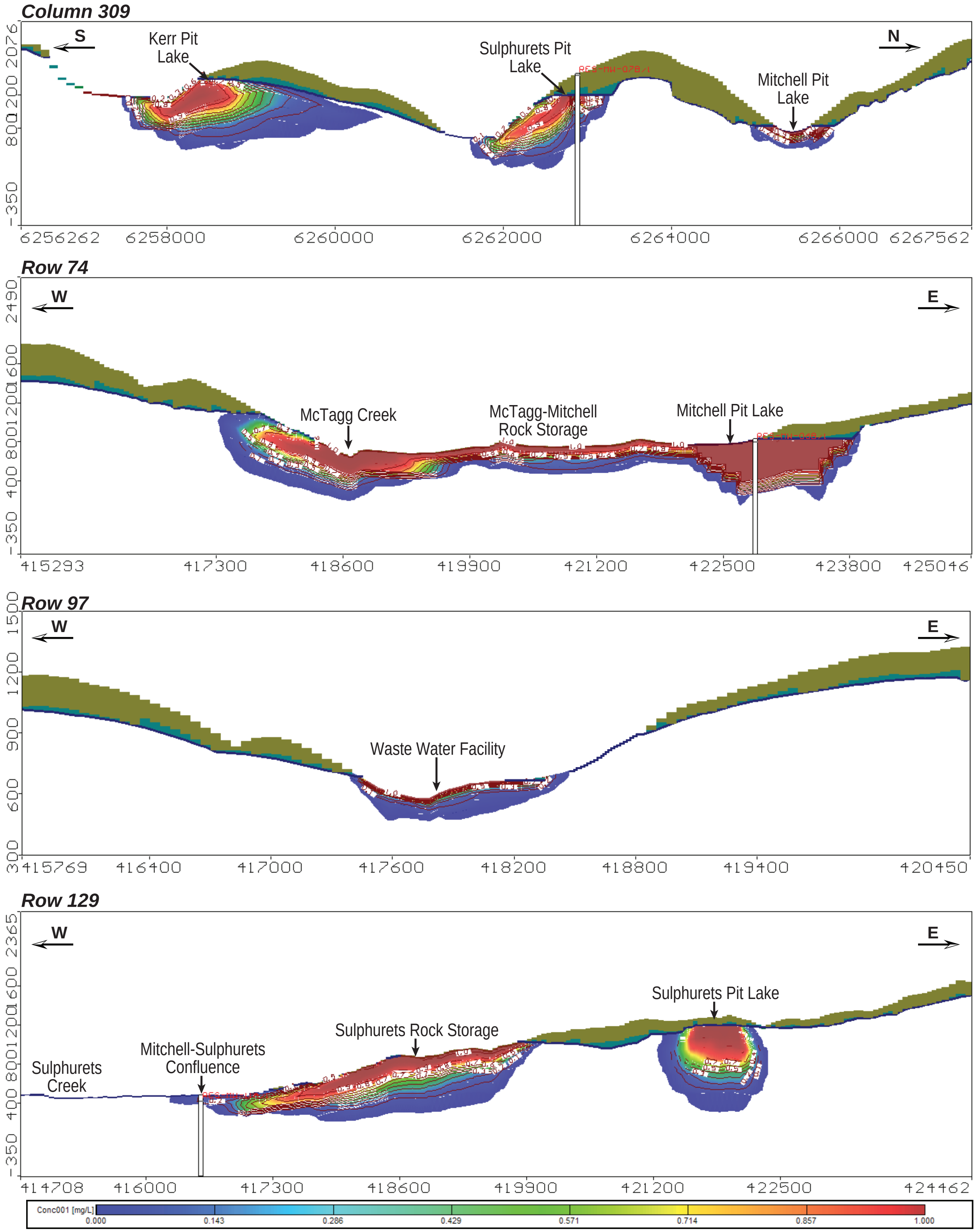

Legend

—0.7— Concentration Isopleths
▨ Dry Cells (Unsaturated)
▯ Existing Well Location

Mining Area Post-closure Solute Plumes (Base Case, Cross-sections, 100 Years)

FIGURE 3.4-3

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The results of the sensitivity analysis (Figure 3.4-4) show that the solute plumes from Sulphurets and Kerr Pit Lakes and from the Rock Storage Facilities are sensitive to the hydraulic conductivities of the geological materials and the recharge rate. The plumes in the Mitchell Pit Lake and Water Storage Facility are less sensitive to these parameters. The sensitivity scenarios were carried out in the same way as the previous post-closure flow model, by varying the same parameters in the same orders of magnitude from the Base Case (see Table 3.3-1 in Section 3.3.4). Generally speaking, the sensitivity results provide similar conclusion as the Base Case: the solute plume from the Sulphurets Rock Storage Facility is going to potentially affect the downstream water quality in Sulphurets Creek.

For water quality assessment in the EA, it is recommended that the results of the Base Case solute transport model (the concentration isopleths) be used in calculating the groundwater contribution to surface water quality. Further details about the water quality assessment in the mining area with Rescan's Water Quality Prediction Model can be found in Annex 10-1.

3.4.4 Summary

Using the flow solutions from the previous post-closure mining area steady-state flow model, solute transport modelling for the post-closure was carried out using MT3DMS (within Visual MODFLOW package), to assess the potential groundwater impact of the proposed KSM Project and for the water quality at downstream receptors. The transport simulations were implemented by assigning conservative contaminant sources (with a constant concentration 1.0 mg/L) in Pit Lakes, Water Storage Facility and Rock Storage Facilities. The results of the post-closure scenario represent the largest effects that the mining activities are likely to cause, as the refilled Pit Lakes together with the Water Storage Facility and Rock Storage Facilities (in their full capacities) will serve as continuous contaminant sources in the mining area. The effects of the mining during the operational years with dewatered pits and smaller scales of Rock Storage Facilities are expected to be less than at the post-closure. The predicted concentration values in groundwater are relative to the specified source concentration and represent the conservative long-term “worst” case, as they do not include the complex biogeochemical processes such as adsorption/desorption, biodegradation or surface water dilution. The Base Case post-closure transport results are applied in Rescan's Water Quality Prediction Model to predict the concentrations of various chemicals by incorporating those processes.

For Mitchell Pit Lake, the Base Case transport results demonstrate that the plume from the Pit Lake migrates a limited distance because the Pit Lake is a local groundwater sink post-closure, and its impact on groundwater quality in the deeper aquifer and downstream surface water will be limited. However, the solute plumes from Sulphurets and Kerr Pit Lakes are more likely to affect the groundwater quality in the deeper aquifer and downstream Sulphurets Lake and Sulphurets Creek.

For the Rock Storage Facilities, the Base Case transport results indicate that the solute plume from the McTagg-Mitchell Rock Storage Facility will migrate to the Water Storage Facility; the plume from the Sulphurets Rock Storage Facility will migrate to the Mitchell and Sulphurets Creeks and possibly reach the Mitchell/Sulphurets confluence (at monitoring well RES-MW-11) and the outlet of Gingras Creek (before the proposed compliance point SC-2). The results demonstrate that the seepage from Sulphurets Rock Storage Facility is a factor that could affect the water quality in the Sulphurets Creek.

For the Water Storage Facility, the Base Case transport results demonstrate that the plume migration is limited within the Seepage Collection System and the seepage from the facility is unlikely to be a concern to downstream surface water quality. The facility is located in the Mitchell Canyon, and steep topography and hydraulic gradients are considered to minimize seepage out of the facility.

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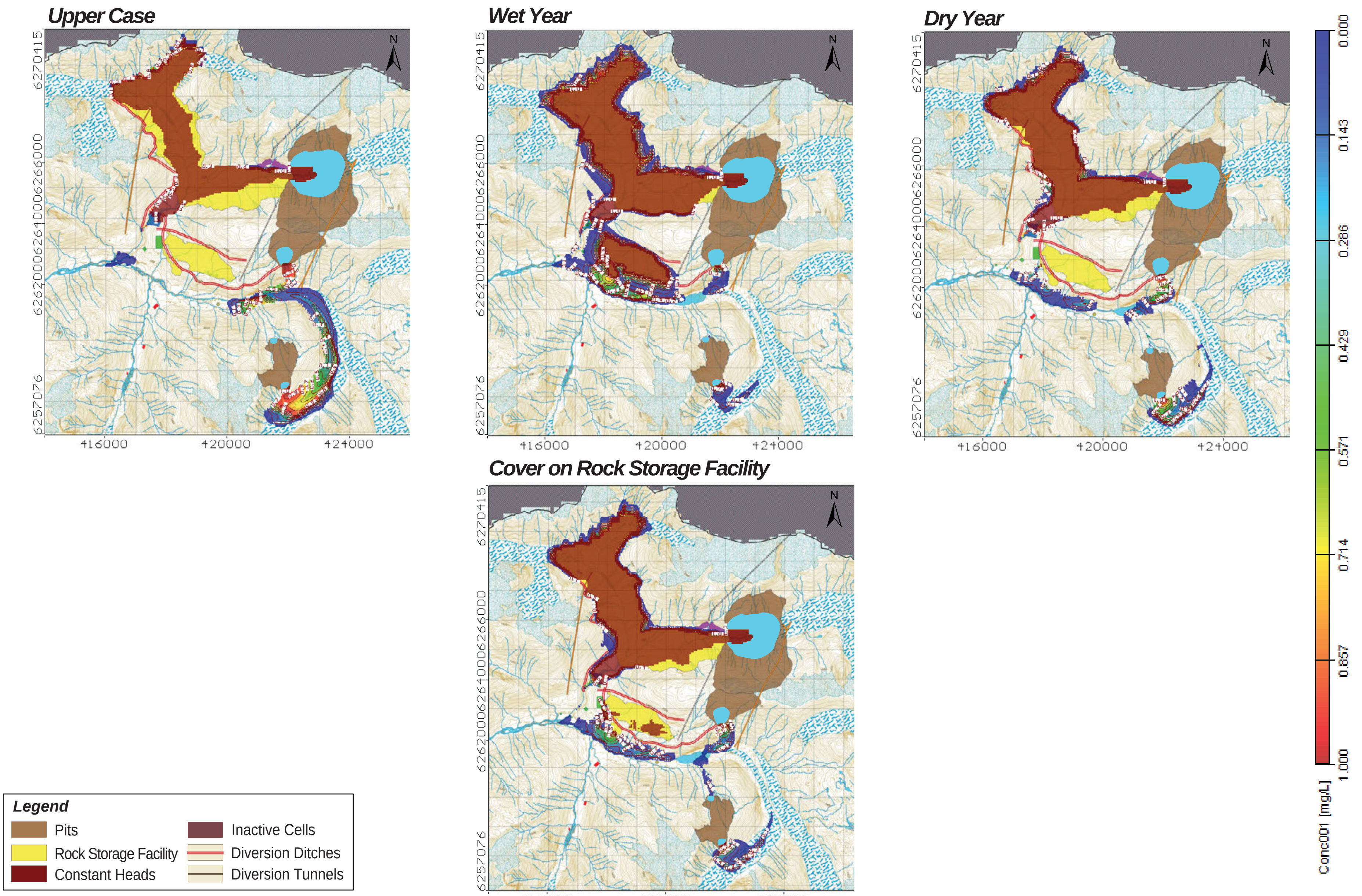


FIGURE 3.4-4

Mining Area Post-closure Solute Plume Sensitivities
(Layer 1, 100 Years)

The results from sensitivity analysis indicate that the solute plumes from Sulphurets and Kerr Pit Lakes and from the Rock Storage Facilities are sensitive to the hydraulic conductivities of the geological materials and recharge rates. The plumes in the Mitchell Pit Lake and Water Storage Facility are less sensitive to these parameters.

3.5 CONCLUSIONS

Groundwater Flow at Pre-mining

A conceptual hydrogeological model has been developed using the data available as of July, 2010, and a three-dimensional baseline model constructed to characterize the ambient groundwater conditions and surface water – groundwater interactions in the proposed KSM Project mining area. The baseline model was calibrated to multiple targets including the observed water levels in the monitoring wells/piezometers and the baseflows in the creeks. The NRMS (Normalized Root Mean Square) is 1.4% and the residual mean of the difference between the observed and simulated hydraulic heads is 2.7 m. The rule of thumb for a good calibration is that the NRMS is less than 10%. The good calibration results demonstrate that the conceptual and baseline model is valid and representative to the physical hydrogeological system in the study area, and therefore reliable for prediction.

The baseline model results show that simulated steady-state head equipotential contours at the pre-mining conditions generally mimic the surface topography, and water table is deep in high elevations and shallow in low elevations. The results demonstrate that the regional groundwater system is recharged on the mountain tops and slopes, and discharges to the surface water bodies on the valley bottoms. The proposed Mitchell Pit is located in both groundwater recharge and discharge zones, receiving recharge from slopes and upper Mitchell valley but discharging into the downstream aquifer and Mitchell Creek along the valley. The Sulphurets and Kerr Pits are located in groundwater recharge zones at high elevations. The McTagg/Mitchell Rock Storage Facility is located in a groundwater discharge zone, but the Sulphurets Rock Storage Facility is located in both groundwater recharge and discharge zones. The Water Storage Facility in Mitchell valley is located in a groundwater discharge zone.

The simulated flow budget results in the baseline model show that at pre-mining, the baseflow varies from 0.12 m^3/s to 1.49 m^3/s at the mouth of Sulphurets Creek entering Unuk River, 0.1 m^3/s to 1.39 m^3/s at the confluence of Mitchell and Sulphurets Creeks, and 0.01 m^3/s to 0.1 m^3/s at the McTagg Creek mouth. The total groundwater flow through the areas of the proposed ultimate Mitchell, Sulphurets and Kerr Pits at pre-mining is estimated to be approximately 10,158.0 m^3/d (117.6 L/s), 758.5 m^3/d (8.8 L/s), 708.3 m^3/d (8.2 L/s), respectively. The total flow through the areas of the proposed Rock Storage Facilities in Mitchell-McTagg valleys and above the Sulphurets Creek is about 16,843.0 m^3/d (194.9 L/s), and 726.4 m^3/d (8.4 L/s), respectively; the flow into the proposed Water Storage Facility is 2,545.0 m^3/d (29.5 L/s) at the operational low water level and 4,366.0 m^3/d (50.5 L/s) at the operational high water level. The estimated groundwater flow results are highly sensitive to the recharge rates, the hydraulic conductivities of glacial till materials and the bedrock formations in the top/shallow, upper and middle zones in the mining area, as well as their anisotropy ratios.

Impact of Mining on Flow Patterns and Water Quantity

Mitchell Pit dewatering at the end of operation and Mitchell Pit Lake at the post-closure will cause a significant change to the local flow patterns, compared to the pre-mining. The dewatered Mitchell Pit and the refilled Pit Lake will behave as a large sink for groundwater and draw groundwater to the pit from the surrounding aquifer and also from the proposed Mitchell Rock Storage Facility. This implies that the water in the Mitchell Pit and the Pit Lake will be affected by potentially poor quality water from the Rock Storage Facility. The groundwater flow direction along the upper Mitchell valley is going to reverse as a result of the Mitchell Pit dewatering and the Pit Lake. In the pre-mining scenario, groundwater flows from the pit footprint area along the valley toward Mitchell Creek, but will flow toward the Mitchell Pit and the Pit Lake in the upper part of the valley during operations and post-closure (there will be a water divide between the pit and the Water Storage Facility).

The Sulphurets and Kerr Pits will also become groundwater sinks during operational dewatering, and affect the local groundwater flow direction, but the effect is much smaller compared to the Mitchell Pit. At post-closure, however, the Sulphurets and Kerr Pit Lakes, which are located at high elevations and modelled to refill to their spill elevations, will become continuous sources of aquifer recharge. Seepage from the Pit Lakes will infiltrate the aquifer and discharge into the Sulphurets Lake and the upstream of the Sulphurets Creek.

In the proposed McTagg/Mitchell Rock Storage Facility area, the results show that at the end of operation and the post-closure, seepage from the upper section of the Rock Storage Facility in the Mitchell valley with discharge to the Mitchell Pit and Pit Lake wherease seepage from the lower section of the Rock Storage Facility will discharge to the Water Storage Facility. Seepage from the Rock Storage Facility in the McTagg valley will discharge to the Water Storage Facility, but a small portion of water in the upper valley could seep to the McTagg Diversion Tunnel.

In the Sulphurets Rock Storage Facility area, the results indicate that the most of the seepage from this facility will discharge into the Sulphurets Creek and the small streams on the slopes while a small portion will discharge to the Water Storage Facility and the Seepage Collection System in Mitchell Creek. The travel (residence) time of the seepage from the Sulphurets Rock Storage Facility to the receiving waters is estimated to be 20 to 30 years on average, but could be as short as 2 to 3 years in high permeable fracture networks or faults. For the Water Storage Facility, the results show that the seepage from the facility will be largely captured by the Seepage Collection System during the mine operation and at post-closure.

The results demonstrate that the Sulphurets Rock Storage Facility may affect the water quality in the Sulphurets Creek and further assessment of the loadings compared to natural background and other mining sources is warranted. The seepage from the Water Storage Facility is not a major concern provided seepage control measures such as effective grouting of the dam foundations is carried out. The seepage out of the McTagg-Mitchell Rock Storage Facility will be intercepted by the Water Storage Facility, and will be managed there. The pits will only affect the flows in the local areas, and they have no effect on flows under the Water Storage Facility or under the Sulphurets Rock Storage Facility.

The Base Case model calculation results show that at the end of operation and post-closure, the total baseflow at the outlet of Sulphurets Creek at Unuk River will be reduced by 50% from the pre-mining. This is because the contribution to baseflow from the McTagg Creek and Mitchell Creek as well as the small streams on slopes in the Mitchell Pit will be captured by the Water Storage Facility and the mine pits / lakes. However, the loss of baseflow to the Sulphurets Creek is likely to be compensated by the discharge of diverted surface runoff through the Diversion Tunnels and from the discharge of treated mine water. Furthermore, the results show that there is no change in the baseflow to Sulphurets Lake, Sulphurets Creek upper reach, Ted Morris Creek, Joe Mandy Creek and Gingras Creek. The effects of the mining activities to the stream baseflow quantities are limited within the McTagg and Mitchell valleys above the Water Storage Facility.

The seepage out of the Water Storage Facility is predicted to be small (3 L/s in Base Case, less than 22 L/s in extreme case with high permeable geological materials) at both the end of operation and the post-closure. The steep hydraulic gradients in the Mitchell Canyon limit the seepage out of the Water Storage Facility. The seepage out of the Sulphurets Rock Storage Facility is estimated to be about

32 L/s to 33 L/s in the Base Case, and varies from 17 L/s to 59 L/s in sensitivities at the end of operation and the post-closure. Flows into the pits and the tunnels are predicted to be variable with the uncertainties of geology and climate. There will generally be more flows to the tunnels in wet years, less in dry years and more flow into the tunnels from the Mitchell and Sulphurets Pit Lakes at the post-closure than during the mine operations.

Impact of Mining on Water Quality

The results for the non-reactive solute transport modelling represent the long-term “worst-case” effect from the mining activities as they do not consider retardation from complex biogeochemical processes. Overall, the solute transport results substantiate the results of the flow patterns.

For the Base Case, the results suggest that the plume from the Mitchell Pit Lake migrates a very limited distance because the Pit Lake behaves as a local groundwater sink. The impact of the Pit Lake on the groundwater quality in the underlying bedrock and downstream surface water will therefore be limited. In contrast, the solute plumes from Sulphurets and Kerr Pit Lakes are likely to affect the groundwater quality in the underlying bedrock and downstream Sulphurets Lake and Sulphurets Creek.

For the Rock Storage Facilities, the results indicate that the solute plume from the McTagg-Mitchell Rock Storage Facility will migrate into the Water Storage Facility; the plume from the Sulphurets Rock Storage Facility will migrate to the Mitchell and Sulphurets Creeks and possibly reach the Mitchell/Sulphurets confluence (at monitoring well RES-MW-11) and the outlet of Gingras Creek (before the proposed compliance point SC-2). The results demonstrate that the seepage from Sulphurets Rock Storage Facility may impact the water quality in the Sulphurets Creek.

For the Water Storage Facility, the Base Case transport results demonstrate that plume migration is limited to within the Seepage Collection System and that the seepage from the facility is unlikely to be a concern for downstream surface water quality, due to the hydraulic containment within this facility.

4. Hydrogeological Model in TMF Area

This chapter describes hydrogeological modelling analysis in the proposed Processing Plant and Tailing Management Facility (TMF) area of the KSM project (see Figure 1.3-2). The objectives are: 1) building a three-dimensional numerical baseline model to represent the pre-mining hydrogeological system in the TMF area; 2) using the calibrated baseline model to characterize the regional and local groundwater flow regime including water table, flow directions, groundwater recharge and discharge zones under the pre-mining conditions; 3) using the model to predict the potential impacts of the seepage and solute migration from the Tailing Management Facility on water quantity and quality; and 4) providing the results for calculation of the water balance and assessment of the environmental impact of the mining plan.

The pre-mining baseline model is built on the basis of the conceptual hydrogeological model developed with inputs from the available information and data for the TMF area as of July, 2010. The inputs in the baseline model are also collected from the literature already referred to in the KSM mining area model, including the overburden and sedimentary bedrock specific storage, specific yield and porosities.

The calibration targets for the baseline model include field measured hydraulic heads in the monitoring wells of Rescan and KCBL, the stream baseflow measured and estimated by Rescan, and the groundwater levels adjacent to the creeks, lakes and wetlands in the TMF area. The calibrated baseline model has been run for steady-state conditions, and the output represents the long-term average, pre-mining groundwater flow regime in the area.

The calibrated baseline model was then used to assess the seepage and solute migration from the Tailing Management Facility during the mine operation, closure and post-closure as well as the groundwater discharge to downstream creeks. These results have been used to calculate the water balance and to assess the effects of the proposed TMF on the water quantity and quality as part of the environmental impact assessment for the KSM Project.

The details of the methodologies utilized for the hydrogeological modelling in the TMF area as well as the results are described in the following sections.

4.1 CONCEPTUAL MODEL

The conceptual model for the pre-mining hydrogeological system is based on the available meteorological, geological, hydrological and hydrogeological information and data summarized in Chapter 2.

Groundwater enters the aquifer system as recharge from precipitation, snow melting and surface runoff, and leaves the system as evapotranspiration and groundwater discharge into surface waterbodies (i.e., lakes, rivers, creeks and wetlands). Recharge to groundwater in the bedrock occurs by infiltration through overburden or directly through exposed fractured bedrock. Groundwater recharge rates are expected to have a similar pattern as in the mining area: more recharge in higher elevations but less recharge under the glaciers and permanent snow packs on the top of ridges. The surface topography relief (1529.3 m difference between the highest and lowest elevations) in the TMF study area suggests that the regional groundwater recharge zones are located in the mountainous uplands and slopes at higher elevations. The regional groundwater discharge zones are considered to be at lower elevations on the valley bottoms where the rivers, creeks, lakes and swamps are located.

The proposed Processing Plant and Tailing Management Facility in the Teigen South Tributary and Treaty North Tributary valleys are located in regional groundwater discharge zone.

Hydrostrategraphically, the groundwater aquifer in the proposed TMF area is relatively simple in comparison with the KSM Project mining area. According the regional geological survey and the onsite drilling, the aquifer is composed of massive folded and fractured sedimentary bedrock formation of the Bowser Lake Group, which consists of mainly sandstone, siltstone, mudstone and conglomerate. Overburden materials (glacial till and colluvium) with thickness greater than 5 m occur predominantly on the valley bottoms of the Teigen Creek, Treaty Creek, Bell-Irving River and their tributaries, but are not considered to be significant aquifers. Fluvial sediments are mainly distributed in the valleys of the main surface water bodies: Teigen Creek, Treaty Creek and Bell-Irving River. No large regional-scale faults are identified in the aquifer system. Generally, the aquifer is unconfined in the steep slope areas and high elevations where the overburden is thin or doesn't exist, but it could be confined on some part of the valley bases where the glacial till is thick. The information for overburden distribution in the prefeasibility study stage is limited, however investigations are ongoing and these data can be used to better delineate the overburden distribution and provide a more representative hydrogeological model.

The measured hydraulic conductivity for overburden in the TMF area is limited to one estimate at 6.4×10^{-5} m/s for fluvial sediment downstream of the proposed TMF South Dam. There are no test data for the hydraulic conductivities of glacial till and colluvial sediments in the TMF study area. The measured hydraulic conductivities of the sedimentary bedrocks (mainly siltstone and mudstone) in the TMF area up to 100 mbgs range from 3.8×10^{-9} m/s to 1.4×10^{-5} m/s with the geometric mean of 3.2×10^{-7} m/s. Conceptually, the hydraulic conductivities for overburden in the TMF area are considered to be similar to those in the mining area, and the permeability of the bedrocks is believed to gradually decrease with depths despite the available test data shows such a trend is weak within the limited depths of hydraulic testing.

