RED MOUNTAIN UNDERGROUND GOLD PROJECT
VOLUME 3 | CHAPTER 10
HYDROGEOLOGY EFFECTS ASSESSMENT

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10 HYDROGEOLOGY EFFECTS ASSESSMENT

10.1 Introduction

Hydrogeology is an aspect of the environment that may be altered by the proposed Red Mountain Underground Gold Project (the Project), as proposed by IDM Mining Ltd. (IDM). Figure 10.1-1 to Figure 10.1-3 below illustrate the established disturbance limits for the entire Project footprint: for the Mine Site (location of Upper and Lower Portals) and for Bromley Humps (location of Process Plant and Tailings Management Facility (TMF)), respectively.

Hydrogeology (i.e., groundwater flow system) has been identified as an intermediate component (IC), which forms an effect pathway to the aquatic environment. This chapter describes the hydrogeology in the Project area and evaluates the potential interactions between Hydrogeology and the Project components, specifically the mine inflows, groundwater flow pathways, contributions of groundwater flow to creek baseflows, and proportions of mine contact groundwater discharging to surface water receptors. Linkages to other components of the aquatic environment include the Surface Hydrology (Volume 3, Chapter 12), Surface Water Quality (Volume 3, Chapter 13), Aquatic Resources (Volume 3, Chapter 17), and Fish and Fish Habitat (Volume 3, Chapter 18).

The chapter follows the effects assessment methodology described in Volume 3, Chapter 6 of the Application for an Environmental Assessment Certificate / Environmental Impact Statement (Application/EIS).

Further details on baseline studies and numerical modelling completed in support of the environmental assessment are provided in the following reports:

- SRK report “Red Mountain Underground Gold Project – Mine Area Hydrogeology Report” (Volume 9, Appendix 10-A);
- Knight Piésold report “Bromley Humps Baseline Hydrogeology Report” (Volume 8, Appendix 10-B);
- SRK report “Baseline Climate and Hydrology Report” (Volume 8, Appendix 12-A);
- SRK report “Surface Water and Groundwater Quality Baseline Report” (Volume 8, Appendix 14-A);
- Palmer report “Water Quality Assessment of the Reasonable Upper Limit Case” (Volume 8, Appendix 14-B); and
- SRK report “Water and Load Balance Model Report” (Volume 8, Appendix 14-C).