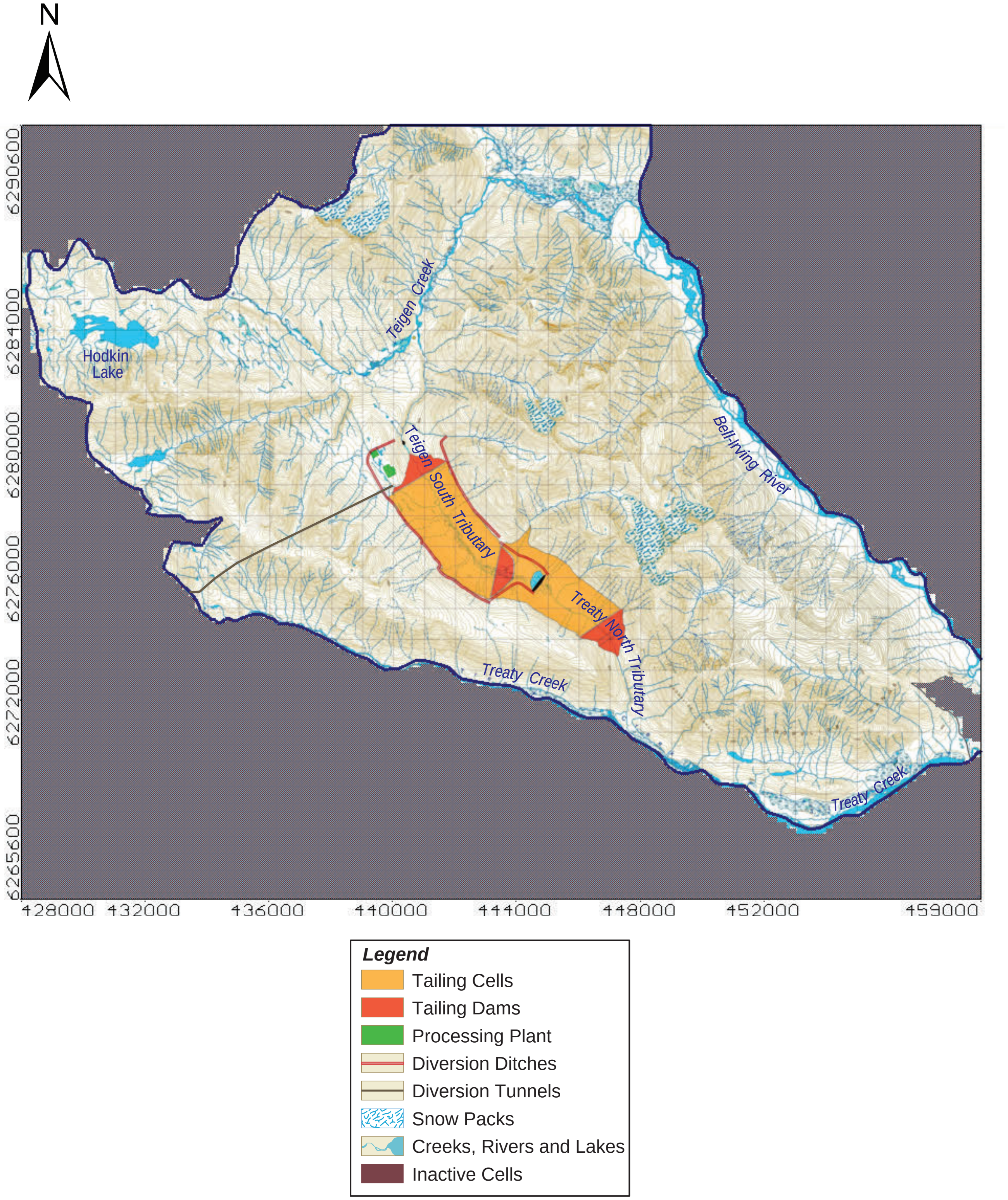
The potentiometric surface map produced from measured groundwater levels from a limited number of monitoring wells (9 wells at 6 locations) indicates that the groundwater table tends to reflect topography and the unsaturated zone thickness increases with groundwater surface elevations. Groundwater flows from higher elevations towards lower elevations in the valleys. The groundwater flow system in the study area is observed generally in a steady state within normal climate-driven variation.

4.2 BASELINE PRE-MINING MODEL

4.2.1 Model Domain and Grids

The model domain for the TMF area is shown in Figure 4.2-1. The east boundary of the domain is the Bell-Irving River, the south boundary is the Treaty Creek, and the boundaries in the west and north are natural watershed divides. The valleys of the Teigen Creek South Tributary and the Treaty Creek North Tributary where the proposed tailing pond will be situated are in the central part of the model domain.

The model domain has a maximum north to south extent of 22.9 km (from 6,267,700 m N to 6,290,600 m N) and a maximum west to east extent of 31.0 km (from 428,000 m E to 459,000 m E). The surface elevation in the model domain varies from a minimum of 483.5 masl at downstream Bell-Irving River valley to a maximum of 2012.8 masl on the mountain between the Teigen Creek south tributary and the Bell-Irving River. The base of the model domain is set to mean sea level.



TMF Area Baseline Hydrogeological Model Domain

FIGURE 4.2-1

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The model grid consists of a total of 318 rows (north to south) and 303 columns (west to east). The model domain is spatially discretized with finer grids within the TMF and the potentially impacted areas of the TMF, which includes the Teigen South Tributary, the Treaty North Tributary, downstream of the Teigen Creek, middle and the lower reaches of the Treaty Creek. The element size used for these areas is 50 m by 50 m for more precise computations. To reduce the instability of the numerical solutions outside of these areas, the sizes of elements gradually increases by 1.5 times as a rule of thumb. Figure 4.2-2 and Figure 4.2-3 show the plan view and the vertical cross-sections of the model grids with refinement in the proposed TMF area (Column 128, Row 206).

The model domain contains a total of nine layers from the top to the bottom (Layers 1 to 3 representing overburden and bedrock, Layers 4 to 9 presenting bedrock only). The thickness of the top layer varies from 5 m to 16 m under the proposed TMF footprint in Teigen South Tributary and Treaty North Tributary. The thickness of the deeper model layers increase gradually by following the rule of thumb stated above.

4.2.2 Flow Boundary Conditions

Figure 4.2-4 shows the flow boundary conditions applied to the pre-mining baseline hydrogeological model in the TMF area to simulate the flow conditions observed on site.

4.2.2.1 Recharge Zones

Using the same criteria for the recharge zones in the mining area model of the KSM Project, four recharge zones are defined in the TMF area baseline pre-mining model domain based on the surface elevation and glacier/permanent snow pack coverage (Figure 4.2-5). The recharge rates assigned to the water table in these zones are shown in Table 4.2-1, representing the estimated net recharge into the groundwater system from precipitation minus surface runoff and evapotranspiration. For the area without glaciers and permanent snow packs, the recharge rates are estimated to be equal to 84 mm/yr to 108 mm/yr (equivalent to 8% to 10% of the mean annual precipitation of 1,083 mm/yr provided as a long term average from BC Climate. The recharge rate applied in the valleys is slightly smaller than in the upper lands with the same rational described in the mining area model. For the area under the glaciers and permanent snow packs, the recharge rate is estimated to be 40 mm/yr, the same as in the mining area model. The effects of the uncertainty of the recharge rates will be examined in sensitivity analysis of the model calibration and prediction.

Table 4.2-1. Recharge Rates Applied in Baseline Hydrogeological Model – TMF Area

Recharge Zones	Recharge Rate (mm/yr)	Descriptions
1	84	< 900 masl (valley bottom and no glacier coverage)
2	96	900 to 1300 masl (mid-slope and no glacier coverage)
3	108	> 1300 masl (uplands and no glacier coverage)
4	40	Glacier and permanent snow pack coverage

4.2.2.2 Constant Heads

As shown in Figure 4.2-4, a constant head boundary condition is assigned to represent the three lakes within the model domain: Hodkin Lake, South Teigen Lake and Treaty Valley Lake (located in the downstream valley of Treaty Creek), where the water levels are assumed to remain constant or experience insignificant variation. The constant head levels applied for these lakes are respectively 1,024 masl, 911 masl and 730 masl.

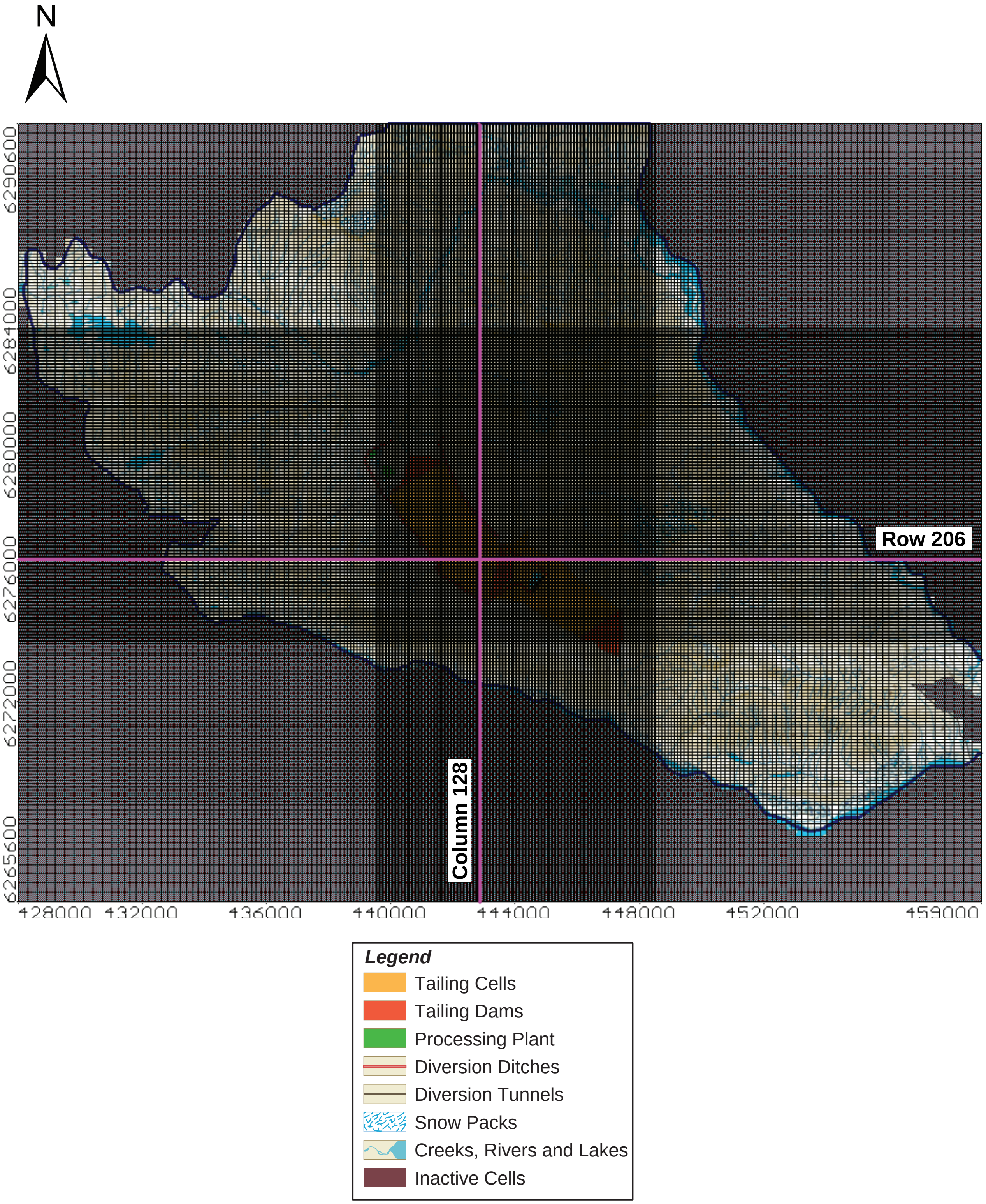

FIGURE 4.2-2

TMF Area Baseline Hydrogeological Model Grids
(Plan View)

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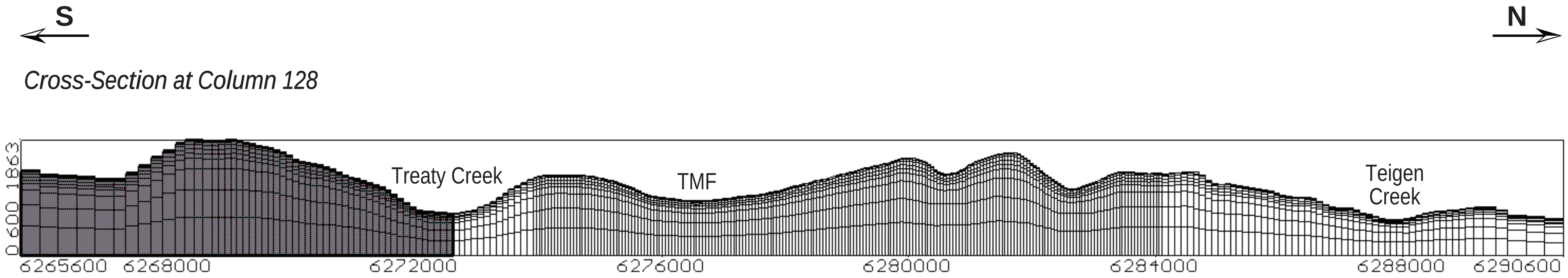
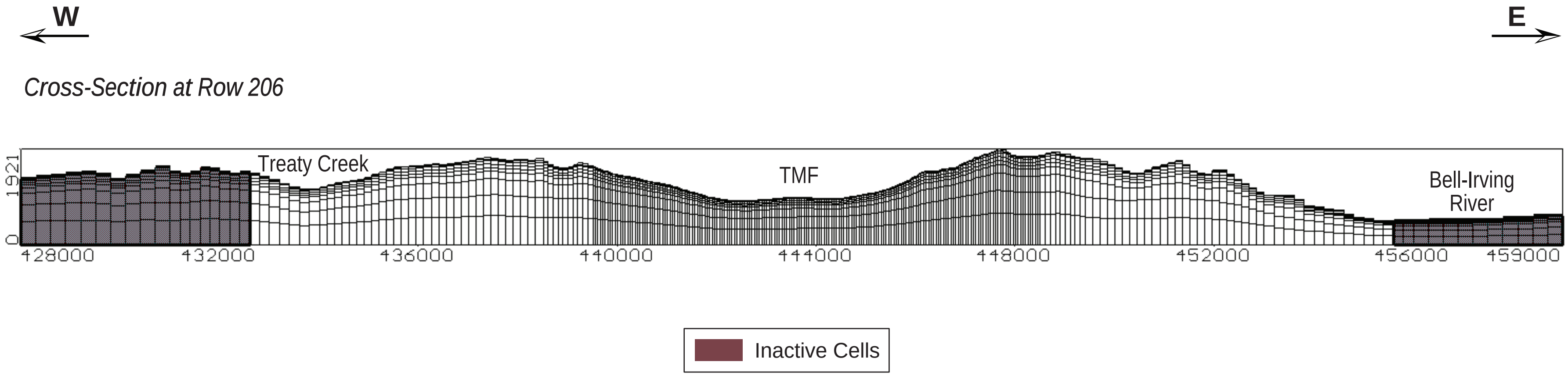

Cross-Section at Column 128


Cross-Section at Row 206

TMF Area Baseline Hydrogeological Model Grids (Cross-Sections)

FIGURE 4.2-3

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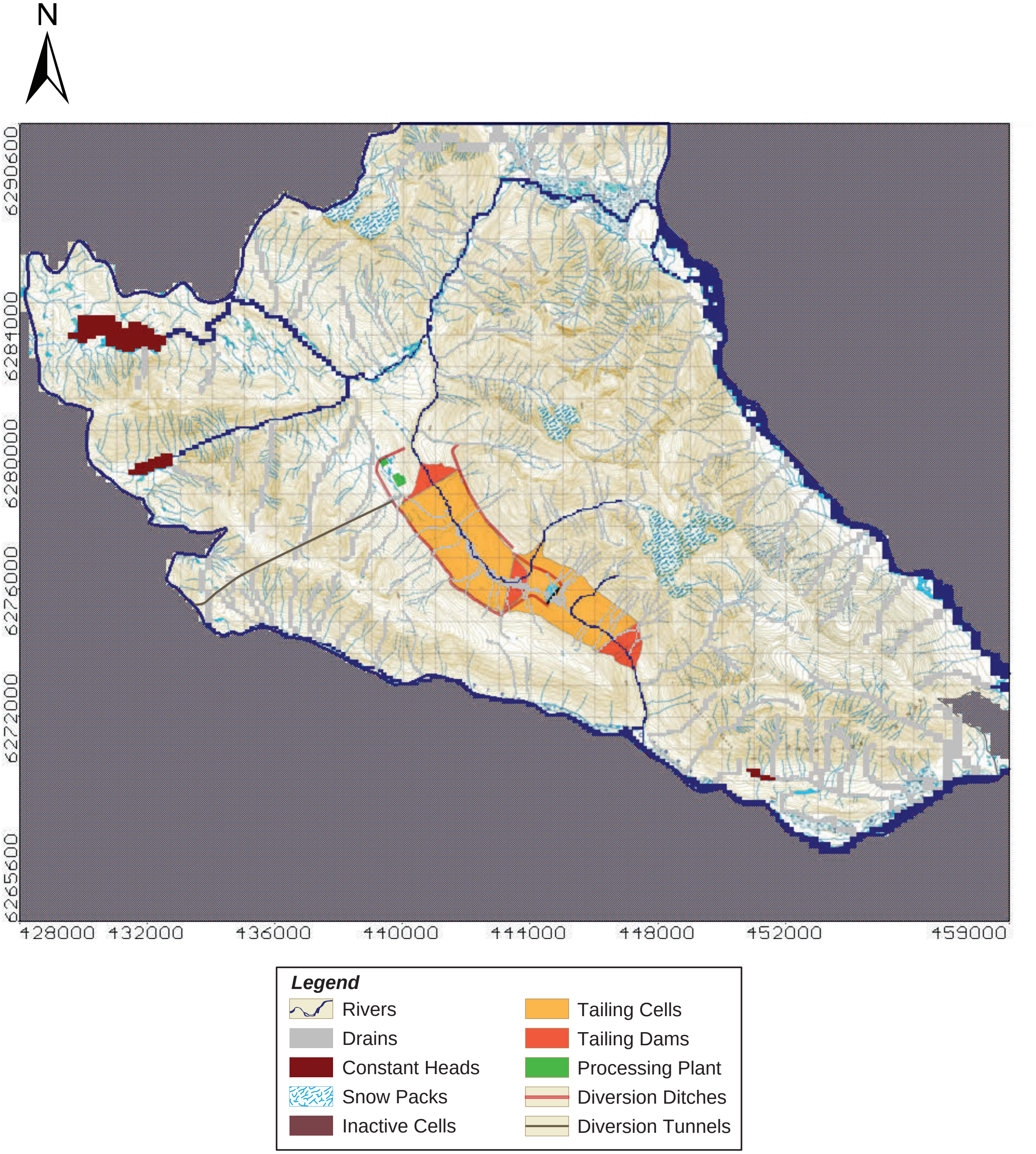


Flow Boundary Conditions in TMF Area
Baseline Hydrogeological Model (Layer 1)

FIGURE 4.2-4

SEABRIDGE GOLD

Rescan™

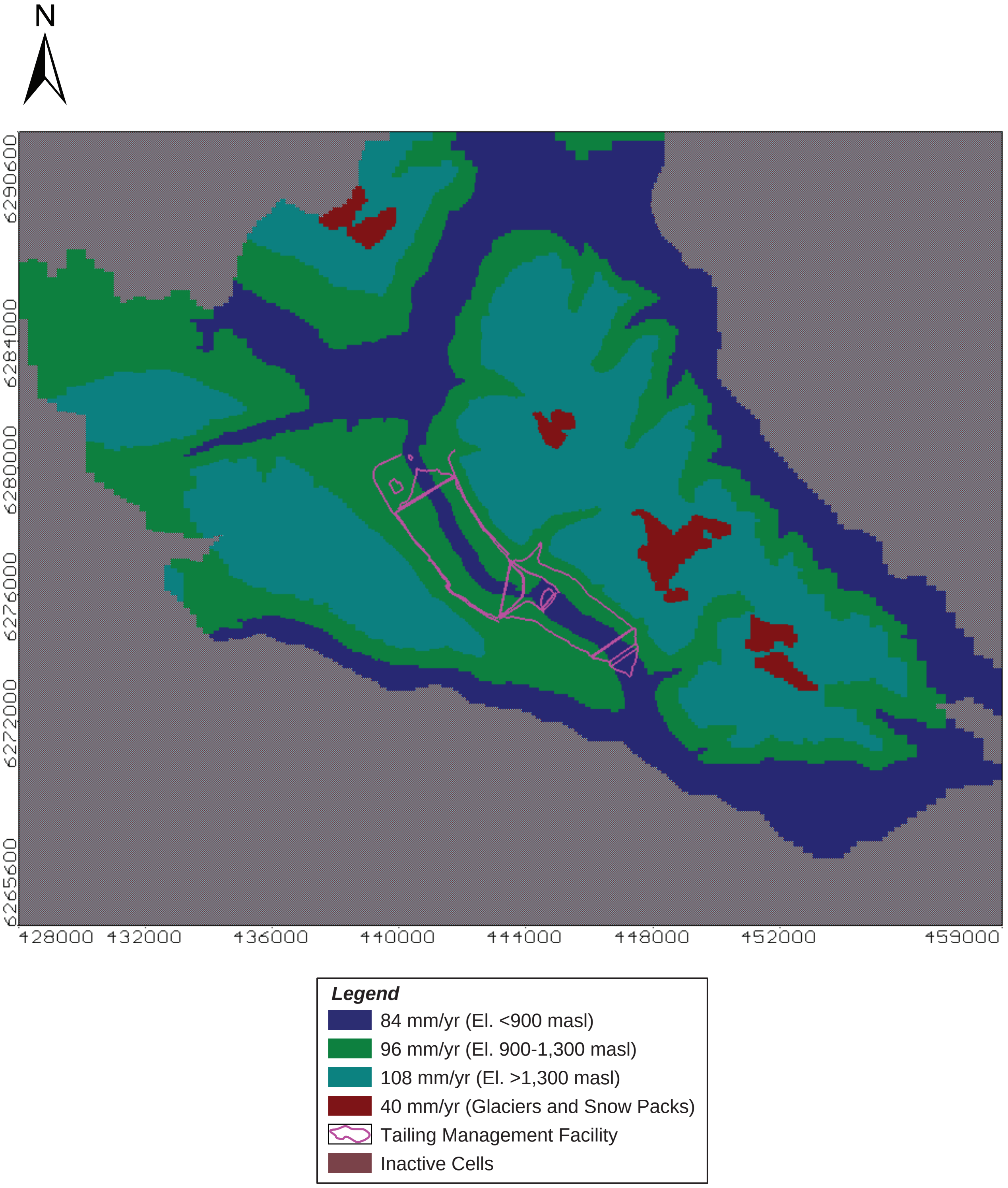


FIGURE 4.2-5

Recharge Zones in TMF Area Baseline Hydrogeological Model

4.2.2.3 Rivers

Also as shown in Figure 4.2-4, the river boundary condition is assigned to represent the main portion of Teigen Creek, Teigen South Tributary (through the proposed TMF area) and Teigen West Tributary, Treaty Creek and Treaty North Tributary, as well as Bell-Irving River. The river boundary condition is used to characterize the interactions between groundwater and surface water along the main valleys and to simulate groundwater discharge into the surface water bodies. The water depths and widths of the creeks and rivers assigned in the model are taken from Rescan's hydrologic field observation data for the gauged stations (Rescan 2010a) and are estimated for the ungauged stations based on the catchment areas and the aerial photography, as well as by referring to the observation data from the gauged stations.

For all these creeks and rivers, the riverbed elevations are estimated from surface topography; the riverbed thickness varies between 0.1 m (in the headwaters of the creek tributaries) and 3.0 m (in Bell-Irving River). The riverbed hydraulic conductivity was set at 1.0×10^{-5} m/s (same as in the mining area model), and is the same order of magnitude as the measured hydraulic conductivity of 6.4×10^{-5} m/s for fluvial sediments in the borehole RES-MW-02B located in the valley of Treaty North Tributary.

4.2.2.4 Drains

Drain boundaries are used to represent the wetlands under the proposed Tailing Management Facility footprint area, and they are also applied to small streams on steep slopes. The drain boundaries are assigned at ground surface and they receive groundwater seepage when the groundwater table is on or above ground surface; the conductance used for the drains is 0.1 m/d from the experience of the similar projects (Cho 2009; Rescan 2009). In total, there are 139 drains assigned in the model domain. Unlike the river boundaries, the drain boundaries assigned on the steep slopes do not simulate recharge to the aquifer from the streams when the groundwater table is lower than the ground surface.

4.2.2.5 No Flow Boundaries

Except for the river boundaries (the Bell-Irving River on the east side of the model domain and the Treaty Creek on the south side), the exterior boundary of the model domain is chosen as the natural watershed divide and assigned as a 'no-flow' boundary in the model with the assumption that the watershed divide is the same as the groundwater divide. A no-flow boundary is also assigned at the bottom of the model domain at sea level, which is considered reasonable as it is about 770 m to 1,100 m below ground surface in the proposed TMF area at which depths the permeability of the bedrock should be extremely low.

4.2.3 Aquifer Properties

According to the conceptual model, the hydrogeological units within the TMF area include overburden materials (glacial till, colluvium, fluvial) and sedimentary bedrock. To build the baseline model, initial inputs of hydrogeological properties are applied to these units, including material properties for both the unsaturated and saturated zones. The baseline model can then be calibrated by varying some of the key parameters, within reasonable bounds, to find the best match between the modelled and observed hydraulic heads. Some of the aquifer properties were constrained by the available hydrogeological data as summarized in the previous section 2.6, others had to be assumed due to the lack of data.

4.2.3.1 Unsaturated Zone Properties

The steep slopes at the KSM project site creates a challenge for numerical solutions of highly non-linear variably saturated groundwater flow, especially with the inherent problems of dry cells in Visual

MODFLOW. Considering that there are no test data available for the unsaturated flow properties of the overburden and bedrock materials in the study area, and the difficulty in obtaining such data, the default experimental pseudo-soil function of relative permeability and pressure head versus soil moisture in the software MODFLOW-Surfact flow package version 3.0 (HydroGeologic 1996) was utilized to characterize unsaturated flow for overburden and bedrock in the unsaturated zone. This is considered to be acceptable since groundwater flow and transport of dissolved metals from the copper and gold mining occurs dominantly in saturated zone at the regional scale.

4.2.3.2 Saturated Hydraulic Conductivity

Figures 4.2-6a, 4.2-6b, 4.2-7a and 4.2-7b show the representative model layers and vertical cross-sections with the hydraulic conductivity zones assigned for the overburden and bedrock in the baseline model. Table 4.2-2 shows the initial inputs of the hydraulic conductivity values for the overburden materials and bedrock zones in the baseline model before calibration.

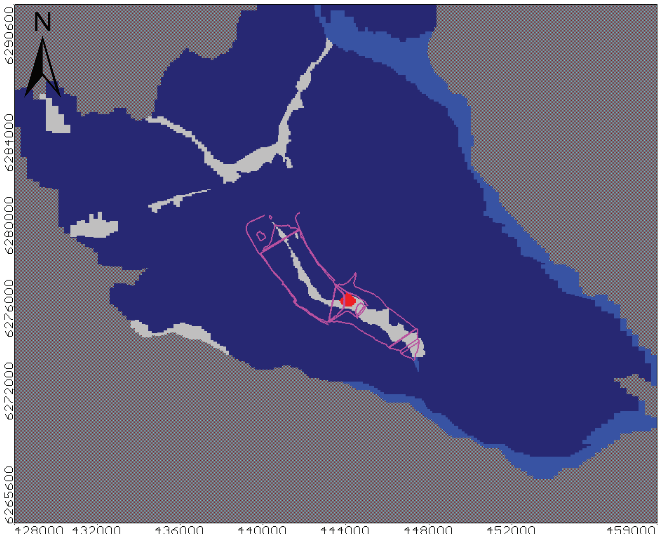
The overburden is assigned in Layers 1 to 3 of the valley bottoms based on the overburden and surficial geological maps and borehole results presented in Chapter 2, and has been classified into three hydraulic conductivity zones: glacial till, alluvium fan and fluvial sediments. The overburden is represented only in those areas where it is thicker than 5 m. The glacial till under the proposed TMF footprint varies from 12 m to 35 m thick, the alluvium fan near the South Tailing Dam (close to the borehole KC08-05) is about 60 m thick, and the fluvial sediments at the location of monitoring well RES-MW-02 and the surrounding area in the Treaty North Tributary is about 45 m thick. The hydraulic conductivity for glacial till is assigned the geometric mean 6.8×10^{-8} m/s of the field measured values; the hydraulic conductivity for fluvial sediments is assigned with the field estimate 6.4×10^{-5} m/s; the hydraulic conductivity for the alluvium fan is not available but has been assigned an assumed value of 6.8×10^{-7} m/s, one order of magnitude higher than the glacial till conductivity. The anisotropy for all the overburden materials is assumed 5:1. The uncertainties associated with the overburden inputs will be examined in the sensitivity analysis.