Figure 10.1-1: Project Overview

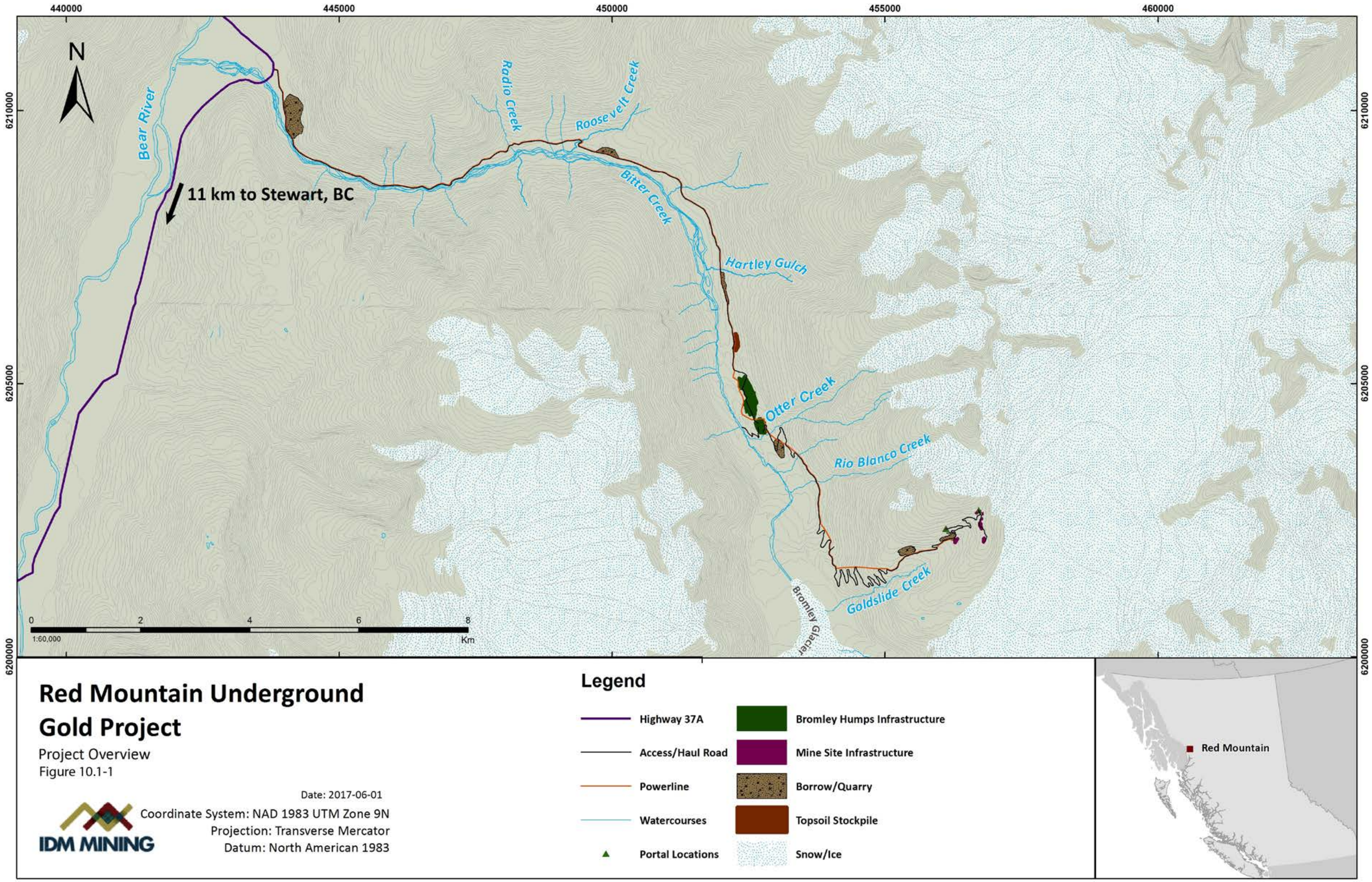


Figure 10.1-2: Project Footprint – Bromley Humps

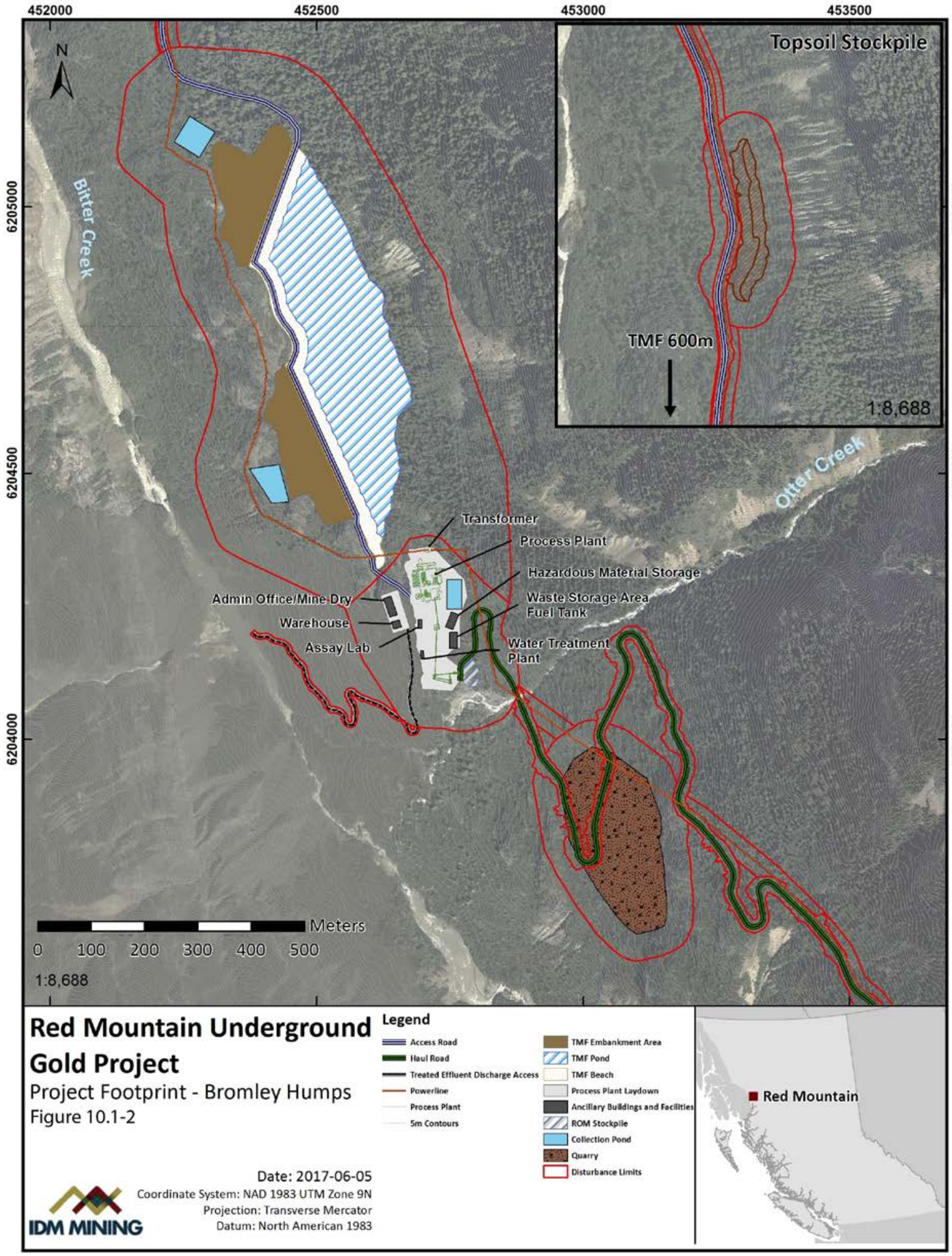
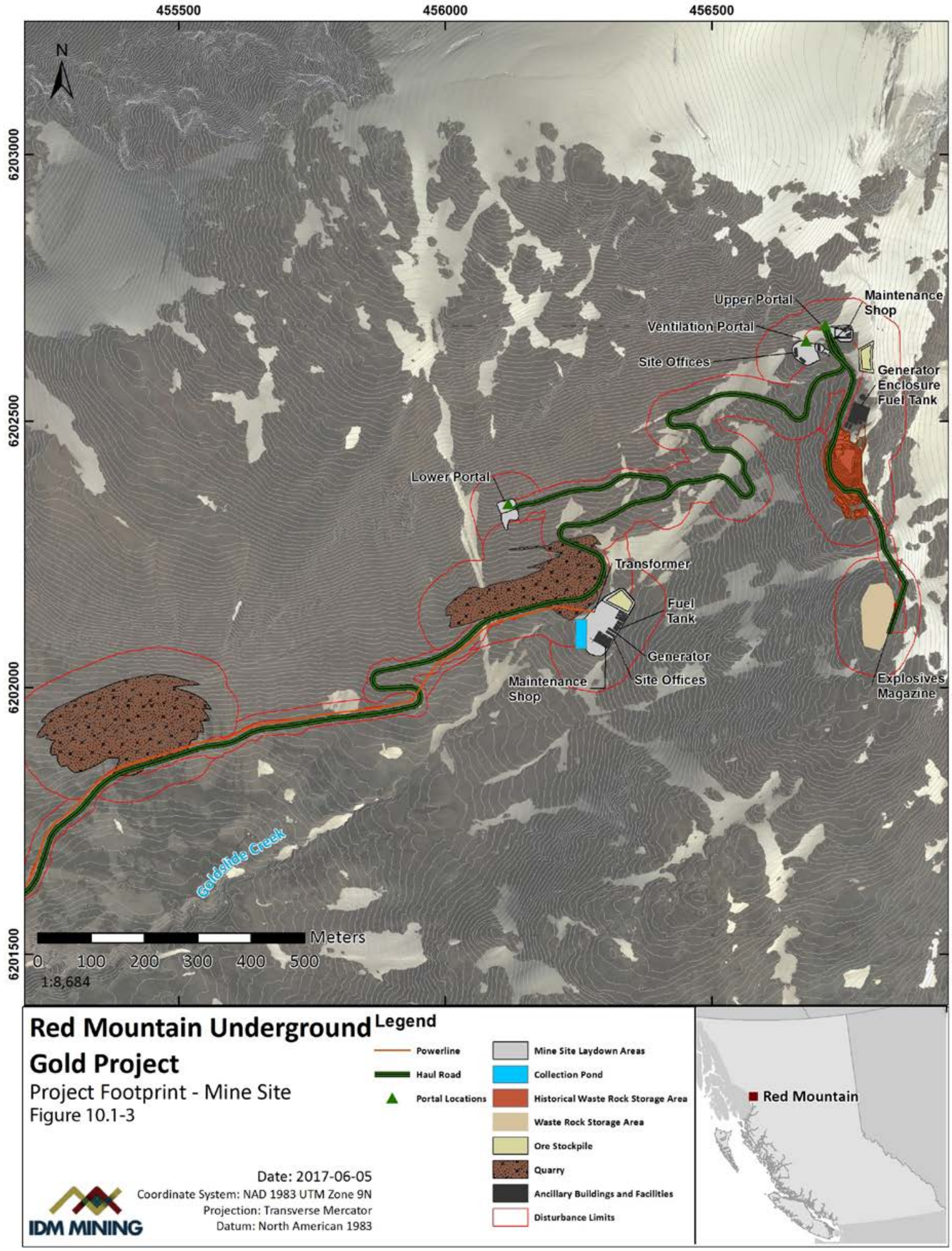