The bedrock is assigned in Layers 1 to 9 (from the top to the bottom) in the baseline model with decreasing hydraulic conductivities in depths according to the conceptual model. The bedrock is divided into six hydraulic conductivity zones vertically: Top Bedrock (Layers 1 and 2), Shallow Bedrock (Layers 3 and 4), Upper Bedrock (Layers 5 and 6), Middle Bedrock (Layer 7), Lower Bedrock (Layer 8) and Bottom Bedrock (Layer 9). Under the TMF footprint, the bedrock is 12 m to 39 m thick in the top bedrock zone, 50 m to 88 m thick in the shallow bedrock zone, 82 m to 144 m thick in the upper bedrock zone, 118 m to 202 m thick in the middle bedrock zone, about 207 m to 260 m thick in the lower bedrock zone, and 290 m to 358m thick in the bottom bedrock zone.

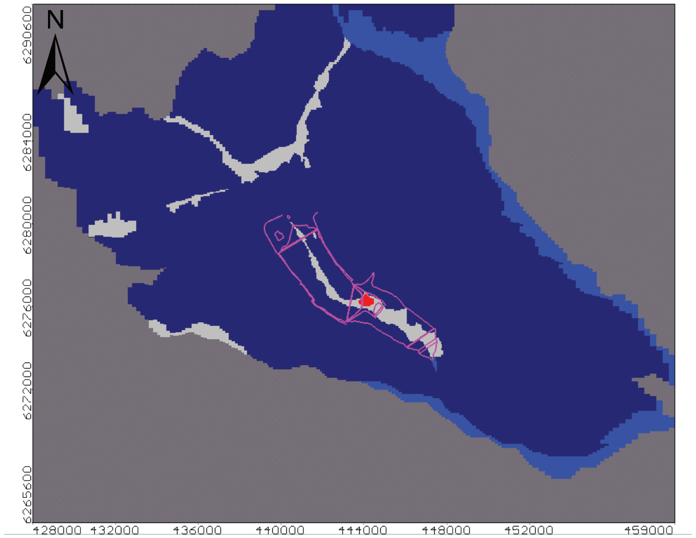
A geometric mean of 3.2×10^{-7} m/s for the sedimentary rocks in the TMF area was used for the shallow bedrock zone in which the hydraulic tests were conducted. There were no measurements for the hydraulic conductivities within the top fractured bedrock zone at the time of the modelling analysis, and therefore an assumed value of 1.0×10^{-6} m/s was used for this zone, which is approximately one order of magnitude higher than that for the shallow bedrock zone. Due to the lack of data in deeper layers, the hydraulic conductivity of the upper bedrock zone is assumed to be 5.0×10^{-8} m/s (about one order of magnitude lower than that for the shallow bedrock zone), and the hydraulic conductivities for the middle, lower and bottom bedrock are assumed to decrease by a factor of 5 from the zone above, which are 1.0×10^{-8} m/s, 5.0×10^{-9} m/s and 1.0×10^{-9} m/s, respectively.

The bedrock anisotropy was assumed at 1:1 in all the zones due to the unavailability of test data. The uncertainties associated with bedrock anisotropy were investigated in the sensitivity analysis.

Layer 1 (Overburden and Top Bedrock)



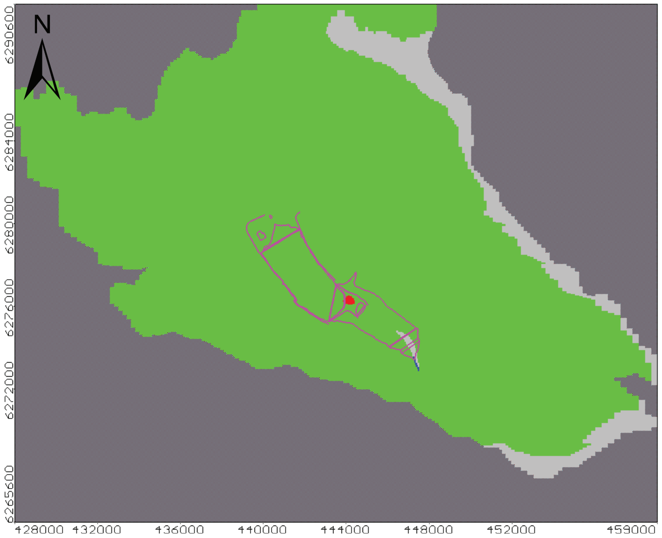
Layer 2 (Overburden and Top Bedrock)



Legend

- 🟦 Fluvial
- ⬜ Glacial Till/Colluvium
- 🟦 Top Bedrock
- 🟩 Shallow Bedrock
- ⬭ Tailing Management Facility
- 🟫 Inactive Cells

Layer 3 (Overburden and Shallow Bedrock)



Layer 4 (Shallow Bedrock)

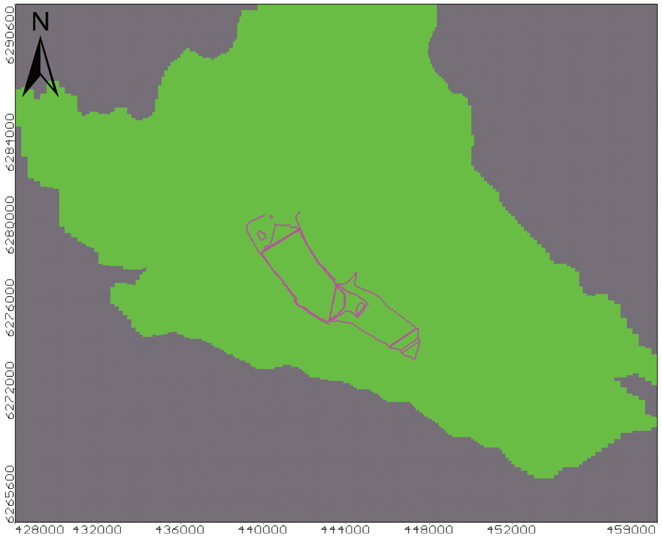


FIGURE 4.2-6a

Hydraulic Conductivity Zones in TMF Area Baseline Model
(Layers 1 to 4)

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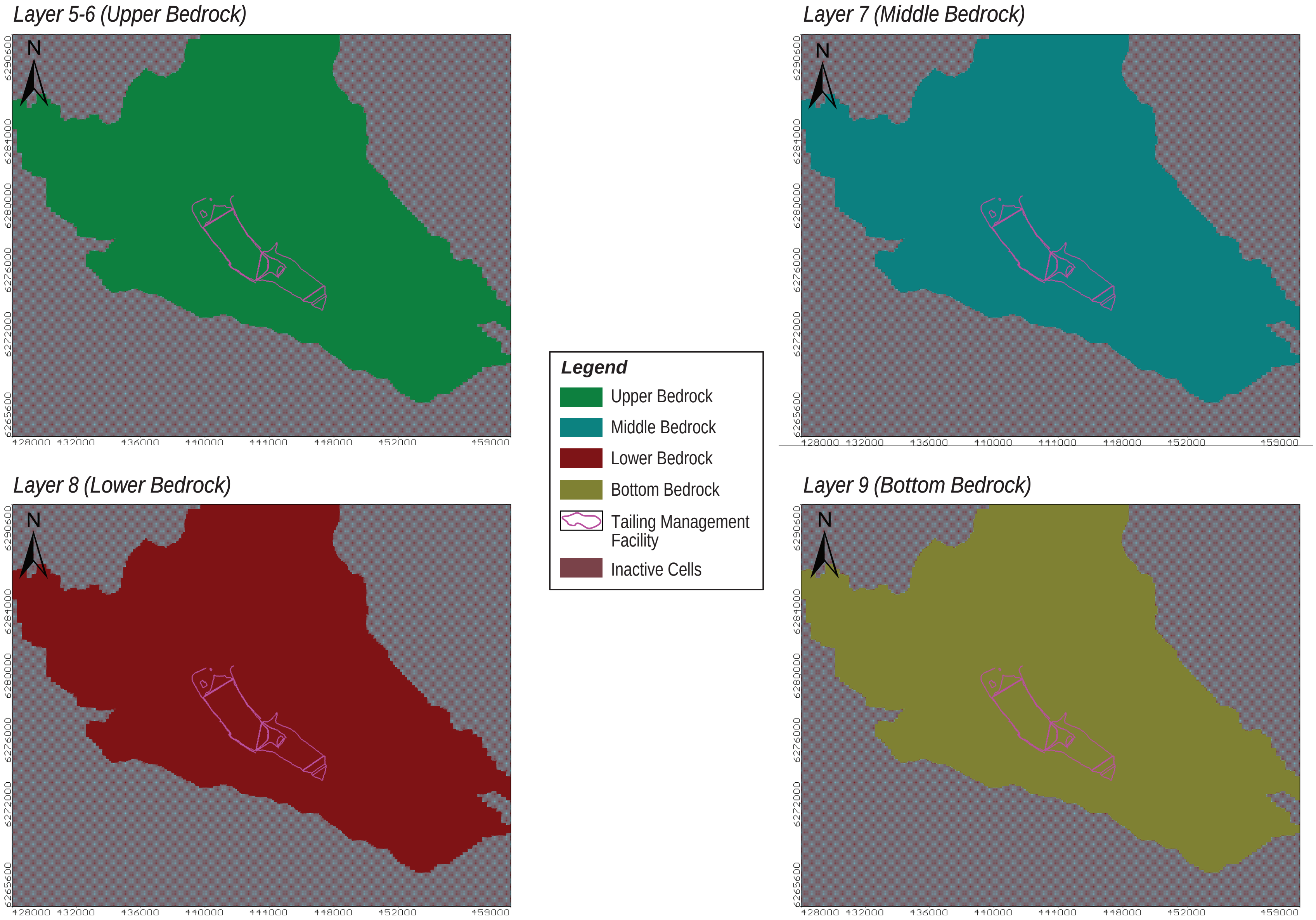

Layer 5-6 (Upper Bedrock)

Layer 7 (Middle Bedrock)

Layer 8 (Lower Bedrock)

Layer 9 (Bottom Bedrock)

FIGURE 4.2-6b

Hydraulic Conductivity Zones in TMF Area Baseline Model (Layers 5 to 9)

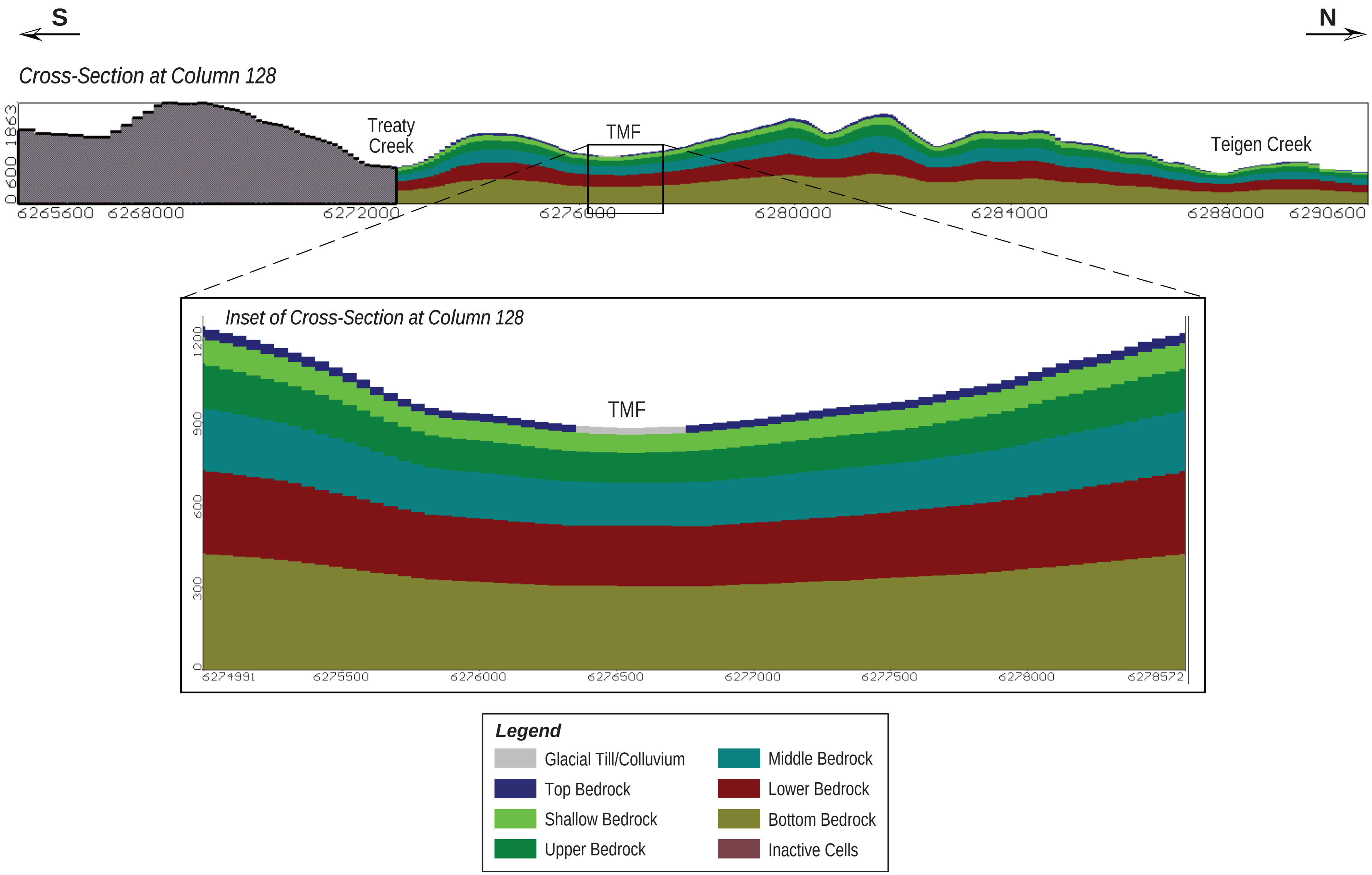
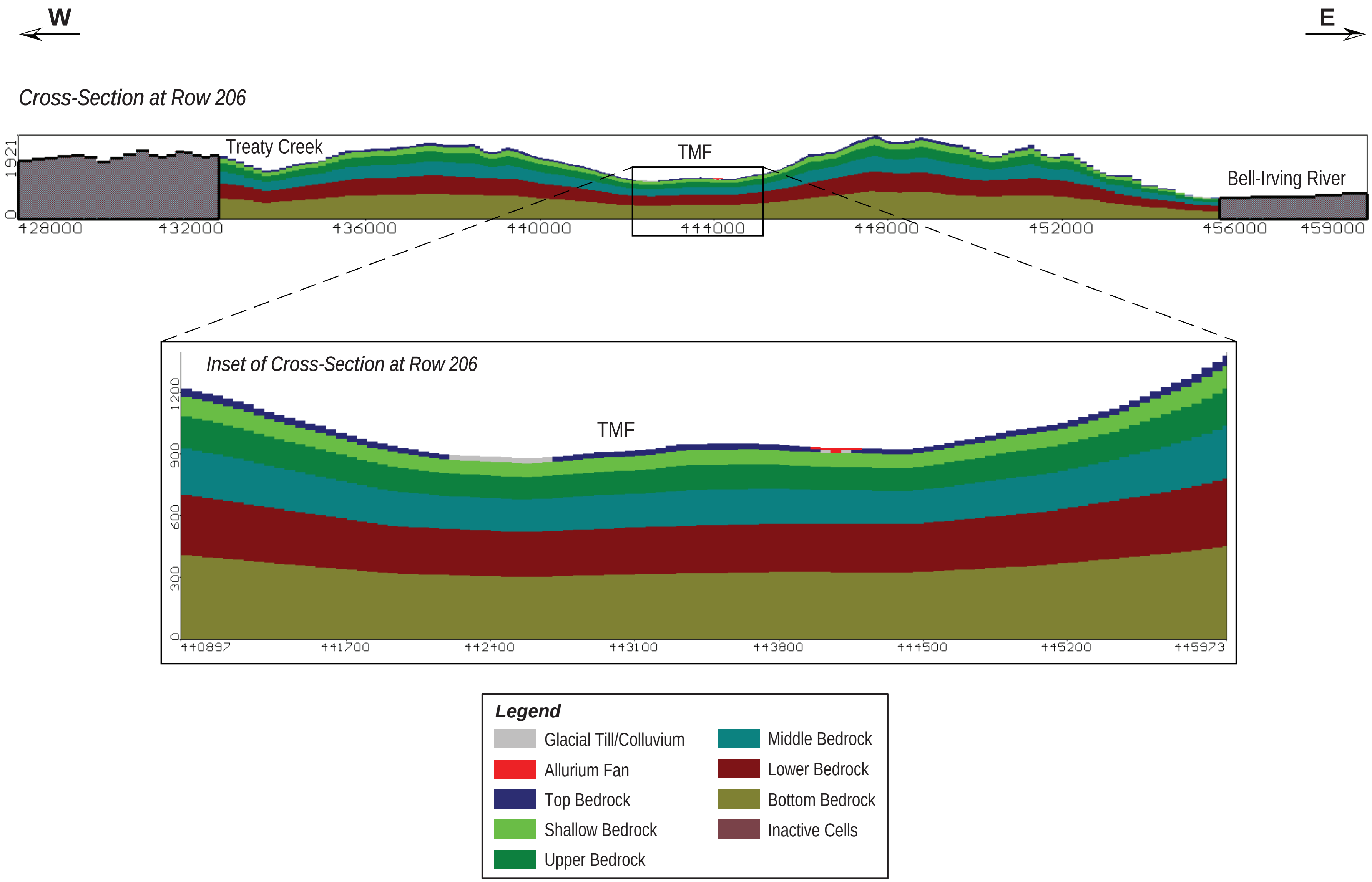


FIGURE 4.2-7a

Hydraulic Conductivity Zones in TMF Area Baseline Model (Cross-sections)

SEABRIDGE GOLD

Rescan™



SEABRIDGE GOLD

Hydraulic Conductivity Zones in TMF Area Baseline Model (Cross-sections)

FIGURE 4.2-7b

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Table 4.2-2. Hydraulic Conductivities in TMF Area Baseline Model before Calibration

Material Type	Property Zone	Hydraulic Conductivity (K_h, m/s)	Anisotropy (K_h/K_v)	Model Layers
Overburden	Glacial Till	6.8×10^{-8}	5:1	1 to 3
	Colluvium	6.8×10^{-7}	5:1	1 to 3
	Fluvial Sediments	6.4×10^{-5}	5:1	1 to 3
Bedrock	Top Bedrock	1.0×10^{-6}	1:1	1 to 2
	Shallow Bedrock	3.2×10^{-7}	1:1	3 to 4
	Upper Bedrock	$5.0\text{x}10^{-8}$	1:1	5 to 6
	Middle Bedrock	$1.0\text{x}10^{-8}$	1:1	7
	Lower Bedrock	$5.0\text{x}10^{-9}$	1:1	8
	Bottom Bedrock	$1.0\text{x}10^{-9}$	1:1	9

All of the overburden materials and the bedrock zones were assumed to be homogeneous within the individual zones of the baseline model. The reason for this assumption is that no hydraulic tests were conducted in the Project area that would have allowed for the determination of heterogeneity (e.g., pumping tests). Nevertheless, with the different hydraulic conductivities and the anisotropy ratios assigned for overburden materials and the bedrock zones, the 3D hydrogeological system as a whole can actually be viewed as being heterogeneous and anisotropic.

4.2.3.3 Specific Storage, Specific Yield and Porosity

The specific storage, specific yield, total and effective porosities assumed in the in the baseline model are provided in Table 4.2-3. The specific storage and specific yield represent the volume of water released from confined and unconfined aquifers respectively under a unit decline in hydraulic head. The total and effective porosities are used in determining the average linear groundwater flow velocities in solute transport modelling. As there were no direct measurements of these parameters within the Project study area, the values assumed in the baseline model are from similar groundwater modelling projects and values from the literature, such as the USGS and other mining-related groundwater modelling reports (Freeze and Cherry 1979; Fetter 1980; Stone and Fontaine 1998; Jones 2002; Lyford et al. 2007; Cho 2009; Rescan 2009).

Table 4.2-3. Specific Storage, Specific Yield and Porosities in TMF Area Baseline Model

Material Type	Property Zone	Specific Storage (S_s, 1/m)	Specific Yield (S_y)	Effective Porosity (n_e)	Total Porosity (n)
Overburden	Glacial Till	$1.0\text{x}10^{-5}$	0.10	0.15	0.20
	Colluvium	$3.0\text{x}10^{-5}$	0.15	0.20	0.25
	Fluvial Sediments	$5.0\text{x}10^{-5}$	0.25	0.25	0.30
Bedrock	Top Bedrock	$5.0\text{x}10^{-6}$	0.02	0.05	0.07
	Shallow Bedrock	$5.0\text{x}10^{-6}$	0.02	0.05	0.07
	Upper Bedrock	$1.0\text{x}10^{-6}$	0.01	0.02	0.05
	Middle Bedrock	$1.0\text{x}10^{-6}$	0.01	0.02	0.05
	Lower Bedrock	$1.0\text{x}10^{-6}$	0.01	0.02	0.05
	Bottom Bedrock	$1.0\text{x}10^{-6}$	0.01	0.02	0.05

4.2.4 Flow Budget Zones

To quantify the groundwater interactions with surface water and to calculate the groundwater discharge (baseflow) to the surface water system (in the pre-mining baseline model calibration and for the EA), six flow budget zones were assigned in the top layer of the model along the Teigen and Treaty creeks and their tributaries in the proposed TMF area. The flow budget zone names and locations are shown in Figure 4.2-8.

4.2.5 Initial Heads, Flow Solver Parameters and Convergence Criteria

The initial head for the steady-state baseline model is assumed to be equal to the midpoint of ground surface elevations, which is 1,248.2 masl. The initial head is used to compute the steady-state flow solutions with the output time set to be 100 years, which is considered to be reasonable based on previous experience and the mining life of the Project.

The pre-conditioned conjugate gradient (PCG4) solver in the MODFLOW-Surfact flow package version 3.0 is used for simulations of variably-saturated flow in the aquifer system, and the solver uses the efficient and rigorous Newton-Raphson linearization approach in solving the non-linear governing equations for unsaturated flow (HydroGeologic 1996). The flow solver parameters and the convergence criteria include:

- the maximum outer iterations: 250
- the maximum inner iterations: 150
- the head change criterion: 0.01 m
- the residual criterion: 0.01 m^3/d

The other parameters of the solver such as the damping factor are kept at their default values from the numerical code (HydroGeologic 1996; Schlumberger 2008). The solver and its parameters and convergence criteria used for simulation of variably-saturated flow in the TMF area model are the same as those used in the mining area baseline model. The small absolute head change and residual criteria were used to ensure accuracy in the flow solutions, and the damping factor applied was to make the solver work more easily for solutions in domains with steep terrains.

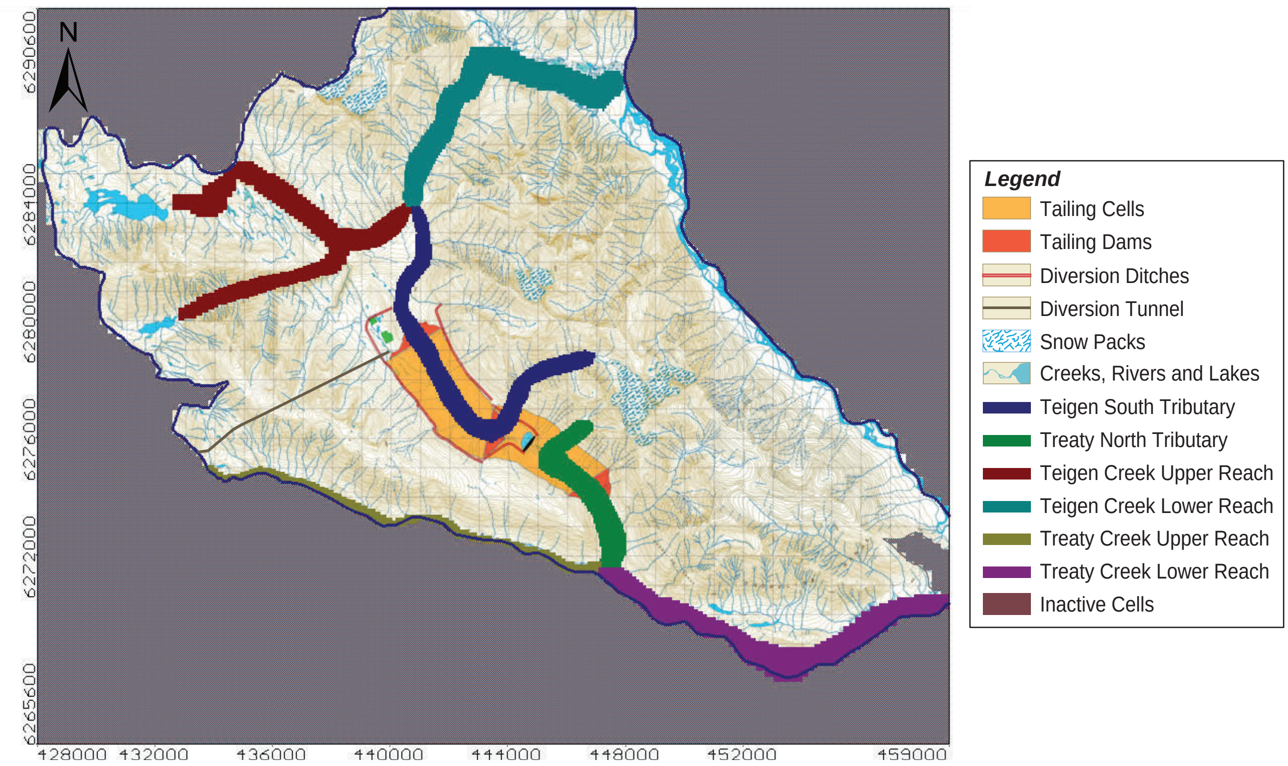
4.2.6 Model Calibration

4.2.6.1 Calibration Targets

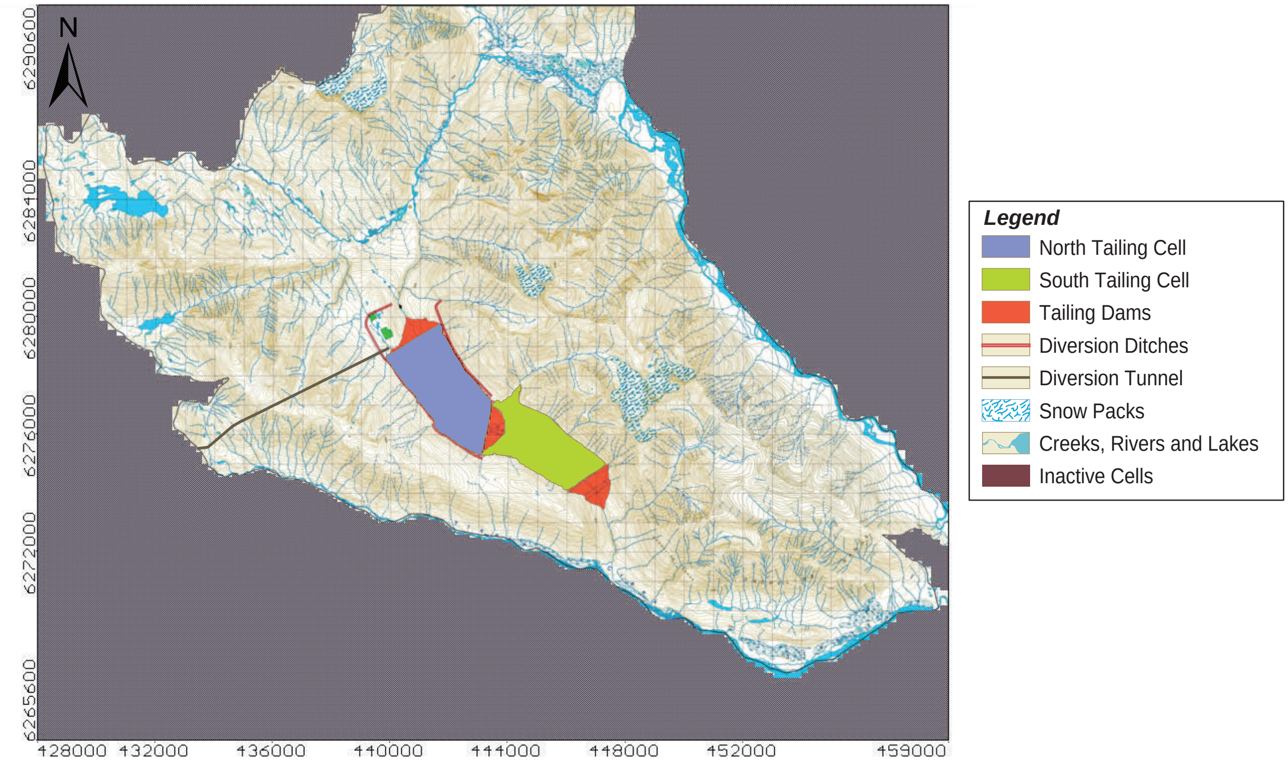
The TMF area baseline model was run at steady state with the parameters and properties described in the previous sections and calibrated with the PEST (a popular parameter estimation program) in MODFLOW package. For final calibration, manual adjustment of the flow and aquifer parameters were made within reasonable ranges of the field tested and estimated data. The model calibration is aimed at maintaining the general concepts of the hydrogeological system and the flow regime (such as decreasing hydraulic conductivity of bedrock with depth, groundwater flow from upper elevations towards the creeks and rivers in the lower elevations, etc.) while making alterations to limited model variables such as hydraulic conductivities to get the best fit between the field observations and the model simulations. The targets for calibration of the TMF area baseline model include:

- Comparison of the simulated hydraulic heads to the observed hydraulic heads in Rescan's monitoring wells and KCBL's piezometers in the TMF area;
- Comparison of the simulated baseflow rates of creeks to the field observed in the TMF area;
- Comparison of the simulated and observed potentiometric surface contours in the TMF area; and
- Examination of the simulated groundwater table adjacent to creeks, rivers, lakes and wetlands.

Creeks



Tailing Cells



Flow Budget Zones in TMF Area Baseline Model

FIGURE 4.2-8

The final step of the model calibration is to assess the validity of the calibrated and measured hydraulic properties of the geologic materials and the conceptual model in the TMF area.

4.2.6.2 Calibration Results

Figure 4.2-9 shows that the simulated and measured hydraulic heads in the monitoring wells match very well, with a normalized root mean squared (NRMS) of 2.9% and a residual mean of 2.1 m (the rule of thumb for a good calibration is the NRMS less than 10%). Figure 4.2-10 shows the simulated and manually interpolated hydraulic head contours in the entire TMF study area, which compares very well. The simulated long-term average steady-state groundwater discharge (baseflow) rates in the Teigen South Tributary and the Treaty North Tributary in the TMF area under the pre-mining conditions are 0.11 m^3/s and 0.05 m^3/s, respectively. These are consistent with the field observed winter low flows at the hydrometric stations (NTMW-1 and STMW-1) located at the outlets of these two tributaries (Table 4.2-4). The simulated water depths along the creeks, rivers, lakes and wetlands also indicate that the model is very well calibrated. Finally, the calibrated hydraulic conductivities for all the property zones are close to the initial inputs or within the range of the field measurements (Table 4.2-5).

Table 4.2-4. Simulated and Observed/Estimated Pre-mining Low Flows in TMF Area

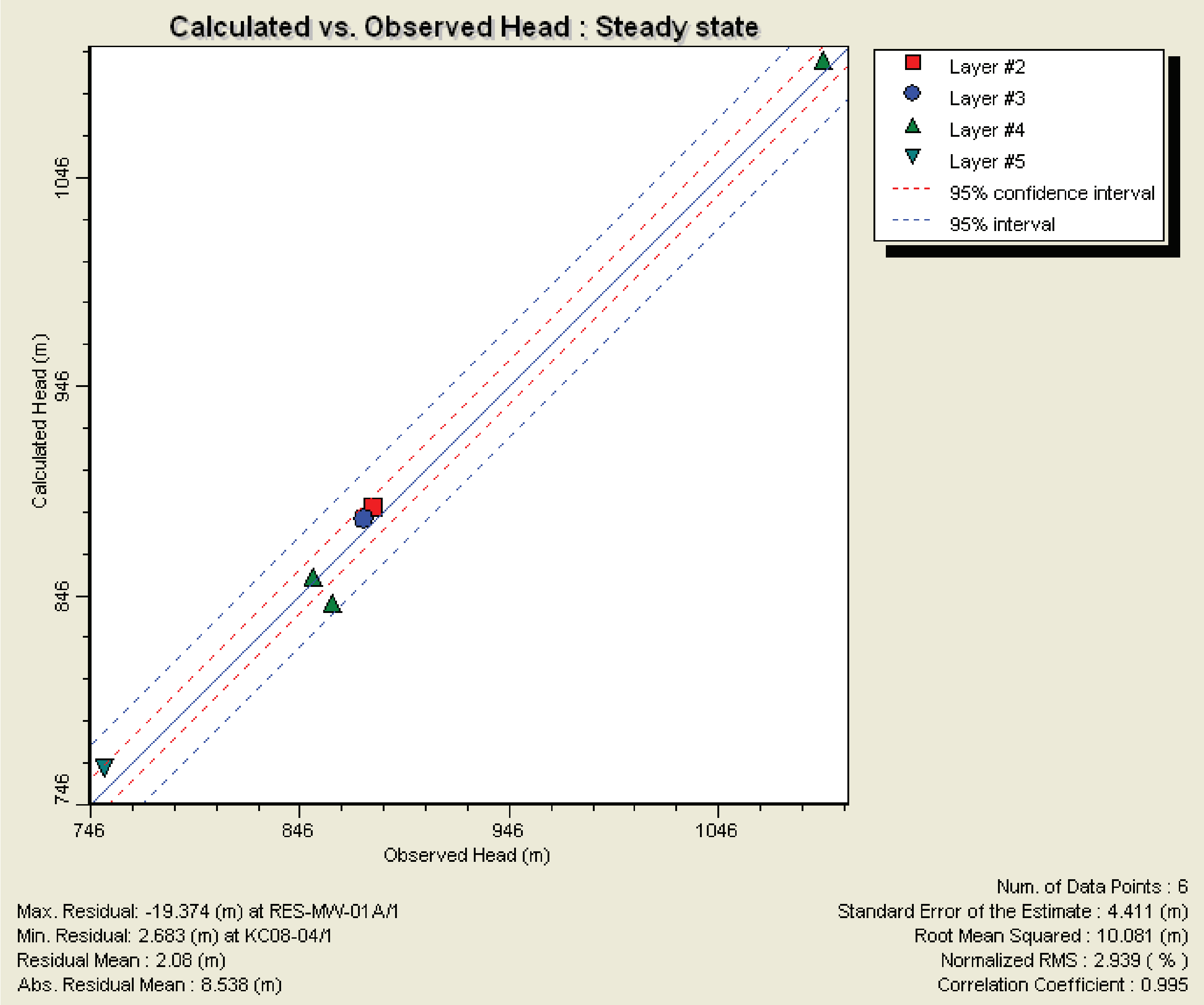
Creeks	Estimated Annual Low Flows from Field Observation (m^3/s)		Simulated Baseflow in Calibrated Baseline Model (m^3/s)
	7-day	7-day Q10[1]	
Teigen South Tributary Mouth	0.16	0.10	0.11
Treaty North Tributary Mouth	0.11	0.05	0.05

[1] Q10 represents the estimated low flows at an occurrence of once in every 10 years.

Table 4.2-5. Hydraulic Conductivities in Calibrated TMF Area Baseline Model

Material Type	Property Zone	Hydraulic Conductivity (K_h, m/s)	Anisotropy (K_h/K_v)
Overburden	Glacial Till	7.0×10^{-7}	5:1
	Colluvium	7.0×10^{-6}	5:1
	Fluvial Sediments	6.0×10^{-5}	5:1
Bedrock	Top Bedrock	1.0×10^{-6}	1:1
	Shallow Bedrock	3.0×10^{-7}	1:1
	Upper Bedrock	$5.0x10^{-8}$	1:1
	Middle Bedrock	$1.0x10^{-8}$	1:1
	Lower Bedrock	$5.0x10^{-9}$	1:1
	Bottom Bedrock	$1.0x10^{-9}$	1:1

Overall, the good quality of calibration results clearly demonstrate that the conceptual model developed from the available information for the TMF area is valid, and the calibrated baseline pre-mining model is reliable for being used to assess the potential environmental impact of the mining on water quantity and quality.

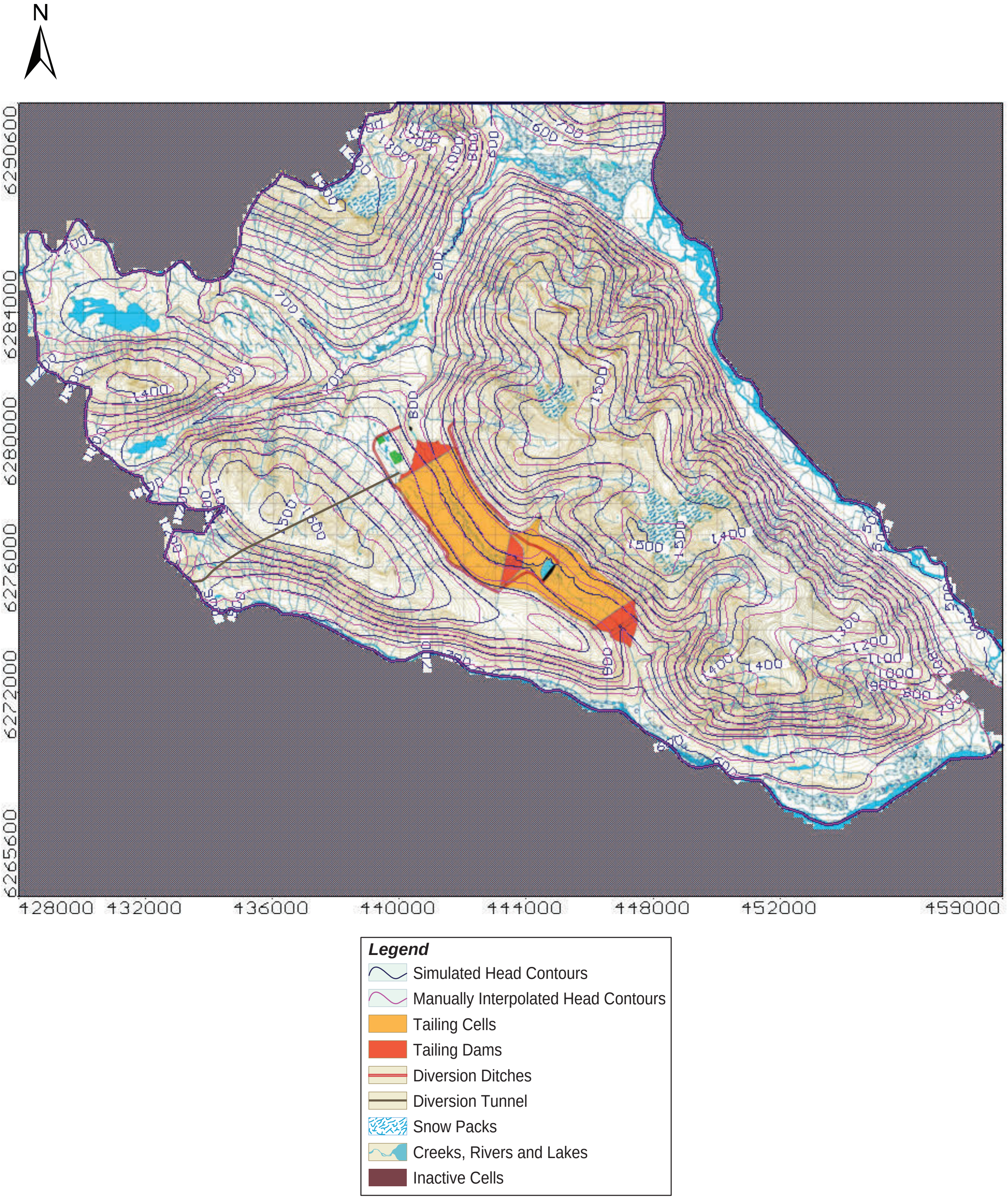


Max. Residual: -19.374 (m) at RES-MW-01A/1
Min. Residual: 2.683 (m) at KC08-04/1
Residual Mean : 2.08 (m)
Abs. Residual Mean : 8.538 (m)

Num. of Data Points : 6
Standard Error of the Estimate : 4.411 (m)
Root Mean Squared : 10.081 (m)
Normalized RMS : 2.939 (%)
Correlation Coefficient : 0.995

Observed vs. Calculated Hydraulic Heads in Monitoring Wells in Calibrated TMF Area Pre-mining Baseline Model

FIGURE 4.2-9



Simulated and Interpolated Pre-mining Hydraulic Head Contours in TMF Area

FIGURE 4.2-10

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4.2.7 Calibrated Baseline Pre-mining Model Results and Sensitivities

4.2.7.1 Baseline Model Results

The calibrated baseline model was run under steady-state. The outputs from the baseline model represent the current and also the long-term average of the pre-mining flow conditions. The results were used in the effects assessment of the proposed Tailing Management Facility on groundwater flows by comparing the outputs against those for the end of mining and post-closure scenarios.

Figures 4.2-11 shows the simulated hydraulic head contours (100 m intervals) and flow vectors in plan view (Layer 1 variably-saturated and Layer 6 fully-saturated). Figure 4.2-12 shows the head equipotential contours and the groundwater table, as well as the flow vectors in the vertical cross-sections through the proposed TMF area. The results clearly show that the regional groundwater flows from the high lands and slopes towards the creeks and rivers on the valley bottoms, and that the proposed TMF is located in a regional groundwater discharge zone. The simulated head contours under the pre-mining conditions generally mimic the surface topography. These results are consistent with the flow system described in the conceptual model. The flow budget results show that under the pre-mining conditions, groundwater discharge into the proposed Tailing Management Facility footprint area is estimated to be 3,551.8 m^3/d (41.1 L/s). The calculated baseflow rates in the creeks in the TMF area under the pre-mining conditions are provided in the following section.

4.2.7.2 Baseline Model Sensitivities

A sensitivity analysis was carried out to examine the sensitivity of the baseline model calibration to the uncertainties in the model parameters such as the recharge rates, hydraulic conductivities in overburden and bedrock materials and the anisotropy ratios (i.e., horizontal versus vertical hydraulic conductivities). Sensitivity analyses were also performed to investigate the variability of the predicted baseflows in the TMF baseline model based on the uncertainties of specific parameters.

The parameters altered in the sensitivity analyses, the calibration results (the NRMS and residual mean), and the predicted baseflows are shown in Table 4.2-6. The recharge rates examined were half and twice the baseline case values. The hydraulic conductivities of overburden materials and bedrock zones were reduced and increased by one order of magnitude compared to the baseline. The anisotropy ratios investigated were 1:10, 1:1 and 10:1 for the overburden materials, and 1:10 and 10:1 for the bedrock. The sensitivities were assessed by altering one parameter at a time while keeping all other parameters unchanged.

The results show that the most sensitive parameters to affect the baseline model calibration and the predicted baseflows are the hydraulic conductivities of the glacial till, the bedrock in the top, shallow and upper zones, as well as the recharge rates. The least sensitive parameters are the hydraulic conductivities of the alluvium and the middle, lower and bottom bedrock zones. The fluvial sediments affect the calculation of baseflows mainly in the lower reach of Teigen and Treaty Creeks, but have no effect on the flows in the Teigen South Tributary and the Treaty North Tributary in the TMF area. The results show that the anisotropy ratios are less sensitive.

Using the combination of the lower and upper bounds of the identified most sensitive parameters (glacial till, top bedrock, shallow bedrock, upper bedrock, and recharge rates), the TMF area baseline model was run to predict the possible range of baseflow to the creeks at the pre-mining. Table 4.2-7 shows that the simulated baseflow rates prior to mining vary between 0.03 m^3/s and 0.30 m^3/s in the Teigen South Tributary, and between 0.02 m^3/s and 0.14 m^3/s in the Treaty North Tributary. These results match well within the range of field observed winter low flow rates shown in Table 4.2-4 in the previous Section 4.2.6.2, which again demonstrates that the baseline hydrogeology model is reliable.

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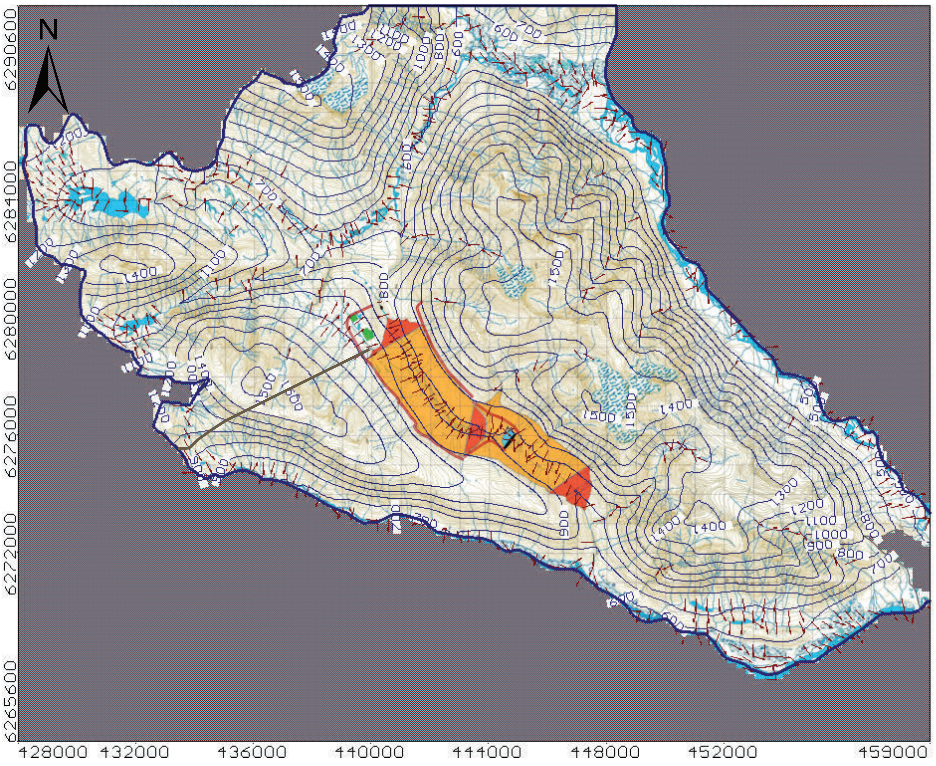
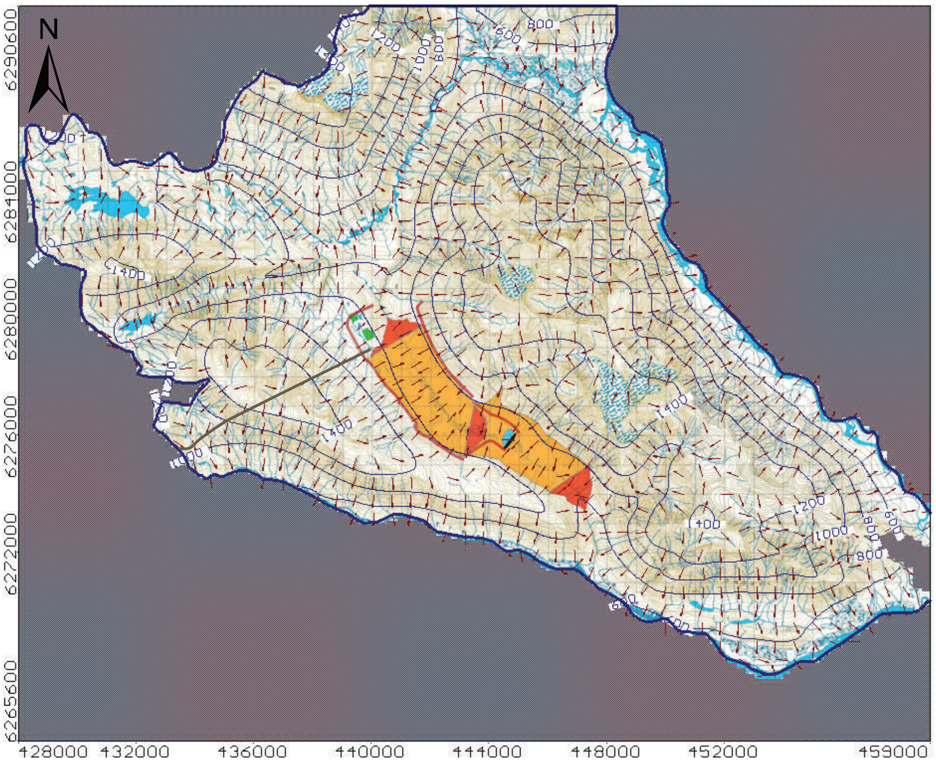
Layer 1 (Variably-Saturated)



Layer 6 (Saturated)



Legend

- 🟧 Tailing Cells
- 🟥 Tailing Dams
- ▭ Diversion Ditches
- ▭ Diversion Tunnel
- 🟩 Processing Plant
- ▨ Snow Packs
- 🟫 Inactive Cells

Simulated Pre-mining Hydraulic Head Contours and Flow Directions in TMF Area (Plan Views)

FIGURE 4.2-11

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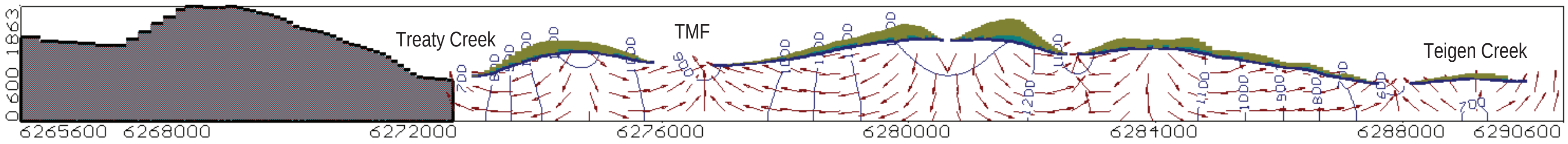
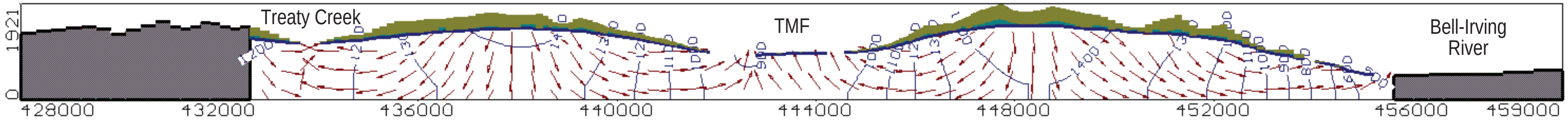
S ← → N

Cross-Section at Column 128



W ← → E

Cross-Section at Row 206



🟩 Dry Cells
🟥 Inactive Cells

FIGURE 4.2-12

Simulated Pre-mining Hydraulic Head Contours and Flow Directions in TMF Area

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Table 4.2-6. KSM Project TMF Area Baseline Model Sensitivity Analysis