Figure 10.1-3: Project Footprint – Mine Site



10.2 Regulatory and Policy Setting

The Application Information Requirements (AIR) for the Project, approved by the British Columbia (BC) Environmental Assessment Office (EAO) in March 2017 as well as the final Guidelines for the Preparation of an Environmental Impact Statement pursuant to the *Canadian Environmental Assessment Act, 2012,* (the EIS) Guidelines) issued by the Canadian Environmental Assessment Agency (the Agency) in January 2016, outline the requirements of the Hydrogeology effects assessment to meet both the provincial and federal environmental assessment requirements under the *BC Environmental Assessment Act* (2002) and *Canadian Environmental Assessment Act, 2012* (CEAA 2012), respectively.

Further environmental regulations and guidelines are listed below and were consulted to help with the characterization of hydrogeological baseline conditions and the assessment of potential project influences on the groundwater system:

- *Water Sustainability Act, Groundwater Protection Regulation* (includes amendments up to *B.C. Reg. 152/2016*, June 10, 2016);
- "*Framework for a Hydrogeologic Study in support of an Application for an Environmental Assessment Certificate under the Environmental Assessment Act and Regulations*". BC Ministry of Environment, Water Stewardship Division;
- "*Water and Air Baseline Monitoring Guidance Document for Mine Proponents and Operators*" Version 2. BC Ministry of Environment (BC MOE 2016a); and
- BC MOE's "*Guidelines for Groundwater Modelling to Assess Impacts of Proposed Natural Resource Development Activities*", (Wels et al. 2012).

The Project is within the Nass Area and the Nass Wildlife Area, as set out in the Nisga'a Final Agreement (NFA). Pursuant to the NFA, Nisga'a Nation, as represented by Nisga'a Lisims Government (NLG), has Treaty rights to the management and harvesting of fish, wildlife, and migratory birds within the Nass Wildlife Area and the larger Nass Area. The Project is also within the asserted traditional territory of Tsetsaut Skii km Lax Ha (TSKLH) and is within an area where Métis Nation BC (MNBC) claims Aboriginal rights.