Property and Parameter		**Base Case Value**	**Lower and Upper Limits of Uncertainty**	**Calibration**		**Teigen Creek: Simulated Baseflow Rates**						**Treaty Creek: Simulated Baseflow Rates**						**Overall Sensitivity**
				NRMS (%)	**Residual Mean (m)**	**South Tributary** *(Proposed TMF Location)* **(m^3/s)**	**Change from Base Case (%)**	**Lower Reach (m^3/s)**	**Change from Base Case (%)**	**Upper Reach (m^3/s)**	**Change from Base Case (%)**	**North Tributary** *(Proposed TMF Location)* **(m^3/s)**	**Change from Base Case (%)**	**Lower Reach (m^3/s)**	**Change from Base Case (%)**	**Upper Reach (m^3/s)**	**Change from Base Case (%)**	
Overburden	Glacial Till (K_h)	7.0E-07	7.0E-08	9.8	20.8	0.10	-8.8	0.16	-8.4	0.16	-8.2	**0.04**	**-15.0**	0.34	-0.5	0.18	-7.8	High
			7.0E-06	4.5	-7.0	0.12	9.3	**0.19**	**12.6**	**0.22**	**26.9**	**0.07**	**39.9**	0.35	4.0	**0.22**	**13.3**	
	Alluvium (K_h)	7.0E-06	7.0E-07	2.9	2.1	0.11	1.5	0.17	0.0	0.18	0.0	0.05	0.0	0.34	0.0	0.19	0.0	Low
			7.0E-05	2.9	2.0	0.10	-0.6	0.17	0.0	0.18	0.0	0.05	0.0	0.34	0.0	0.19	0.0	
	Fluvial (K_h)	6.0E-05	6.0E-06	3.5	3.4	0.11	0.0	**0.10**	**-38.7**	0.18	0.0	0.05	-5.9	**0.14**	**-59.4**	**0.12**	**-40.1**	High
			6.0E-04	2.7	1.2	0.11	0.0	**0.30**	**73.5**	0.18	0.0	0.05	6.4	**0.93**	**172.4**	**0.25**	**28.1**	
Bedrock	Top Bedrock (K_h)	1.0E-06	1.0E-07	3.4	10.2	**0.09**	**-14.8**	0.17	-1.3	**0.15**	**-13.2**	**0.04**	**-11.3**	0.34	-1.1	**0.17**	**-12.0**	High
			1.0E-05	4.3	-5.5	**0.16**	**51.1**	0.18	4.2	**0.28**	**56.3**	**0.06**	**20.0**	0.37	9.2	**0.30**	**54.7**	
	Shallow Bedrock (K_h)	3.0E-07	3.0E-08	3.8	9.3	**0.09**	**-15.7**	0.16	-5.4	**0.15**	**-14.0**	0.05	-9.4	0.33	-1.8	0.18	-8.1	High
			3.0E-06	10.6	-18.7	**0.14**	**30.5**	**0.19**	**10.9**	**0.25**	**42.1**	**0.07**	**39.6**	**0.39**	**13.9**	**0.26**	**35.6**	
	Upper Bedrock (K_h)	5.0E-08	5.0E-09	3.3	2.7	0.10	-5.3	0.17	-2.7	0.17	-4.2	0.05	-2.7	0.34	-1.0	0.19	-2.5	High
			5.0E-07	10.3	-12.7	0.11	7.0	0.19	8.4	**0.21**	**17.4**	**0.06**	**13.5**	0.36	6.6	0.21	6.0	
	Middle Bedrock (K_h)	1.0E-08	1.0E-09	3.0	2.0	0.10	-1.5	0.17	-1.2	0.17	-1.4	0.05	-1.0	0.34	-0.3	0.19	-0.8	Low
			1.0E-07	3.8	-0.9	0.10	-2.6	0.19	9.3	0.19	7.8	0.05	8.1	0.35	2.7	0.21	6.4	
	Lower Bedrock (K_h)	5.0E-09	5.0E-10	3.0	2.1	0.10	-0.5	0.17	-0.9	0.18	-0.8	0.05	-0.8	0.34	-0.2	0.19	-0.5	Low
			5.0E-08	3.0	0.8	0.10	-1.6	0.18	7.1	0.19	5.7	0.05	6.2	0.35	2.0	0.20	4.5	
	Bottom Bedrock (K_h)	1.0E-09	1.0E-10	2.9	2.1	0.11	-0.1	0.17	-0.2	0.18	-0.2	0.05	-0.2	0.34	-0.1	0.19	-0.1	Low
			1.0E-08	2.9	1.9	0.11	0.1	0.17	2.1	0.18	1.8	0.05	1.8	0.34	0.7	0.20	1.3	
Anisotrophy of Overburden (K_h/K_v)		5:1	1:10	2.8	-0.8	0.11	0.7	0.18	5.0	0.18	1.3	0.05	3.2	0.35	2.5	0.20	3.9	Low
			1:1	2.7	-0.1	0.11	0.6	0.18	3.9	0.18	0.9	0.05	2.1	0.35	2.0	0.20	2.9	
			10:1	3.3	3.8	0.10	-0.7	0.17	-3.2	0.18	-0.7	0.05	-0.9	0.33	-2.0	0.19	-2.6	
Anisotrophy of Bedrock (K_h/K_v)		1:1	1:10	3.2	-0.3	0.11	6.1	0.17	0.2	0.19	5.7	0.05	3.5	0.34	0.0	0.20	5.6	Low
			10:1	4.7	13.0	0.10	-7.7	0.17	-0.4	0.17	-5.6	0.05	-6.9	0.34	0.2	0.18	-7.0	
Recharge Rates		84 mm/yr in Zone 1 96 mm/yr in Zone 2 108 mm/yr in Zone 3 40 mm/yr in Zone 4	1/2 of Base Case	5.0	-9.6	**0.06**	**-42.0**	**0.13**	**-26.1**	**0.11**	**-36.4**	**0.04**	**-29.7**	0.32	-5.1	**0.17**	**-14.7**	High
			2 times Base Case	5.2	12.3	**0.17**	**63.4**	**0.25**	**46.9**	**0.28**	**59.5**	**0.08**	**52.5**	0.37	9.0	**0.24**	**25.0**	
Base Case Calibration and Baseflow Rates:				*2.9*	*2.1*	*0.11*		*0.17*		*0.18*		*0.05*		*0.34*		*0.19*		

Table 4.2-7. Predicted Range of Pre-mining Baseflow in TMF Area

Creek	Base Case (m^3/s)	Range of Baseflow (m^3/s)	
		Lower	Upper
Teigen South Tributary	0.11	0.03	0.30
Treaty North Tributary	0.05	0.02	0.14
Teigen Creek - Lower Reach	0.17	0.11	0.34
Teigen Creek – Upper Reach	0.18	0.06	0.57
Treaty Creek – Lower Reach	0.34	0.31	0.51
Treaty Creek – Upper Reach	0.19	0.12	0.46

4.2.8 Summary

Based on the conceptual model developed, a three-dimensional baseline pre-mining hydrogeological model was constructed to represent the long-term average pre-mining hydrogeological conditions within the proposed Tailing Management Facility area of the KSM Project. The baseline model was developed using all relevant information and data available in the study area, as well as the assumed data from similar projects and the literature.

The model is very well calibrated with the multiple targets including the field measured hydraulic heads and potentiometric surface contours, observed baseflows into the creeks, water depths in and along the creeks, rivers, lakes and wetlands. The calibrated hydraulic parameters are consistent with the field data. The high quality of calibration demonstrates that the conceptual model is representative of the hydrogeological system under the pre-mining conditions, and that the calibrated baseline model is reliable for predictive simulations of flow and solute transport. The model is therefore considered to be valid for use in assessment of the potential impact of the proposed Tailing Management Facility of the KSM Project on groundwater quantity and quality.

4.3 PREDICTIVE SIMULATIONS OF GROUNDWATER FLOW

4.3.1 Overview

This section describes the methodology used for predictive simulations of seepage from the proposed Tailing Management Facility (the north tailing cell only for the current EA) at the end of operation and post-closure of the KSM Project. The section also presents the key results from flow simulations to be used in assessing the potential effects of groundwater discharge on downstream water quality, and to calculate the water balance for environmental impact analysis in the TMF area. The results include:

1. The estimated seepage rates from the TMF at the end of mine operation and post-closure under the current climate conditions and the possible range of seepage rates due to the uncertainties of hydraulic conductivities of the geological materials; and
2. The estimated seepage rates from the TMF at the end of operation and post-closure and possible ranges of the prediction in extreme wet and dry climate conditions.

According to the mine design plan, the proposed Tailing Management Facility is located in the upstream of Teigen South Tributary valley and the headwater of the Treaty North Tributary valley, and the designed maximum water level of the ultimate tailing pond is 1,085 masl at the end of mine operation as well as the post-closure. The predictive flow simulations were run under steady-state condition using the calibrated baseline hydrogeological model with modifications of the boundary conditions and the tailing material properties to best represent the proposed mining conditions. The sensitivity analyses were carried out to estimate the possible ranges of seepage rates from the TMF and changes to stream baseflows based on the uncertainties associated with the hydraulic conductivities of the geological materials and the climatic conditions. Since the model inputs for the end of operation and post-closure (assuming no cover on tailing beaches) are identical, the results for the end of operation and the post-closure are the same and represent the long-term maximum effect of the TMF.

4.3.2 Approaches

4.3.2.1 Flow Boundary Conditions

Figure 4.3-1 shows the flow boundary conditions in the Base Case end of operation and post-closure flow model in the TMF area. To simulate the effect of the tailing deposit, a constant head boundary with an elevation 1,085 masl was assigned in the first layer of the model under the TMF footprint (the north cell). This represents the maximum possible water level when the tailing facility is full at the end of operation. A constant head boundary was also assigned for the North and South Seepage Collection Ponds, at an elevation of 818 masl and 885 masl, respectively.

Groundwater flow into the Teigen-Mitchell Tunnel was calculated by assigning the tunnel alignment as a drain boundary in the model. The drain elevation at the tunnel entrance near North Tailing Dam was set at 1,040 masl and at 997 masl at TMF area study boundary in the south. The drain conductance was set to a high value (100 m^2/d) to allow water to flow freely in the tunnel.

Modifications to the flow boundary conditions include removing the river cells representing the upper section of the Teigen South Tributary and the drain cells representing the wetlands and small streams under the TMF footprint. The flow boundary conditions outside the TMF footprint and the tunnel, as well as the recharge, were the same as those in the baseline pre-mining model.

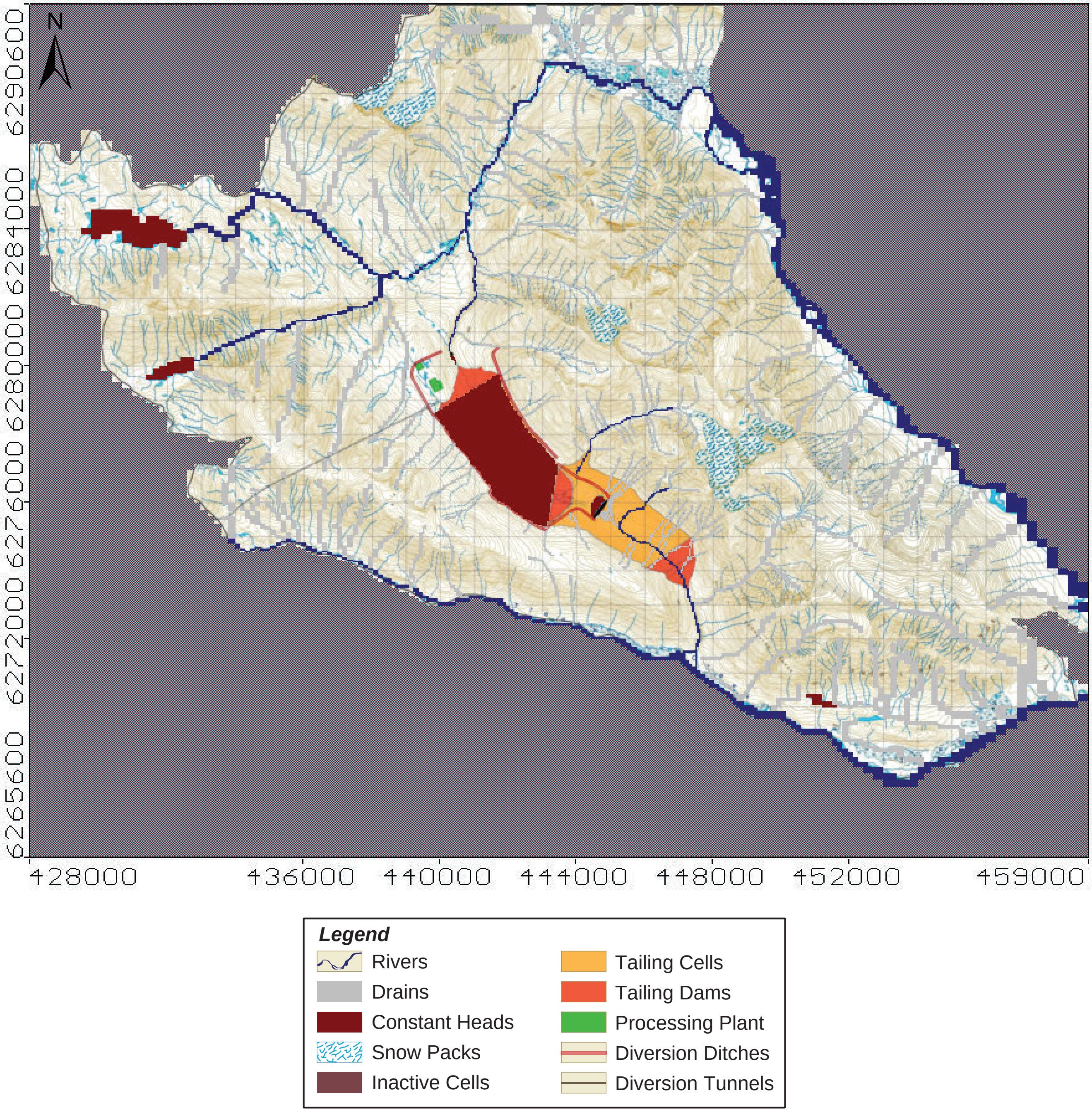
According to the prefeasibility design (Wardrop 2010), the diversion ditches in the TMF area will likely be lined and designed to divert surface runoff from the mountain slopes downstream of the TMF. The diversion ditches will have insignificant effects on groundwater flow and were not represented in the model.

4.3.2.2 Hydraulic Conductivities

Figure 4.3-2 shows the hydraulic conductivity zones in the first layer of the Base Case end of operation and post-closure model in the TMF area. Inside the TMF footprint, the top model layer is assigned with hydraulic conductivities of 5.0×10^{-8} m/s and 5.0×10^{-9} m/s respectively for rougher tailing and cleaner tailing, and with the anisotropy ratio 16:1 for the tailing materials according to the feasibility study (KCBL 2010b; Wardrop 2010). The hydraulic conductivity values used in the model were reduced by one order of magnitude of the tested hydraulic conductivities (5.0×10^{-7} m/s and 5.0×10^{-8} m/s for rougher and cleaner tailing respectively) to account for the average thickness of the tailing deposit compared to the average thickness of Layer 1. The hydraulic conductivities in deep layers under the TMF footprint and outside of the TMF footprint are the same as those in the baseline pre-mining model.

4.3.2.3 Flow Budget Zones

Figure 4.3-3 shows the flow budget zones assigned in the TMF area end of operation and post-closure flow model. Outside the TMF area, the budget zones for the upper and lower reaches of Teigen Creek and Treaty Creek, as well as for Treaty North Tributary are the same as those in baseline pre-mining model; the budget zone for Teigen South Tributary has been modified to reflect the change of the creek due to the TMF construction. All of these budget zones are assigned only in the top layer for calculation of the stream baseflows.



TMF Area End of Operation and Post-closure Flow Boundaries (Layer 1)

FIGURE 4.3-1

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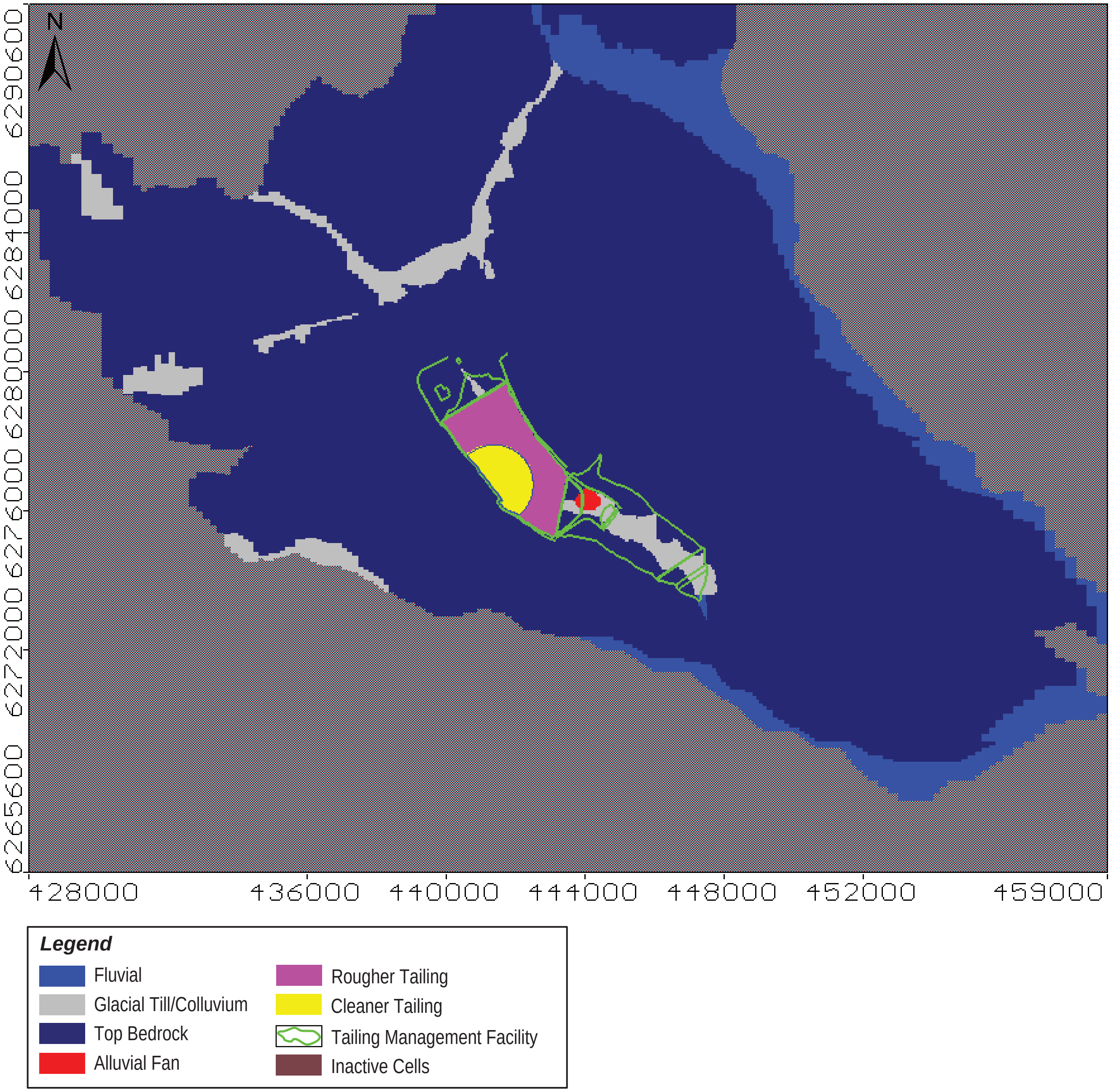

Hydraulic Conductivity Zones at TMF Area End of Operation and Post-closure (Layer 1)

FIGURE 4.3-2

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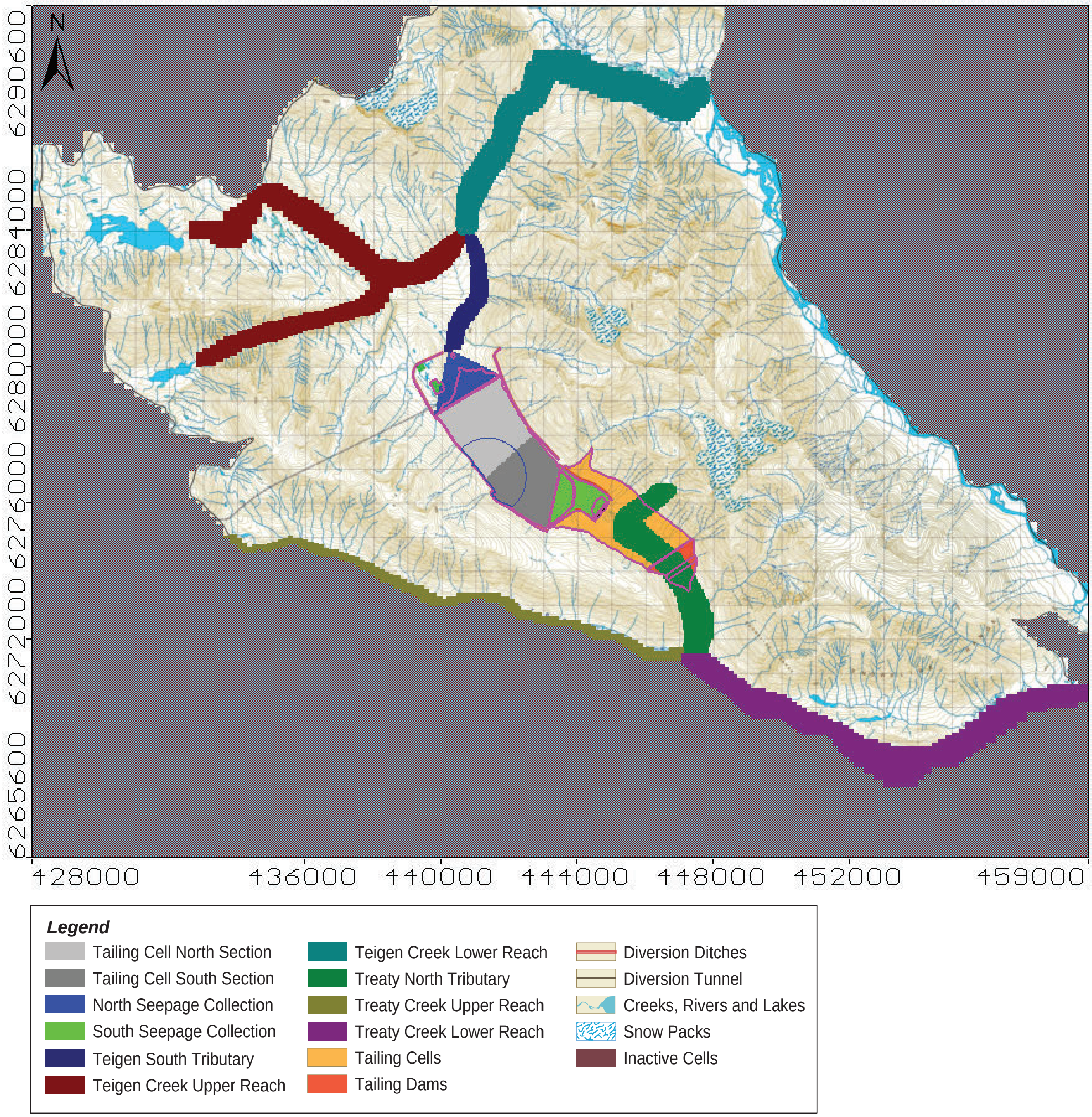

FIGURE 4.3-3

Flow Budget Zones at TMF Area
End of Operation and Post-closure (Layer 1)

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Inside the TMF area, separate budget zones have been assigned for the northern and southern parts of tailing pond (the north tailing cell), and for the Seepage Collection Systems in the north and south, to calculate the seepage to the north and the south of the TMF. The boundary line between the two budget zones inside the tailing pond follows the simulated water divide near the centre of the pond (see the following Section 4.3.3 for flow patterns). All of the budget zones inside the TMF were assigned from Layer 1 to Layer 7 based on the results of solute plume migration from the TMF (see Section 4.4.3 for solute plumes), in order to calculate the total volume of seepage from the facility including that which has mixed with regional groundwater.

In addition, a separate budget zone was assigned along the Teigen-Mitchell Tunnel (drain cells) to calculate the groundwater flowing through the tunnel.

4.3.2.4 Flow Solver Parameters

As for the baseline pre-mining model, the PCG4 flow solver in the MODFLOW-Surfact flow package version 3.0 was used to simulate steady-state variably-saturated groundwater flow at the end of operation and post-closure. The solver parameters and the convergence criteria are the same as in the baseline model:

- the maximum outer iterations: 250
- the maximum inner iterations: 150
- the head change criterion: 0.01 m
- the residual criterion: 0.01 m^3/d

The other parameters of the flow solver such as the damping factor were kept at default values similar to the baseline model. The small absolute head change and residual criteria are to ensure the accuracy in the flow solutions, and the damping factor applied is to make the solver work more easily for solving the problem in the domain with steep terrains.

4.3.3 Base Case Flow Patterns and Pathlines

Using the approach above, together with the baseline pre-mining model parameters, Base Case steady-state flow simulations were run for the end of operation and post-closure with particles assigned in the aquifer beneath the tailing pond.

Figure 4.3-4 shows the Base Case steady-state flow patterns (equipotential lines and velocity vectors) in TMF area at the end of operation and post-closure (Layer 1 for variably-saturated zone, Layer 6 for fully-saturated zone), and the inset showing the particle-tracking pathlines from the tailing pond to the North and South Seepage Collection Systems (each marker represents the flow distance in 10 years). Figure 4.3-5 shows the cross-sections of the Base Case steady-state flow patterns in the TMF area at the end of operation and post-closure.

The results show that generally speaking, the proposed TMF will not change the regional groundwater flow patterns, despite the fact that the maximum tailing pond water level is up to 200 m above the valley bottom. Similar to the pre-mining, regional groundwater receives recharge from high elevations and discharges into lower elevations and the valley bottoms. However, in comparison with the pre-mining, there will be noticeable changes in the local flow patterns in the TMF area at the end of operation and post-closure. The flow vectors show that groundwater from higher elevations and slopes

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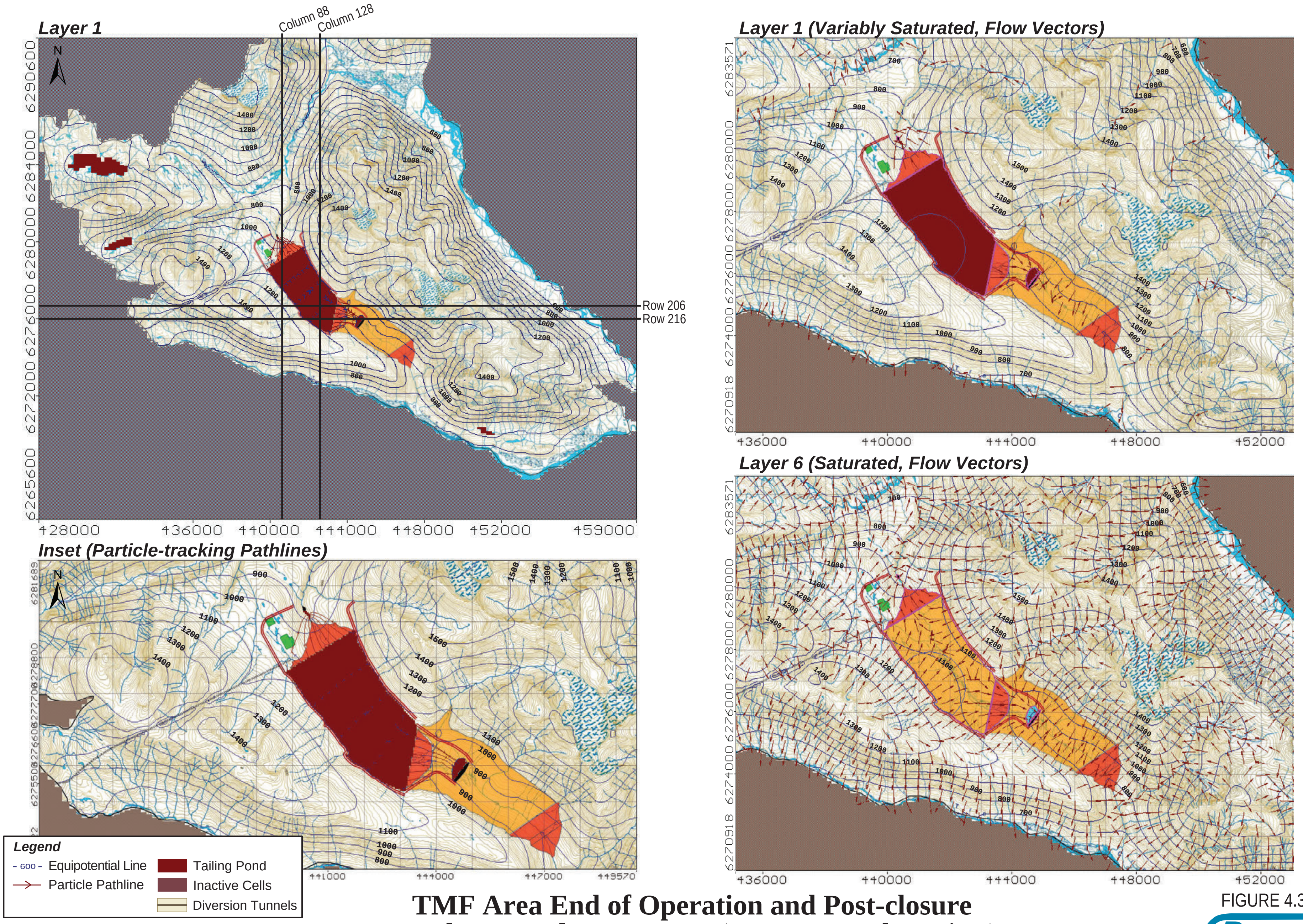

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TMF Area End of Operation and Post-closure Steady-state Flow Patterns (Base Case, Plan View)

FIGURE 4.3-4

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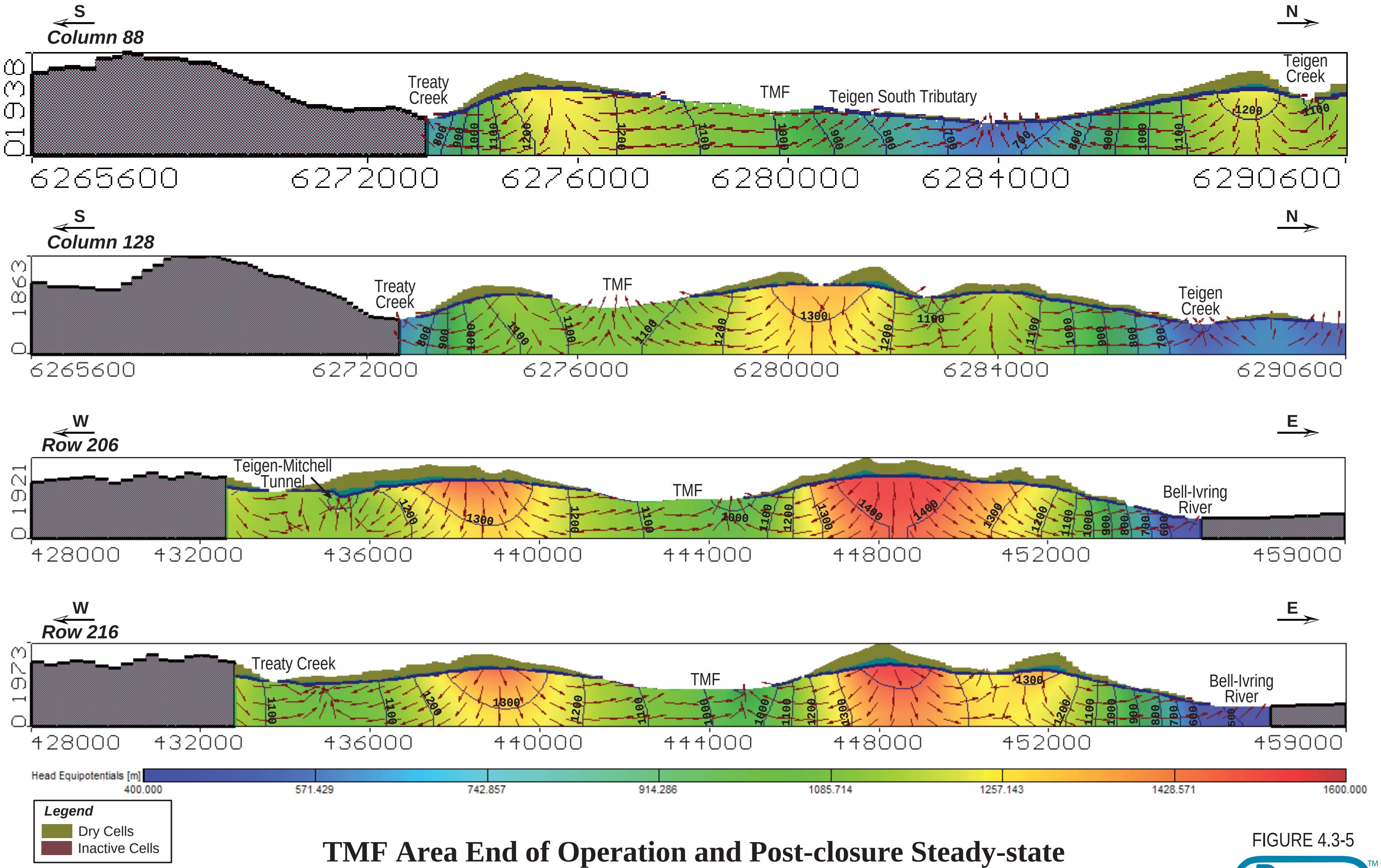

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TMF Area End of Operation and Post-closure Steady-state Flow Patterns (Base Case, Cross-sections)

FIGURE 4.3-5

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will discharge into the tailing pond (diluting the tailing pore water), percolate through the base of the TMF and then flow along the valley bottom towards the North Tailing Dam and the South Tailing Dam. A centrally located water divide perpendicular to the valley axis exists between the northern part and southern part of the tailing pond (Figure 4.3-3). As described in the previous Section 4.3.2.3, separate budget zones were assigned for the northern and southern parts of the TMF according to this water divide, so that seepage from the north and south sides of the TMF could be calculated. In addition, changes to the local groundwater flow patterns can be seen along the Teigen-Mitchell Tunnel, which shows that some groundwater will flow to the tunnel.

The particle-tracking pathlines show that the majority of the seepage out of the TMF will be captured by the Seepage Collection Systems in both the north and the south, while a small portion may flow into the tunnel near its north entrance. Seepage travel (residence) times are estimated to be from 10 to 20 years in the north seepage collection area and 20 to 30 years in the south seepage collection area for the Base Case. Travel times could be as short as 1 to 2 years in the north and 2 to 3 years if high permeable fracture networks and faults exist in the bedrock on the valley bottom. The steep valley topography and upward hydraulic gradients, artesian in many locations, limit the seepage out of the tailing facility.

4.3.4 Groundwater Flow Rates and Sensitivities

To provide the data for calculation of a site water balance and in assessment of water quantity and quality in the TMF area, groundwater flows (baseflows) to creeks, seepage out of the TMF and groundwater flow to the Teigen-Mitchell Tunnel were calculated for the Base Case end of operation and post-closure. The Base Case represents the best estimate as the same parameters for geological materials (glacial till and bedrocks) were used as in the calibrated baseline pre-mining model. Sensitivity analysis were carried out using the same boundary conditions and parameters in the Base Case, but varying the most significant input parameters identified from the baseline pre-mining modelling by the same orders of magnitude as in the baseline model sensitivities (Table 4.3-1).

Table 4.3-1. Parameters for Sensitivity Analysis of Groundwater Flows at TMF Area End of Operation/Post-closure

Parameter	Base Case	Upper Case	Lower Case	Wet Year	Dry Year
Glacial till K (m/s)	7.0×10^{-7}	x10	x0.1	Same as Base Case	Same as Base Case
Top Bedrock K (m/s)	1.0×10^{-6}	x10	x0.1		
Shallow Bedrock (m/s)	3.0×10^{-7}	x10	x0.1		
Upper Bedrock (m/s)	5.0×10^{-8}	x10	x0.1		
Net Recharge (mm/yr)	84 (< 900 masl on valley bottom) 96 (900 to 1300 masl on mid-slope) 108 (>1300 masl on uplands) 40 (Glacier and snow packs)	Same as Base Case	Same as Base Case	x2	x0.5

The predicted Base Case groundwater flows, including the seepage rates out of the north and south of the TMF and Teigen-Mitchell Tunnel inflows at the end of operation and post-closure are presented in Table 4.3-2. Table 4.3-3 provides the seepage rates for the sensitivity analysis and includes the Base Case for comparison. The predicted seepage out of the TMF doesn't include potential seepage through the tailing dams, which is expected to be very low.

Table 4.3-2. Tailing Management Facility - End of Operation/Post-closure Groundwater Flows (Base Case)

	Base Case	
End of Operation / Post-Closure	m^3/day	L/s
Groundwater Flows in TMF North		
Total Seepage from TMF to North	768	8.9
Seepage to Deeper Aquifer (North)	669	7.7
Seepage to Retention Dam (North)	99	1.2
Seepage from Deeper Layers to Retention Dam	1,120	13.0
Contact Water Base Flow to Teigen South Tributary (STE2)	708	8.2
Non-Contact Base Flow to Teigen South Tributary (STE3)	2,089	24.2
Groundwater Flows in TMF South		
Total Seepage from TMF to South	669	7.7
Seepage to Deeper Aquifer (South)	585	6.7
Seepage to Retention Dam (South)	84	1.0
Seepage from Deeper Layers to Retention Dam	1,218	14.1
Contact Water Base Flow to Treaty North Tributary (NTR1)	734	8.5
Non-Contact Base Flow to Treaty North Tributary (NTR2)	4,378	50.7
Potential Contact Water Discharging through Seeps south of SSRD	277	3.2
Potential Contact Water Discharging through Seeps north of SSRD	289	3.3
Teigen-Mitchell Tunnel Inflow[1]		
Total Inflow to Teigen-Mitchell Tunnel in TMF Study Area	3,313	38.3
Contact Water Inflow to Teigen-Mitchell Tunnel	184	2.1

[1] *For TMF catchment area only; inflows along entire tunnel approximately 82 L/s.*

Table 4.3-3. Tailing Management Facility - End of Operation/Post-closure Groundwater Flows (Sensitivities)

	Base Case	
End of Operation / Post-Closure	m^3/day	L/s
Total Seepage from TMF North		
Base Case	768	8.9
Upper Case - *Kx10*	6,798	78.7
Lower Case - *K/10*	16	0.2
Wet Year - *Recharge x2*	534	6.2
Dry Year - *Recharge x0.5*	949	11.0
Total Seepage from TMF South		
Base Case	669	7.7
Upper Case - *Kx10*	4,968	57.5
Lower Case - *K/10*	2	0.0
Wet Year - *Recharge x2*	430	5.0
Dry Year - *Recharge x0.5*	801	9.3
Teigen-Mitchell Tunnel Inflow[1]		
Base Case	3,313	38.3
Upper Case - *Kx10*	1,570	18.2
Lower Case - *K/10*	3,016	34.9
Wet Year - *Recharge x2*	6,277	72.7
Dry Year - *Recharge x0.5*	1,616	18.7

[1] *For TMF catchment area only; inflows along entire tunnel approximately 82 L/s.*

For the Base Case, it is estimated that the total seepage from the TMF to the north will be 8.9 L/s and to the south will be 7.7 L/s. The sensitivity analysis results show that there would be more seepage out of the TMF north and south when the geological materials have higher permeability (Upper Case: 78.7 L/s from the TMF north and 57.5 L/s from the TMF south). The sensitivity analysis also show that there would be less seepage out of the TMF in wet years when the regional groundwater hydraulic gradients are higher (Wet Years: 6.2 L/s from the TMF north and 5.0 L/s from the TMF south), but more seepage in dry years when the regional groundwater hydraulic gradients are lower (Dry Years: 11.0 L/s from the TMF north and 9.3 L/s from the TMF south). The results of sensitivity analysis show that the TMF seepage rates are sensitive to the hydraulic conductivities of geological materials and the recharge rates in the TMF area.

For baseflows to the creeks, it is estimated that in Base Case, there will be 8.2 L/s of contact groundwater flowing to the Teigen South Tributary downstream of the North Seepage Collection Dam (i.e., up to compliance point STE2, located at the toe of the North Seepage Collection Dam) and 24.2 L/s of non-contact groundwater (without contact groundwater) flowing to the Teigen South Tributary further downstream (at compliance point STE3, located at the outlet of the Teigen South Tributary). The results predict that there will be 8.5 L/s of contact groundwater flowing to the Treaty North Tributary downstream of the South Seepage Collection Dam (up to compliance point NTR1, located at the toe of the South Seepage Collection Dam), and 50.7 L/s of non-contact groundwater (without contact groundwater) flowing into Treaty North Tributary further downstream (at compliance point NTR2, located at the outlet of Treaty North Tributary). The locations of these compliance points are shown in Figure 5.2-1 in Chapter 5. In general, the flow budget calculation results indicate that there is no change to the baseflows in the entire Teigen South Tributary, Teigen Creek upper and lower reaches, Treaty North Tributary, and Treaty Creek upper and lower reaches.

The estimated groundwater flow to Teigen-Mitchell Tunnel in TMF study area is 38.3 L/s, of which 2.1 L/s is contact groundwater from the North Seepage Collection System. The sensitivity analysis results show that the groundwater flow to the tunnel is most sensitive to variations in the bedrock permeability and the recharge. The results predict that there will be more flow to the tunnel during wetter periods.

For the purpose of water balance calculation and the environmental effects assessment, it is recommended that the Base Case results for the TMF seepage rates, baseflows in the creeks and the Teigen-Mitchell Tunnel inflow be used. The results of the sensitivity analysis represent the potential range of the groundwater flows for the uncertainties in the permeability of the geological materials and the recharge rates in the TMF area.

4.3.5 Summary

Based on the calibrated TMF area baseline hydrogeological model, steady-state flow simulations were carried out to predict the potential change to the groundwater flow patterns and flows in the TMF area (including the seepage rates out of the TMF) at the end of operation and post-closure. The Base Case scenario was run with the flow boundary conditions assigned to represent the ultimate Tailing Management Facility and the Seepage Collection Systems at the end of operation and post-closure, and with rougher and cleaner tailing materials assigned in the TMF. The sensitivities were run with the same flow boundary conditions and the permeability of the tailing materials as in Base Case, but with variation of the most sensitive input parameters identified in the calibrated baseline flow model.

The results indicate that the proposed TMF and the Teigen-Mitchell Tunnel will affect the local groundwater flow patterns but not the regional groundwater flow. Regional groundwater receives recharge from high elevations and discharges to low elevations and valley basis. Groundwater in the local TMF valley discharges from the slopes into the TMF, and then flows along the valley bottom toward the North Tailing Dam and the South Tailing Dam. A local water divide exists in between the northern part and the southern part of the TMF.

Using the budget zones assigned, the total seepage out of the TMF is estimated to be 8.9 L/s in the north and 7.7 L/s in the south in the Base Case. The sensitivity analysis shows that the seepage will increase when the geological materials are more permeable or when the recharge to the regional aquifer is lower in dry years. However, as shown by the particle-tracking pathlines, most of the seepage out of the TMF will be captured by the Seepage Collection Systems in both the north and the south, while a small portion may flow into the Teigen-Mitchell Tunnel at the north entrance. The travel (residence) time of the seepage is estimated to be 10 to 20 years in the north seepage collection area and 20 to 30 years in the south seepage collection area but could be much shorter if high permeability fracture networks and faults exist in the valley bottom. The steep topography and vertical hydraulic gradients limit the seepage out of the TMF.

In addition to the predicted seepage rates, the flow budget calculation results indicate that the TMF won't change the end of mining and post closure baseflows compared to the baseline in the entire Teigen South Tributary, Teigen Creek upper and lower reaches, Treaty North Tributary, and Treaty Creek upper and lower reaches. The total groundwater flow to the Teigen-Mitchell Tunnel in TMF study area is estimated to be 38.3 L/s in Base Case.

In summary, it is recommended that the Base Case TMF seepage rates be applied in water balance calculations and in the environmental effects assessment for water quantity and quality. The results from the sensitivity analyses represent the possible ranges associated with the uncertainty in the geological material properties and different climate conditions.

4.4 PREDICTIVE SIMULATIONS OF SOLUTE TRANSPORT

4.4.1 Overview

This section describes the methodology for predictive simulations for solute transport in the TMF area at post-closure and presents the key results from these simulations. The objective is to predict the solute plumes and concentrations in the seepage from the TMF at post-closure for the purpose of assessing the water quality downstream of the TMF area.

The solute transport simulations were run with the flow solutions for the Base Case TMF area post-closure modelling and sensitivities, using the MT3DMS version 5.2 transport engine within the Visual MODFLOW package (Zheng and Wang 1999). The solute source zone with a conservative constant unit concentration was assigned within the ultimate TMF footprint, and the output time for post-closure solute transport model is 100 years. The predicted concentrations represent values relative to the source zone unit concentration, and should be interpreted as the conservative long-term "worst" effects that the Tailing Management Facility could cause on water quality, because no retardation (e.g., attenuation by biogeochemical reactions within the aquifer) and surface water dilution are considered. The parameters used for Base Case solute transport and sensitivities are the same as those in the previous flow simulations at the end of operation and post-closure in the TMF area.

4.4.2 Approaches

4.4.2.1 Flow Boundary Conditions

The boundary conditions for steady-state flow solutions in the Base Case solute transport model in the TMF area are the same as those used in the Base Case end of operation and post-closure flow model (see Figure 4.3-1). The constant heads 1,085 masl, 818 masl and 885 masl are assigned in the ultimate tailing pond, the North Seepage Collection Pond and the South Seepage Collection Pond, respectively. The drain boundary assigned for the Teigen-Mitchell Tunnel has drain elevations from 1,040 masl (at the tunnel entrance near the North Tailing Dam) to 997 masl (at TMF area study boundary in the south) and drain conductance of 100 m^2/d. The elevations are taken from the prefeasibility study.

4.4.2.2 Transport Boundary Conditions

A non-reactive solute source zone is assigned in the ultimate tailing pond with a specified unit constant concentration of 1.0 mg/L (in the same area with the specified constant head). Zero mass flux boundaries are specified at all the no-flow boundaries in the model domain. The background concentration is specified as zero in the hydrogeological system including all surface water bodies.

4.4.2.3 Aquifer Properties

The hydraulic properties used for Base Case solute transport modelling in the TMF area are exactly the same as those in the previous end of operation and post-closure Base Case flow modelling, including the hydraulic conductivities for the rougher and cleaner tailing.

4.4.2.4 Transport Solver Parameters

The implicit Generalized Conjugate Gradient (GCG) solver with the Upstream Weighting Finite Difference solution method in the MT3DMS package was used to solve the solute transport in groundwater (Zheng and Wang 1999). The parameters for the transport solver include:

- maximum number of outer iterations: 1
- maximum number of inner iterations: 50
- relative convergence criterion: 0.001 mg/L
- initial timestep size: zero
- maximum timestep size: 90 days
- timestep multiplier: 1.1

Both advection and dispersion were simulated for solute transport using the effective porosity, but the complex biogeochemical processes such as adsorption/absorption to the geological materials or biodegradation were not simulated (so the results should be considered as conservative). The longitudinal dispersivity was set at 10m, which is considered to be representative for the geological materials on site and appropriate for simulation of solute transport on a kilometre-scale in bedrock (Li 1995; Shapiro 2001; Schulze-Makuch 2005; Zhou et al. 2007; Niemann and Rovey 2009). The horizontal and vertical transverse dispersivities in the model are 1 m and 0.1 m, respectively.

The transport equations were solved with the steady-state flow solutions from the Visual MODFLOW-Surfact. The strict transport convergence criterion 0.001 mg/L and small maximum timestep of 90 days to ensure the solutions are precise. The calculated Péclet number and Courant number in the dominant flow direction are small and meet the requirements for numerical solute transport simulations. Other parameters used for the transport modelling are the software defaults (Schlumberger 2008). The final output time for the solute transport simulation is 100 years after the mine closure.

4.4.3 Solute Plumes and Sensitivities

Plan views of the solute plumes migrating from the TMF in different layers for the Base Case post-closure model are shown in Figure 4.4-1. Figure 4.4-2 shows cross-sections (Columns 88 and 128, Rows 206 and 216) of Base Case solute plumes migrating from the TMF. As described earlier, the plumes represent the predicted long-term “worst case”, because the prediction does not include any retardation and dilution. The predicted concentrations are not absolute values, but relative concentrations to the specified unit concentration of 1.0 mg/L in the source zone. The lowest concentration plotted at the plume fronts is 0.01 mg/L, representing 1% of the source concentration. In other words, if the concentration of sulphide is 1,500 mg/L at the source zone, then the concentration at the front of the plume will be 15 mg/L.

Figure 4.4-1 shows that horizontally, the solute plume migration to the east and west of the TMF is contained by the steep slopes and hydraulic gradients, due to the fact that the TMF is located on the valley bottom and predominantly in a groundwater discharge zone. The solute plumes will migrate to the north and south of the TMF along the valley bottom. Similar to the results of particle-tracking pathlines, most of the solute plumes will be captured in the Seepage Collection Systems to the north and south of the TMF. A small portion of the solute plumes is likely to migrate beyond the seepage collection areas but at concentrations around 1% of the source zone concentration.

Both the plan view (Figure 4.4-1) and cross-sections (Figure 4.4-2) show that vertical migration of the solute plume from the TMF is limited to the shallow part of the aquifer largely as a result of the hydraulic containment in the valley from the vertically upward hydraulic gradients. The results demonstrate that seepage from the TMF will have limited effects on water quality in the downstream creeks, and is unlikely to be a concern for the water quality in the Teigen South Tributary and the Treaty North Tributary.

The results of sensitivity analysis for solute transport is shown in Figures 4.4-3 (for Upper Case), 4.4-4 (for Wet Years) and 4.4-5 (for Dry Years). The figures show similar behaviour as in the Base Case: the plume migration is contained by the steep topography and hydraulic gradients both horizontally and vertically, the solute plume from the TMF migrates to the north and the south and will be largely captured by the Seepage Collection Systems. In the extreme cases such as the upper case (with high permeability glacial till and bedrock) and dry years (less recharge resulting in lower water levels in regional aquifer), the seepage out of the TMF will increase and the solute plumes may migrate slightly further along the valleys to the downstream creeks (mainly Teigen South Tributary). However, the groundwater concentrations where they intersect the creek are low (less than 0.1 mg/L or 10% of source zone concentration).

For the water quality assessment in the EA, it is recommended that the results of Base Case solute transport should be used to calculate the surface water and the groundwater quality by incorporating the background concentrations of the chemicals, together with the biogeochemical processes and surface water dilution. The water quality assessment of the TMF area is provided in Rescan’s Water Quality Prediction Model Annex 10-1.

4.4.4 Summary

Using the steady-state flow solutions for the TMF area, solute transport simulations were carried out by assigning a non-reactive constant concentration source zone in the ultimate tailing pond at post-closure, to predict the solute plumes from the TMF. The concentrations and downstream water receptors can be used to assess the potential long-term “worst” effect of the TMF. The predicted concentrations in groundwater represent the values relative to the specified unit concentration in the source zone, and are conservative because the attenuation from the biogeochemical processes and the surface water dilution are not included.

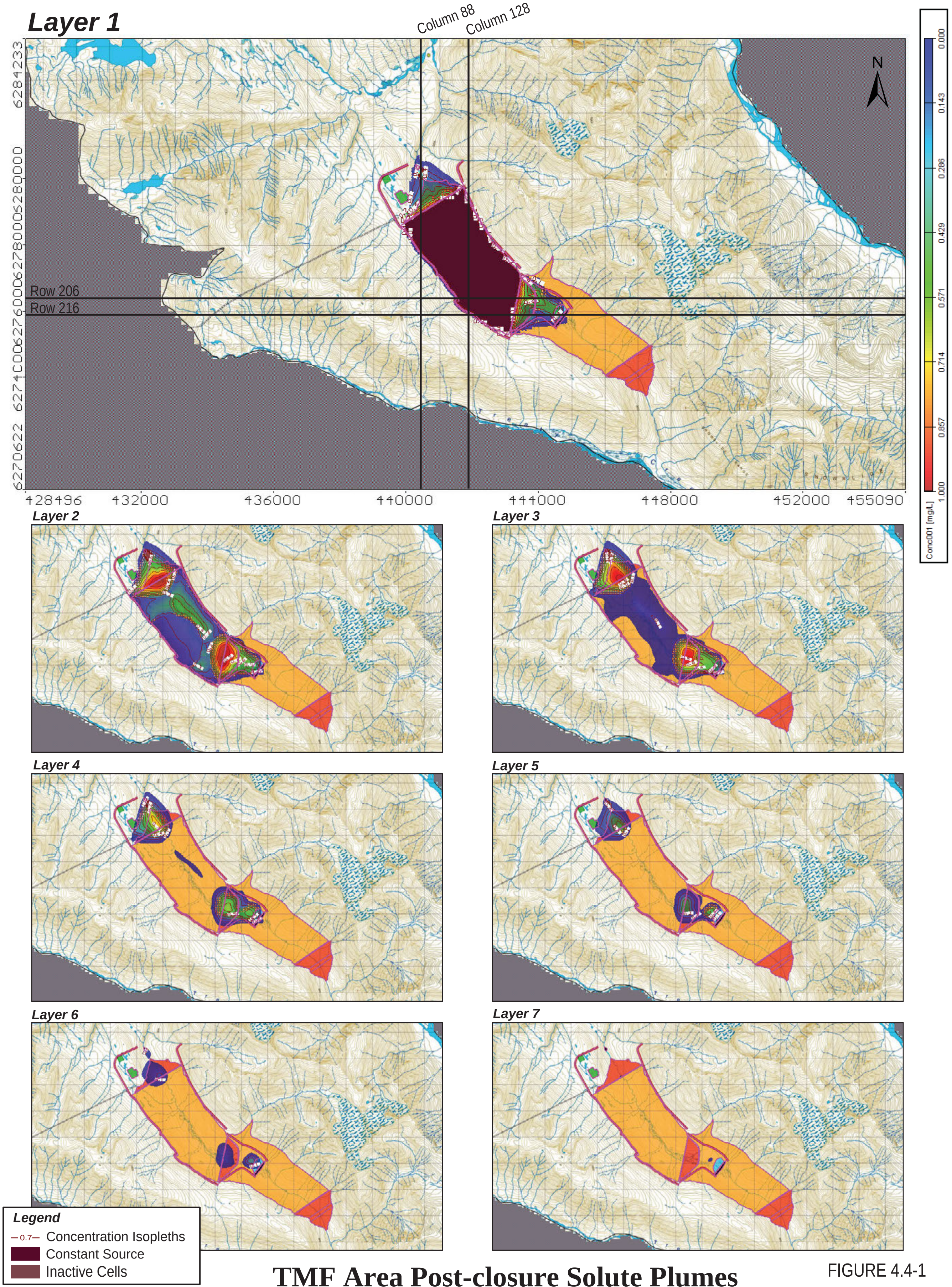

FIGURE 4.4-1

TMF Area Post-closure Solute Plumes (Base Case, Plan View, 100 Years)