10.3 Scope of the Assessment

10.3.1 Information Sources

The following information was reviewed as part of a desktop study:

- High resolution Light Detection and Ranging (LIDAR) Digital Elevation Model;
- *Geology and Mineral Deposits of the Unuk River-Salmon River-Anyox Area, British Columbia* (Grove 1986);

- *Surficial geology, Nass Valley and Kitsault Valley, British Columbia. Geological Survey of Canada* (McCuaig 2003);
- Aquifer Classification Database, Well Record Database, And Water Licences Query Tool available on the MOE website (MOE 2016d, e, f);
- Environmental Baseline Data Report prepared by Hallam Knight Piésold for Lac Minerals Ltd. (HKP 1992);
- Synopsis of Environmental Programs Undertaken and Draft Project Application prepared by Rescan for Lac North America (Rescan 1994, 1995);
- Hydrogeology assessments prepared by Klohn Crippen (Klohn 1994a, b);
- Field Investigations at the proposed underground mine and tailings impoundment documented by Golder (Golder 1996a, b);
- 1996 Project development review and correspondences on underground discharges from the exiting decline prepared by Royal Oak for the EAO (Royal Oak 1996, 1998);
- *NI43-101 Preliminary Economic Assessment Technical Report* for the Red Mountain Project prepared by JDS in 2016 (JDS 2016);
- Surficial geology and bedrock mapping by IDM; and
- Drillhole database from IDM.

As outlined in Chapter 6 (Effects Assessment Methodology), IDM has not conducted primary traditional use or traditional ecological knowledge (TEK) surveys in support of the Project due to the preferences of Nisga'a Nation, as represented by NLG, and EAO's and the Agency's direction for comparatively low levels of engagement with the other Aboriginal Groups potentially affected by the Project. IDM has committed to using TEK where that information is publicly available. As no TEK relevant to this effects assessment was publicly available at the time of writing, no TEK has been incorporated.

10.3.2 Input from Consultation

IDM is committed to open and honest dialogue with regulators, Aboriginal Groups, community members, stakeholders, and the public.

IDM conducted consultation with regulators and Aboriginal Groups through the Working Group co-led by EAO and the Agency. Where more detailed and technical discussions were warranted, IDM and Working Group members, including sometimes NLG representatives, held topic-focused discussions, the results of which were brought back to EAO and the Working Group as a whole.

Further consultation with Aboriginal Groups, community members, stakeholders, and the public has been conducted as outlined by the Section 11 Order and EIS Guidelines issued for the Project. More information on IDM's consultation efforts with Aboriginal Groups, community members, stakeholders, and the public can be found in Chapter 3 (Information Distribution and Consultation Overview), Part C (Aboriginal Consultation), Part D (Public Consultation), and Appendices 27-A (Aboriginal Consultation Report) and 28-A (Public Consultation Report. A record of the Working Group's comments and IDM's responses can be found in the comment-tracking table maintained by EAO.

The inputs from consultations incorporated to the assessment are summarized in Table 10.3-1.

Table 10.3-1: Summary of Consultation Feedback on Hydrogeology

Topic	Feedback by* NLG, G, P/S, O	Consultation Feedback	Response
Groundwater Quantity	G	To ensure that this section includes the groundwater flow system in its entirety, this section could be called Hydrogeology rather than Groundwater Quantity. (Like the Hydrology section not being called Surface Water Quantity).	The chapter title was changed to Hydrogeology Effects Assessment
		In addition to groundwater levels and groundwater flow, primary measurement indicators of groundwater quantity can also include baseflow to streams, groundwater seepage into mine workings and other areas of groundwater discharge (i.e., springs, seepages, flowing wells etc.)	The baseflow to streams, groundwater seepage into mine workings and other areas of groundwater discharge are included as measurement indicators of Hydrogeology.
		Baseline hydrogeology conditions should be characterized according to Section 5 of Water and Air Baseline Monitoring Guidance Document for Mine Proponents and Operators, Prepared by MC Ministry of Environment (Version 2 –2016). Groundwater use for project activities should be outlined.	Baseline hydrogeology conditions are characterized according to the guideline. The only groundwater use anticipated by IDM is service water in the underground mine (i.e., drilling water).
		Groundwater monitoring sites should be spatially distributed over the entire site in order to characterize groundwater flow, depth of overburden, hydraulic conductivity of bedrock formations, and distribution of bedrock fracture zones and faults, groundwater recharge and discharge areas, and groundwater-surface water interaction.	The current monitoring locations are distributed at and around the key mining areas (i.e., proposed underground mine and TMF). Baseline monitoring sites are located adjacent and downgradient to the areas that could be affected by mining operations. However, there are no monitoring wells upgradient of the upper portal and upgradient of the TMF because the portal is located under the summit of Red Mountain, and the TMF is below an area that cannot be accessed due to steep topography.
		Groundwater Quantity should also be monitored during Operation and after Closure to ensure there are no long-term residual effects.	A long-term groundwater monitoring program will be established.