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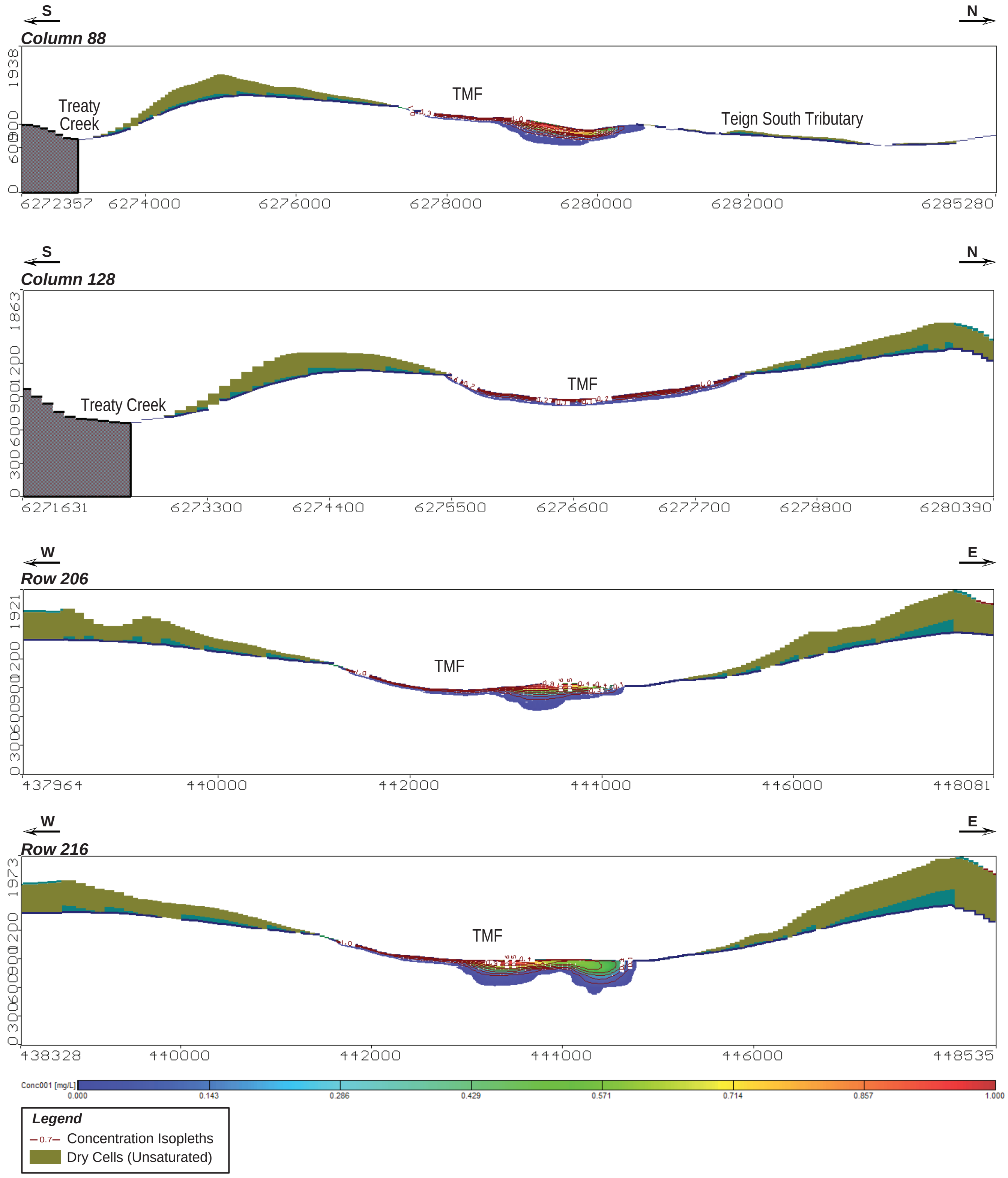

TMF Area Post-closure Solute Plumes (Base Case, Cross-sections, 100 Years)

FIGURE 4.4-2

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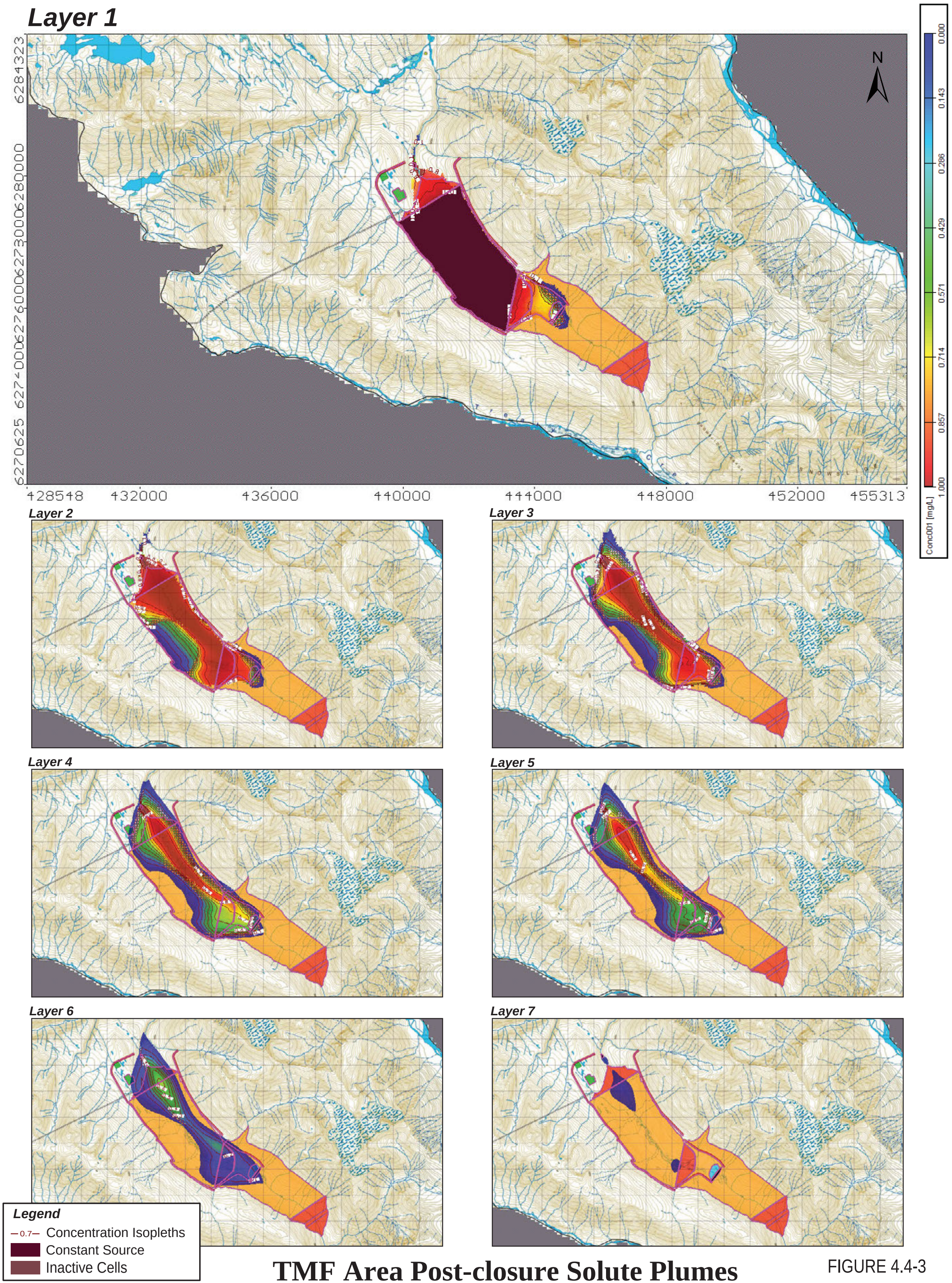

FIGURE 4.4-3

TMF Area Post-closure Solute Plumes
(Upper Case, Plan View, 100 Years)

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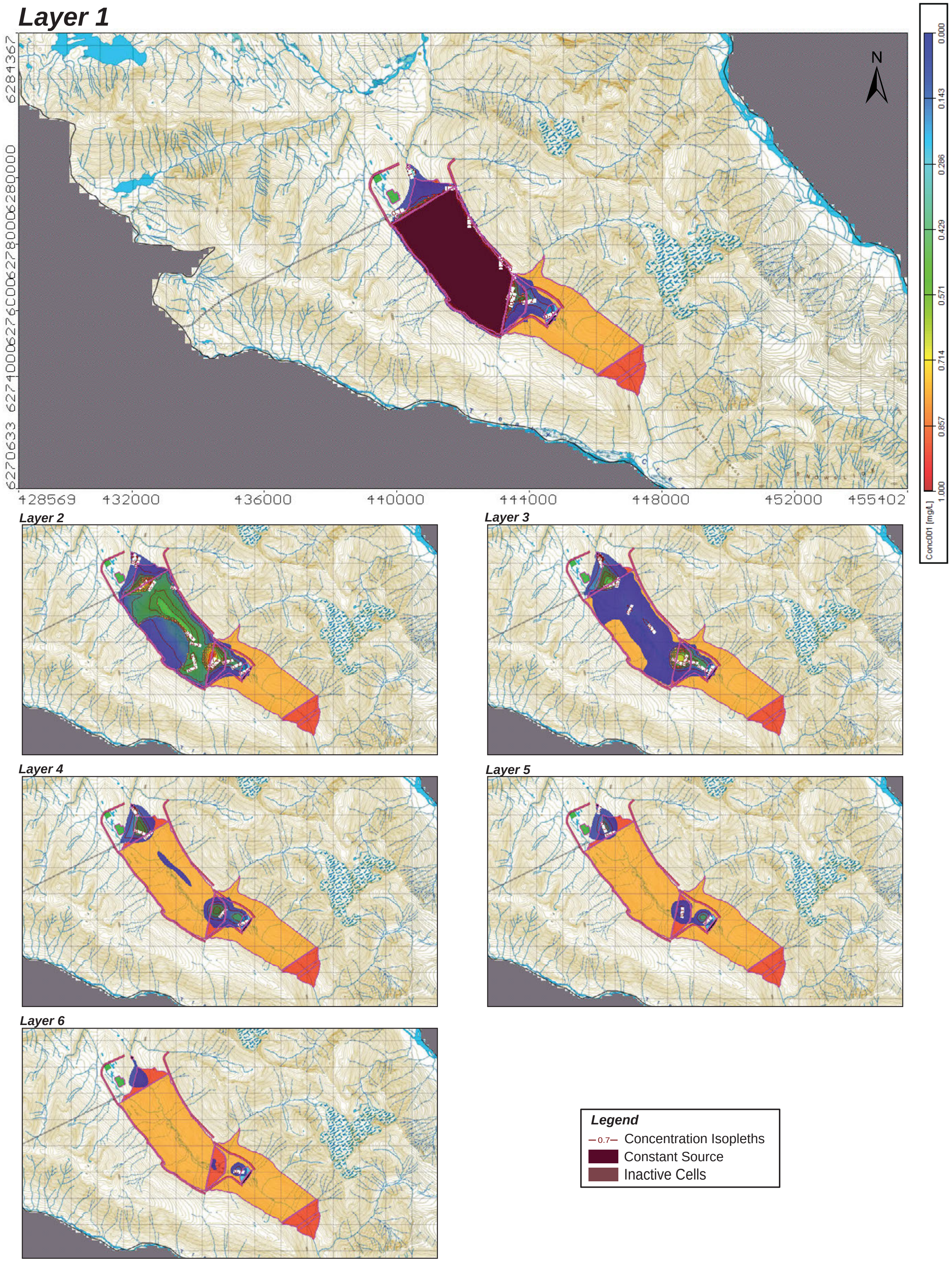

TMF Area Post-closure Solute Plumes
(Wet Year, Plan View, 100 Years)

FIGURE 4.4-4

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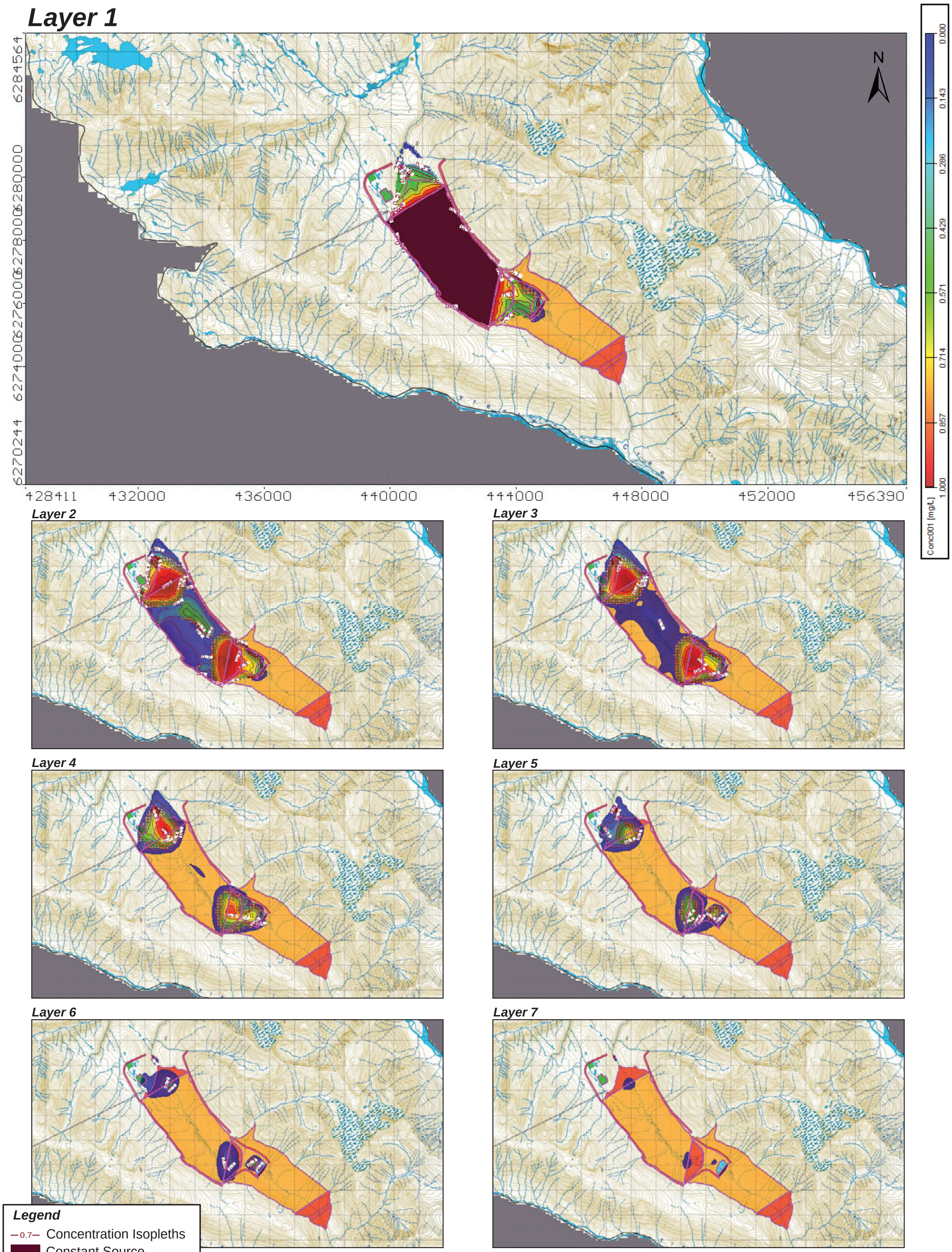

TMF Area Post-closure Solute Plumes (Dry Year, Plan View, 100 Years)

FIGURE 4.4-5

The Base Case solute transport results show that the solute plume migration from the TMF is largely contained by the steep slopes and hydraulic gradients (both horizontally and vertically). The solute plumes will migrate dominantly to the north and south of the TMF along the valley bottom, but most of the solute plumes will be captured by the Seepage Collection Systems to the north and south of the TMF. A small amount of the plumes may migrate beyond the Seepage Collection Dams, but at concentrations lower than 1% of the source zone concentration. The results demonstrate that the seepage from the TMF will have a limited effect on water quality in the downstream creeks, and it is unlikely to be a concern for water quality in the Teigen South Tributary and the Treaty North Tributary.

The results of the solute transport sensitivity analysis show similar result to the Base Case. In the extreme cases such as the Upper Case (with high permeable glacial till and bedrocks) and Dry Years (less recharge resulting in lower water levels in regional aquifer), resulting in more seepage out of the TMF), the solute plumes may migrate further along the valleys to the downstream creeks (mainly into Teigen South Tributary). However, the concentrations are estimated to be low (less than 10% of the source concentration), particularly if the retardation factors within the aquifer are considered.

4.5 CONCLUSIONS

Groundwater Flow at Pre-mining

A three dimensional baseline model was constructed to characterize the long-term average behaviour of the groundwater system and surface water – groundwater interactions at the proposed KSM Project Tailing Management Facility area using information and available data as of July 2010. The baseline model was well calibrated to observed groundwater levels in the monitoring wells and measured baseflows in the creeks. The good calibration indicates that the baseline model is valid and representative of the physical hydrogeological system in the TMF area, and is considered reliable for prediction.

The baseline model results show that the simulated steady-state head equipotential contours at pre-mining conditions generally mimic the surface topography. Deep groundwater levels predominate at high elevations and shallow groundwater levels at lower elevations. The results show that regional groundwater receives recharge in the high mountainous areas and discharges to surface water bodies on the valley bottoms and slopes. The proposed Tailing Management Facility (TMF) is located in a groundwater discharge zone. The simulated pre-mining baseflow rates vary between 0.03 m^3/s and 0.30 m^3/s in the Teigen South Tributary, and between 0.02 m^3/s and 0.14 m^3/s in the Treaty North Tributary. Groundwater discharge into the proposed Tailing Management Facility footprint area is estimated to be 3,551.8 m^3/d (41.1 L/s).

Impact of TMF on Flow Patterns and Water Quantity

The Base Case flow results show that the proposed TMF together with the Teigen-Mitchell Tunnel will affect the local flow patterns but not the regional groundwater flow pattern (i.e., from the mountain tops and slopes to the valley bottom). Groundwater is predicted to discharge from the valley slopes into the TMF deposit, percolate through the deposit and flow along the valley bottom beneath the deposit toward the north and South Tailing Dams. The total seepage from the TMF is estimated to be 8.9 L/s out of the north part of the deposit and 7.7 L/s out of the south part of the deposit. Most of the seepage from the TMF will be captured by the Seepage Collection Systems located in the north and the south of the tailing dams, while a small amount may flow to the tunnel. Seepage travel (residence) time is estimated to be 10 to 20 years in the north seepage collection area and 20 to 30 years in the south seepage collection area. The travel time could be much shorter if high permeable fracture networks and faults exist in the valley bottom. The steep valley topography and vertically upward hydraulic gradients observed in the valley bottom and slopes limits the seepage out of the TMF.

The results show that the proposed TMF won't change the baseflows to the entire Teigen South Tributary, Teigen Creek upper and lower reaches, Treaty North Tributary, and Treaty Creek upper and lower reaches, in comparison with the baseline. The total groundwater flow to the Teigen-Mitchell Tunnel in TMF study area is estimated to be 38.3 L/s in Base Case.

Impact of TMF on Water Quality

The Base Case solute transport results show that the solute plume migration from the TMF is limited by the steep slopes and hydraulic gradients (both horizontally and vertically). The solute plumes that will develop in time will migrate dominantly to the north and south of the TMF along the valley bottom, however, most of the solute plume will report to the Seepage Collection System that are located downstream of both the north and south tailing dams. A small amount of the plumes may migrate beyond the Seepage Collection Dams, but at concentrations of less than 1% of the source zone concentration. The results of solute transport sensitivity analysis show similar pattern of solute migration as in the Base Case. In the extreme case (high permeable geological materials and dry years), the solute plume may migrate slightly further along the valleys but at low concentrations (less than 10% of the source zone concentration). The results demonstrate that the seepage from the TMF will have limited effect on the water quality in the downstream creeks, and is unlikely to be a concern to the water quality in the Teigen South Tributary and the Treaty North Tributary.

5. Groundwater Quality Monitoring

From the predictive flow and solute transport modelling results presented in Chapter 3 (for KSM Project mining area) and Chapter 4 (for KSM Project tailing management area), groundwater quality predictions for the purpose of monitoring the post-closure groundwater quality at downstream of the proposed mining area and TMF area are presented below.

5.1 MINING AREA

Figure 5.1-1 shows groundwater observation well locations that have been selected to illustrate solute concentrations with time and potential breakthrough curves for the purpose of monitoring the groundwater quality at downstream of the mining area at post-closure. According to the predictive flow and solute transport results in the mining area, the proposed Sulphurets Rock Storage Facility and the Water Storage Facility are likely the major components to affect the water quality downgradient of the mining area. Therefore, the groundwater observation locations are selected along the Sulphurets and Mitchell Creeks, including at proposed environmental compliance locations (SC2 at downstream of the Sulphurets/Mitchell confluence, and SC3 at the Sulphurets Creek outlet at Unuk River), the existing groundwater monitoring well (RES-MW-11), and the surface water hydrometric stations (SC1, SC2 and SC3). The observation locations represent monitoring wells be screened at depths of 10m (screen mid-point) below ground surface to sample groundwater that is in an active discharge zone close to the creeks.

Predicted concentration breakthrough curves are shown at the observation locations and depth in 100 years (Figures 5.1-2) and 200 years (Figure 5.1-3). The upper plot in the Figures is for observation locations along the Mitchell Creek (OB-M1 and OB-M2, along with RES-MW-11 at the confluence), and the lower plot is for observation locations along the Sulphurets Creek (SC1 and OB-S, along with RES-MW-11 at the confluence). The predictions assume that the solute sources in the proposed Water Storage Facility, the Rock Storage Facilities, as well as the Pit Lakes are continuous and the source concentrations are constant (1.0 mg/L) and that the background concentration at the observation locations is zero.

The predicions suggest that the solute concentrations and the likelihood of detection at the observation locations downgradient of the Sulphurets Rock Storage Facility (SC1, OB-S, RES-MW-11) will be higher than the locations under the Water Storage Facility in Mitchell valley (OB-M1, OB-M2); less than 2% of source concentration for OB-M1 compared to about 46% for SC1/1. The solute concentration at these observation locations is predicted to peak and stabilize approximately 100 years after mine closure (or could be as short as 10 years where flow to the observation wells is via higher conductivity fracture or fault zones). The results also show that the solute concentrations observation locations located further downstream in the Sulphurets Creek at the proposed compliance points (SC2 and SC3) will be zero and therefore groundwater monitoring at these locations is believed to be unnecessary.

5.2 TMF AREA

Figure 5.2-1 shows groundwater observation well locations that have been selected to illustrate solute concentrations with time and potential breakthrough curves for the purpose of monitoring the groundwater quality at downstream of the TMF area at post-closure. The observation locations are located along the creeks downgradient of the proposed Seepage Collection Dams in the north and south, including at the proposed environmental compliance points (STE2, STE3 and TEC2) in the north and the compliance points (NTR1, NTR1A, NTR2 and TRC2) in the south, as well as the new location

OB1 in between STE2 and STE3. The observation locations are assumed to represent monitoring wells screened at a depth of approximately 10 m (screen mid-point) below ground surface to sample groundwater that is in an active discharge zone close to the creeks.

Figures 5.2-2 and 5.2-3 show the predicted concentration breakthrough curves at the observation locations in 100 years and 200 years respectively (the upper plot for the wells in the north, the lower plot for the wells in the south), with assumption that the solute source in the proposed TMF is continuous and the source concentration is constant (1.0 mg/L) and the background concentration is zero at the observation locations.

The results of breakthrough curves show that the solute from the TMF is likely to be detected only at observation location STE2, located right under the toe of the North Seepage Collection Dam, where the solute concentration will reach about 2% of the source concentration in approximately 50 years after the mine is closed. The results are consistent with the conclusion in Chapter 4 that the proposed TMF will not cause a significant effect to the water quality in the downstream surface water receptors.

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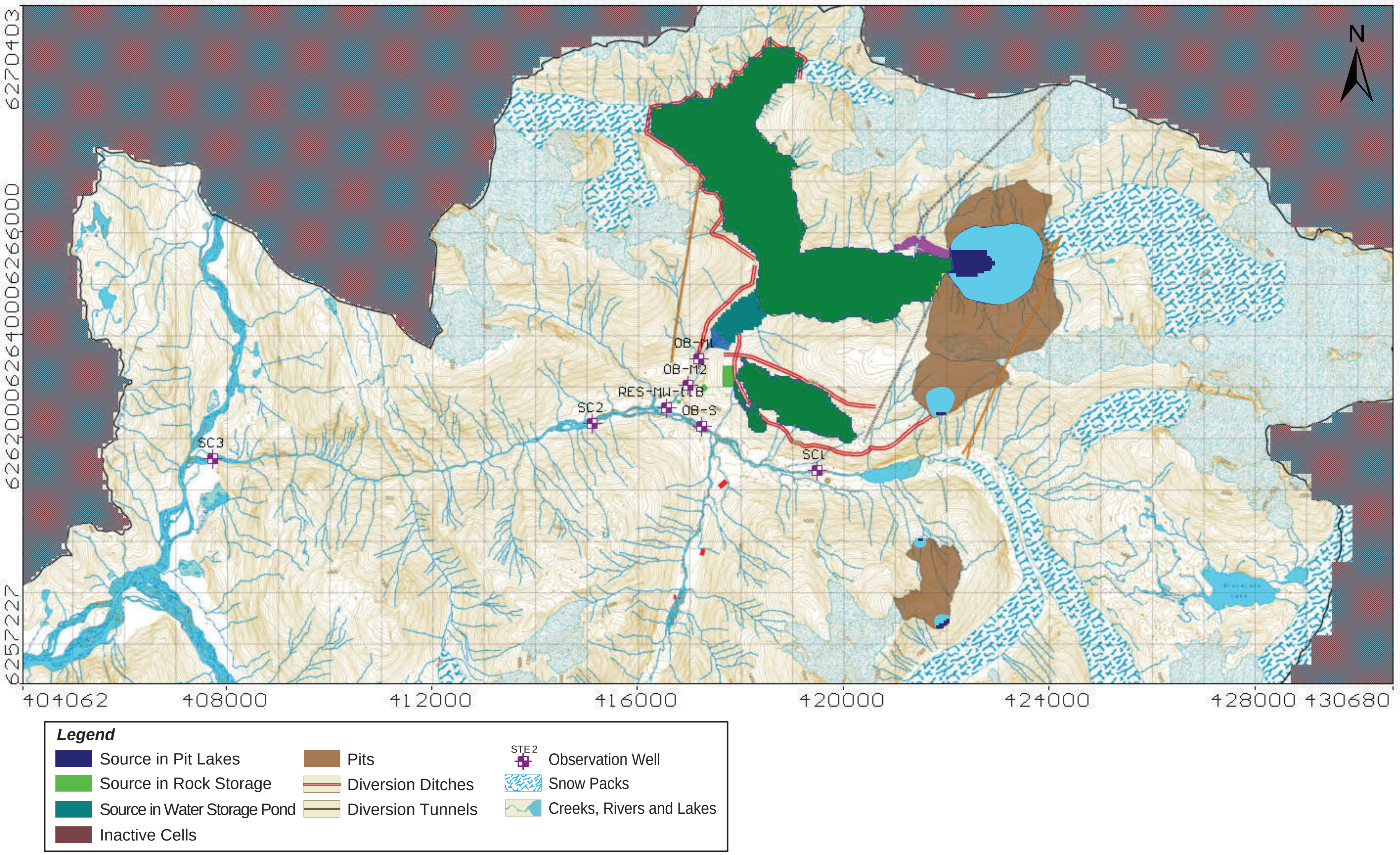

FIGURE 5.1-1

Observation Well Locations for Monitoring Water Quality at Mining Area Post-closure

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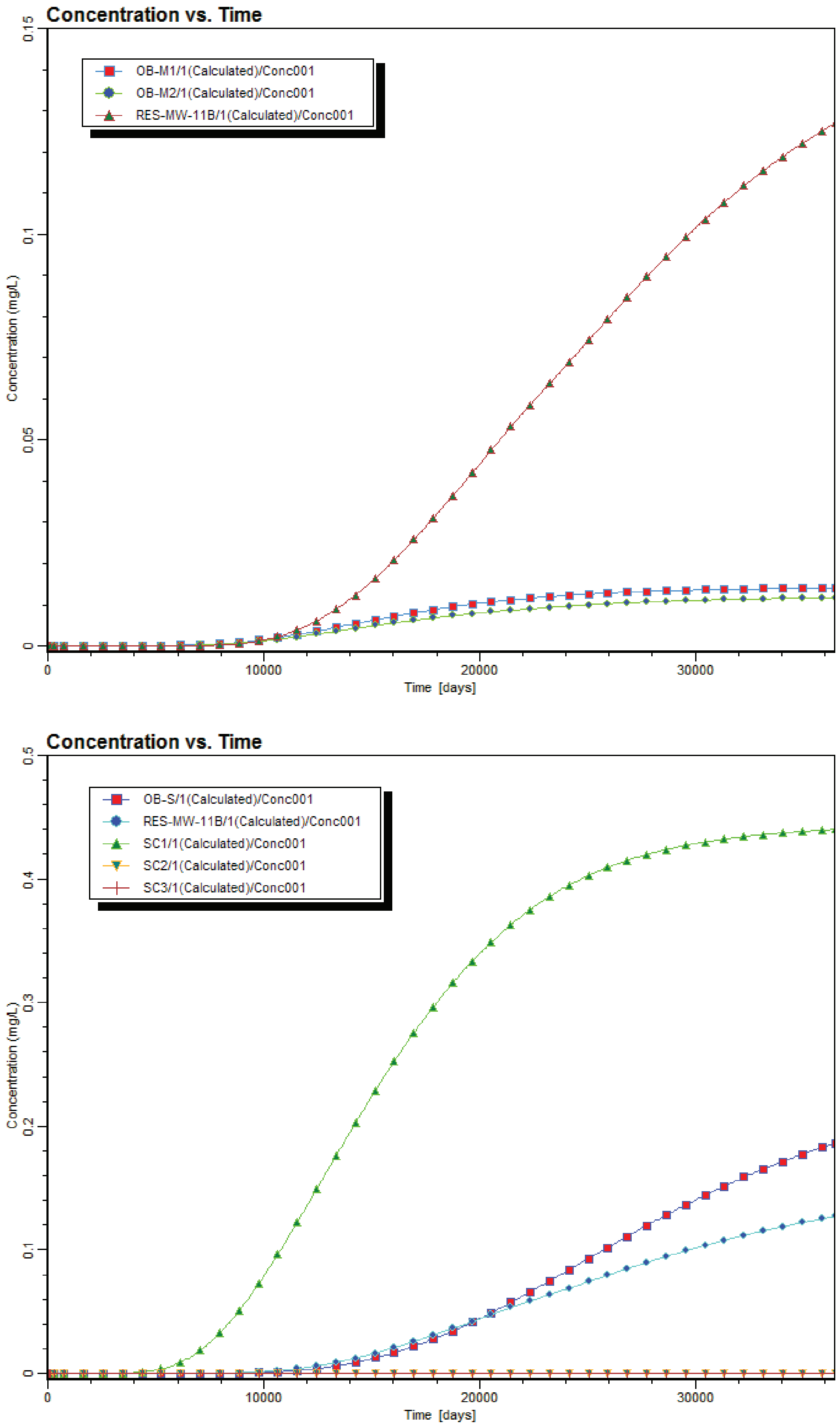

FIGURE 5.1-2

Mining Area Post-closure
Monitoring Well Concentrations
(Base Case, 100 Years)

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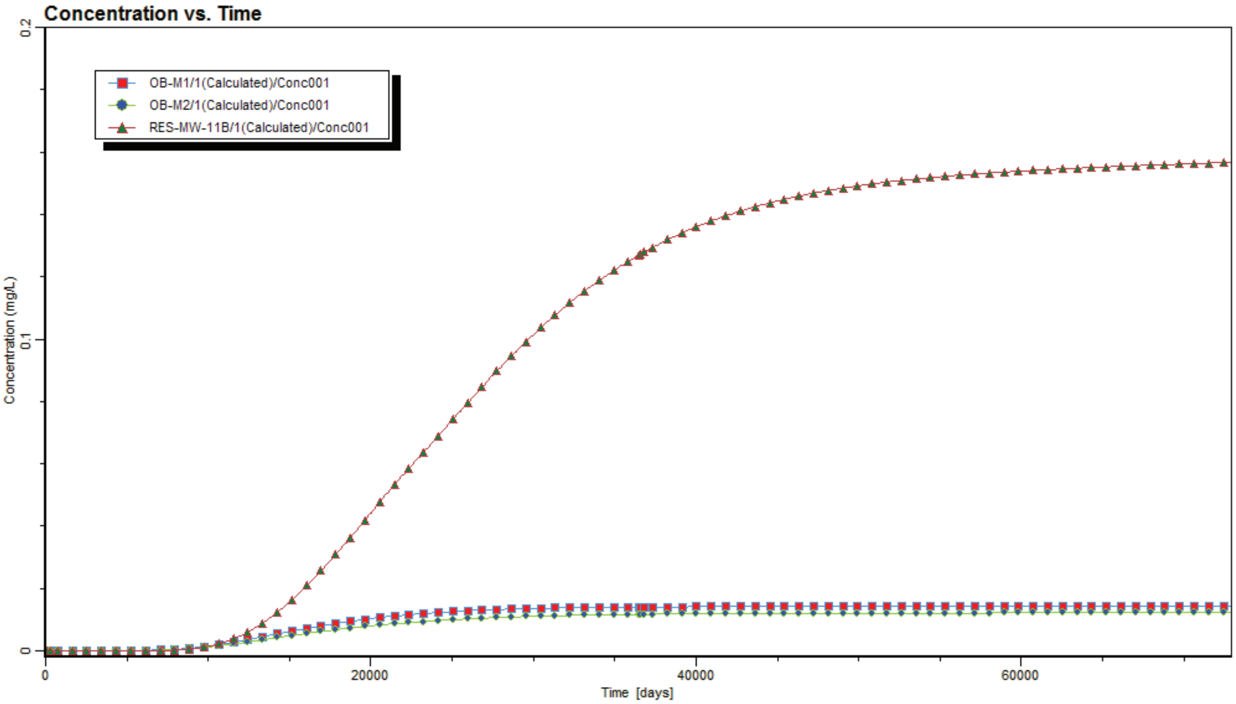

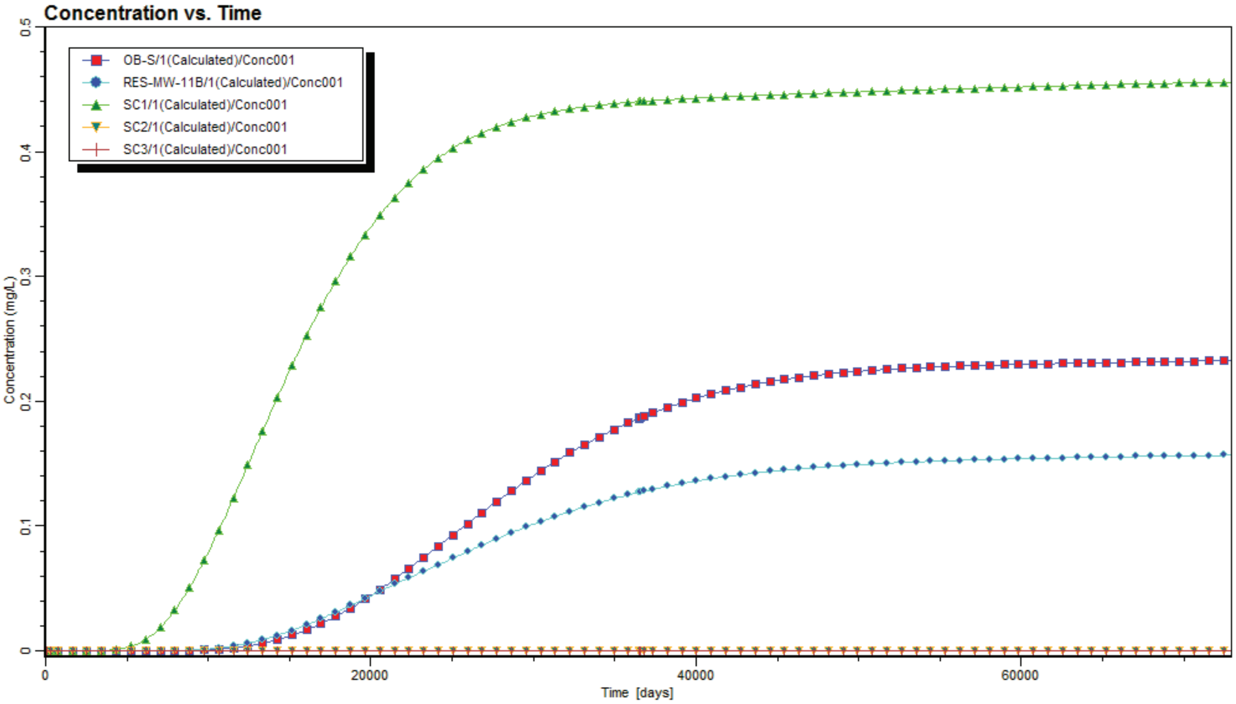

Mining Area Post-closure Monitoring Well Concentrations (Base Case, 200 Years)

FIGURE 5.1-3

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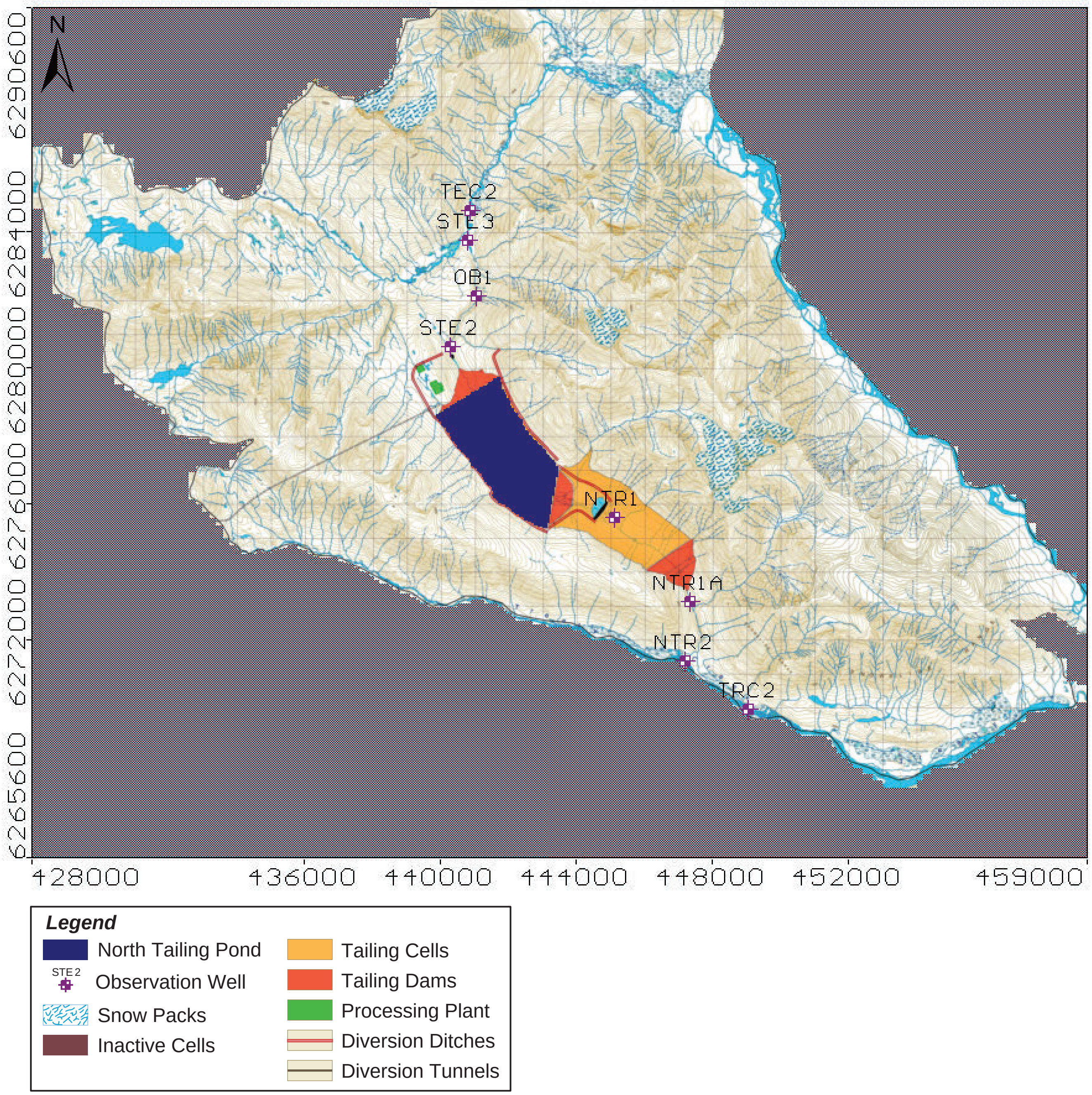

Observation Well Locations for Monitoring Water Quality at TMF Area Post-closure

FIGURE 5.2-1

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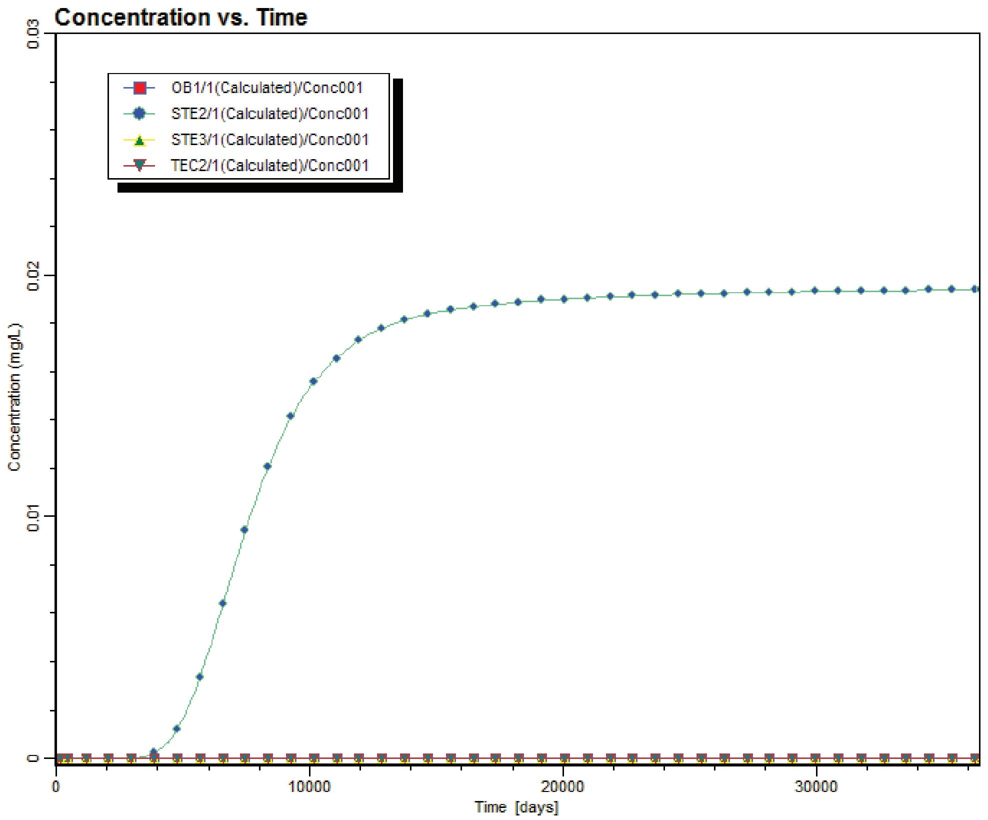

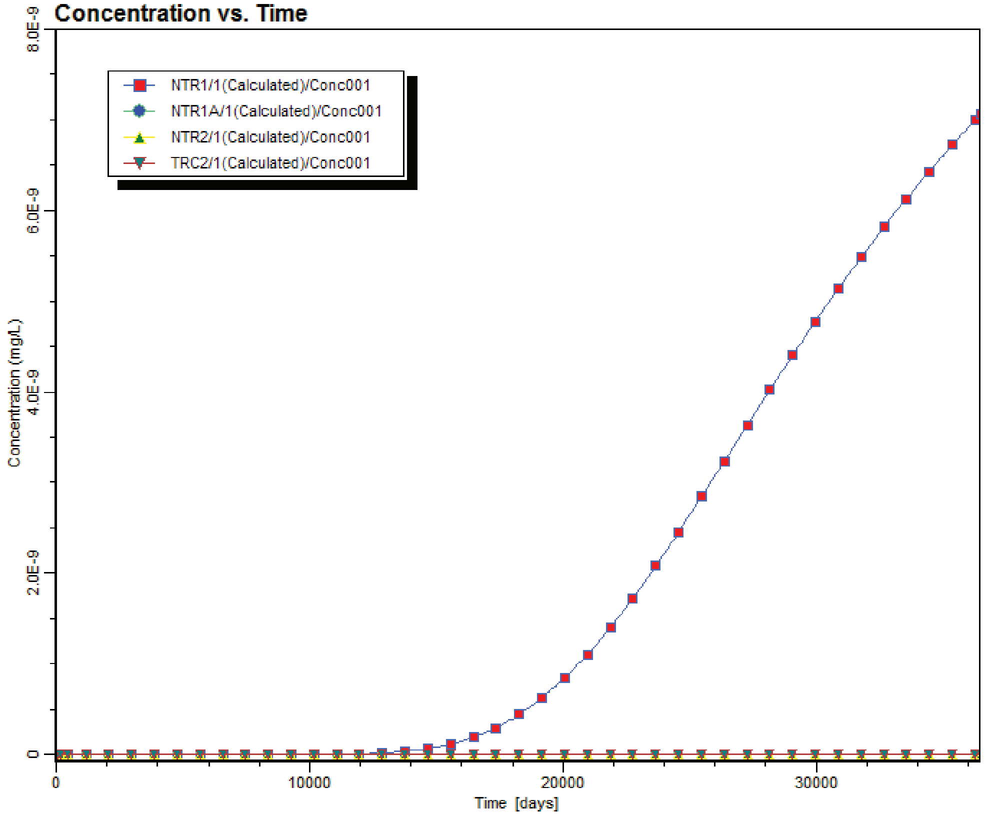

TMF Area Post-closure Monitoring Well Concentrations (Base Case, 100 Years)

FIGURE 5.2-2

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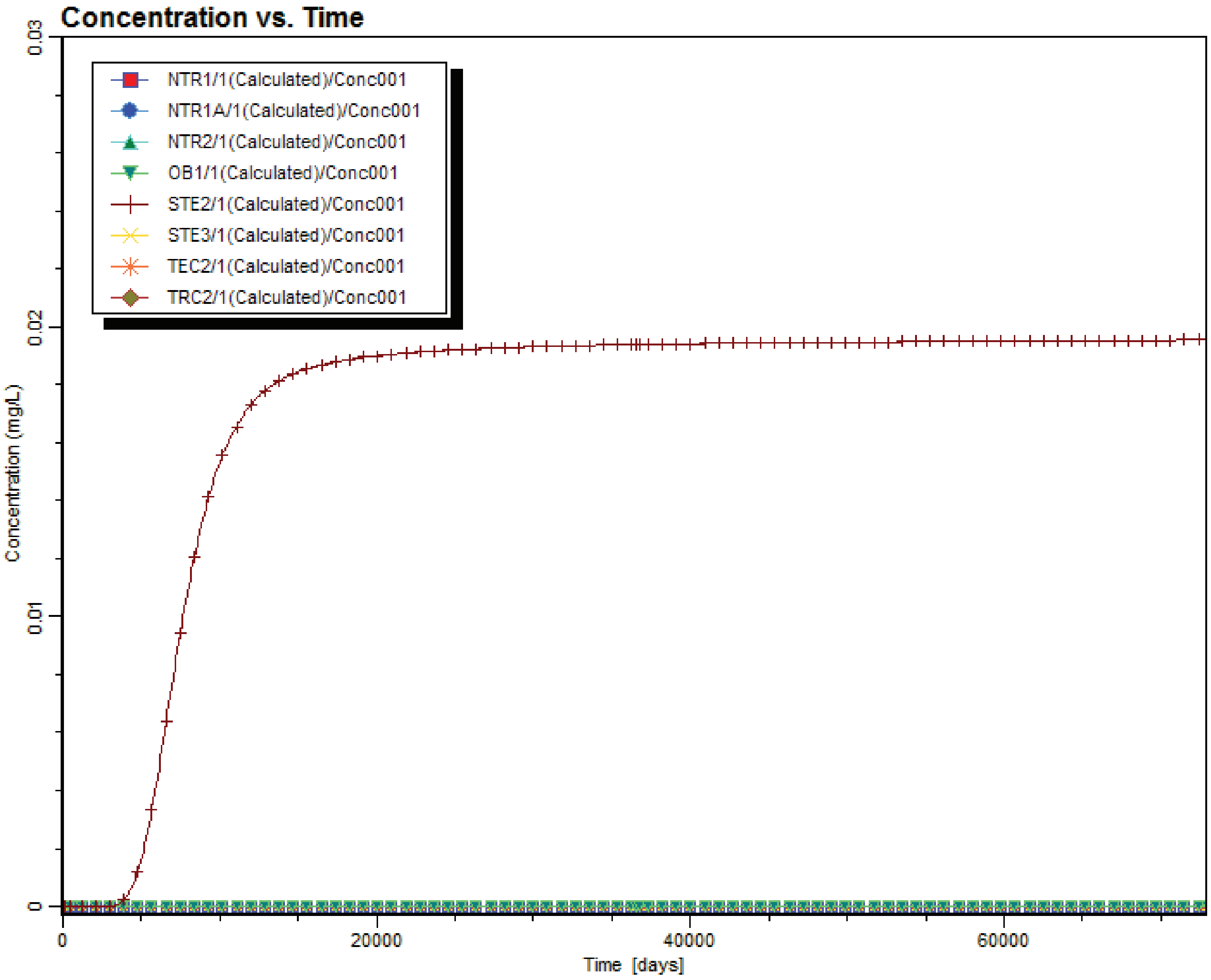

TMF Area Post-closure Monitoring Well Concentrations (Base Case, 200 Years)

FIGURE 5.2-3

6. Limitations

The flow and transport results in the mining area show that the Sulphurets Rock Storage Facility, and to a less degree, the Water Storage Facility are the areas most likely to affect groundwater quality, and therefore impact downstream surface water quality. These conclusions were reached with limited geological information and tested hydraulic conductivities in a few wells limited to depths around 100 m below ground surface. While providing a good estimate of the seepage rates and solute plumes from these facilities, the results from ongoing hydrogeological investigations should be assessed and integrated into the model if these change the conceptual model for the site.

Similarly in the TMF area, the results from ongoing investigations need to be assessed and integrated into the model where these data change the site conceptual model. For example, the occurrence of significant fractures and fault zones under the proposed TMF footprint could change the hydraulic conductivities in the model layers and provide a more accurate estimation of the seepage and solute migration from the TMF. Additional information characterizing bedrock geology will also improve the model as a pumping test would be better to calculate bedrock hydraulic conductivities, anisotropy ratios and porosities. Further characterization of overburden hydraulic properties including the hydraulic conductivities, anisotropy ratios and porosities of overburden materials under the TMF footprint would improve the model predicitons.

The uncertainty around groundwater recharge rates cannot be easily resolved and catchment wide characterization would be data intensive and complex. Recharge rates can vary significantly on the local scale but in our model has been estimated at approximately 7% to 10% of mean annual precipitation in the mining area and 8% to 10% in the TMF area. Ultimately, the recharge rates are best calibrated to stream baseflows or the gauged low flows which are considered to be predominantly from groundwater discharge.

The predicted steady-state inflows to the tunnels are based on predicted seepage rates through the bedrock in the various cells and layers assigned as drain cells along the tunnel alignment. As the model cells have greater dimensions than a tunnel (at least 10 times greater), the flow rates could be overestimated to some degree. However, given the limitations of the equivalent porous media approach for representing the fractured bedrock, the estimated inflow rates do not consider the influence of higher conductivity zones (e.g., in large fracture networks and fault zones) or the instantaneous flows, thus the actual flow rates could be significantly higher.

Implicit in the modelling approach is the assumption of overburden materials and fractured bedrock represented as equivalent homogeneous and isotropic porous media. This does not allow for representation of discrete fractures or fault zones that are thought to locally control groundwater flow. Although these limitations have implications for accurate characterization of groundwater flow on a local scale, they are not considered significant at the regional-scale models presented in this report.

7. Closure Notes

The hydrogeological modelling conducted for the KSM (Kerr-Sulphurets-Mitchell) Copper/Gold Project Environmental Assessment Application, was carried out in accordance with the guidance of the Application of Information Requirements for the Project, represents Rescan's best reasonable modelled representation of the hydrogeological systems, respectively, in the mining area and in the Tailing Management Facility (TMF) area. The effects of the proposed mine plan and activities on the water systems were examined based on the data that was available to Rescan at the time the models are done in both areas.

The methodologies used in analyzing the available information, building the conceptual hydrogeological models, developing and calibrating the three-dimensional baseline pre-mining hydrogeological models, and running the models to predict the groundwater flow and solute transport for the KSM Project represent the best knowledge and experience of the Rescan's Earth Sciences Team with hydrogeologists, hydrologists, geologists, geochemists, soil scientists, environmental scientists, and engineers. The results in this report are obtained from extensive simulations of the comprehensive hydrogeological models with the industry-standard software package of Visual MODFLOW-Surfact and MT3DMS and the best representation of the geological materials and the interactions between surface water and groundwater based on the available information.

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