Topic	Feedback by* NLG, G, P/S, O	Consultation Feedback	Response
		Long-term water level dataloggers should be installed in all wells to establish temporal and seasonal groundwater fluctuations and assist in the ongoing calibration of the numerical model.	Water level dataloggers were installed in existing monitoring locations for this purpose.
		Consider developing a conceptual site model to synthesize all groundwater information, concentrating on Bromley Humps and the Mine Site. Use simplified cross sections to describe the groundwater system at the site.	Conceptual models of the groundwater system at Bromley Humps and the Mine Site are presented in the Application/EIS.
		A numerical groundwater flow model should be generated to simulate existing conditions of the study area. The model should be calibrated to the seasonal Hydraulic head data, discharge data from springs, artesian drill holes, the existing mine portal, and stream flows. Information regarding development, calibration, and objectives of the models should be outlined, as well as all assumptions and uncertainties in the model. The proponent should include all sensitivity analyses that were used for the generation of the model.	A numerical groundwater flow models has been developed and calibrated to the existing condition. The groundwater flow model is used to define groundwater flow and discharge areas, and quantify the effects from the Mine Site. The evaluation of these effects on surface water quantity and quality in the Local Study Area (LSA) and Regional Study Area (RSA) are performed using the site wide water balance and load model, Appendix 14-C. Development and calibration of these models follows the Guidelines for Groundwater Modelling prepared by BC Ministry of Environment (Wels 2012); details are provided in a technical report in Appendix 10-A. The technical report includes the results of a sensitivity analysis as per the previously noted guidelines.
		Hydrogeological modeling should include relevant time-steps in the mine life (i.e., operations, closure, commencement of discharge to the receiving environment, post-closure)	Effects are assessed for the relevant phases of the mine life (i.e., Operation, Closure and Reclamation, and Post-Closure Phases).

*NLG = Nisga’a Lisims Government; G = Government - Provincial or federal agencies; P/S = Public/Stakeholder - Local government, interest groups, landowners, tenure and license holders, members of the public; O = Other

10.3.3 Intermediate Components and Measurement Indicators

The Hydrogeology effects assessment follows the structure indicated in the Project's AIR (EAO 2017) using the measurement indicators listed in Table 10.3-2.

Table 10.3-2: Measurement Indicators for Hydrogeology

Intermediate Components	Primary Measurement Indicators
Hydrogeology	Groundwater levels and groundwater flow, including baseflow to streams, groundwater inflows to mine workings, and other areas of groundwater discharge.

10.3.4 Assessment Boundaries

10.3.4.1 Spatial Boundaries

The spatial boundaries define the limit within which changes to valued components (VCs) or ICs will be evaluated.

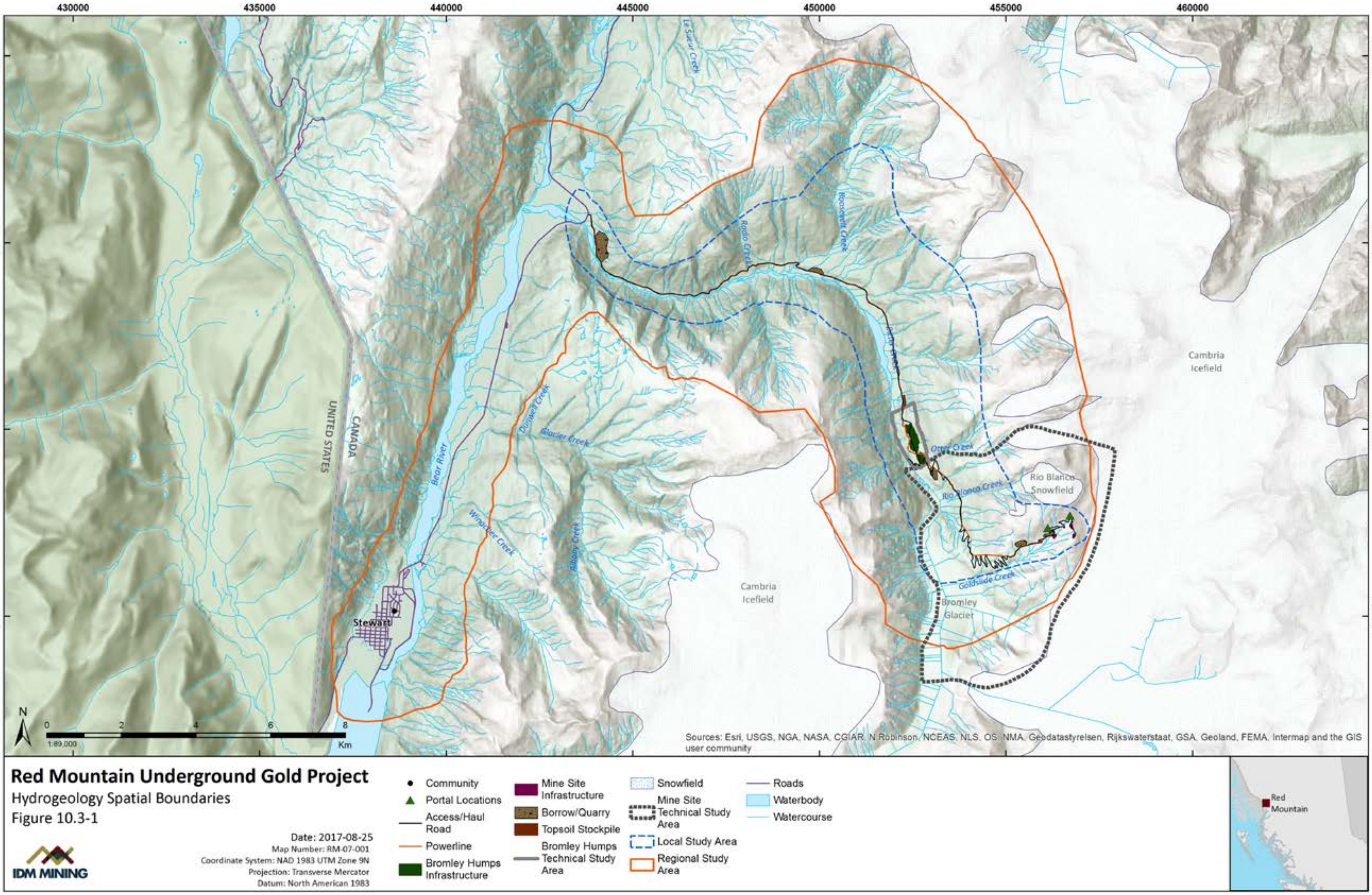
Four spatial boundaries were considered for the Hydrogeology Effects Assessment: the Regional Study Area (RSA), the Local Study Area (LSA), and two Technical Study Areas (TSAs). The LSA encompasses the Project footprint and extends beyond it to include the surrounding area where there is a reasonable potential for adverse Project-specific effects to occur. The RSA is a larger area that is used to provide context for the assessment of potential Project effects and represents the cumulative effects assessment study area. The TSAs delineate the areas of the LSA where the Project components (i.e., within the Mine Site and Bromley Humps) are anticipated to affect the hydrogeological system. The TSAs encompass the area within which technical and scientific hydrogeological information is available.

A description of the spatial boundaries is provided in Table 10.3-3. The extent of the LSA, RSA, and the two TSA's are shown on Figure 10.3-1.

Table 10.3-3: Spatial Boundaries of the Hydrogeology Assessment

Name	Spatial Boundary Description
LSA	The LSA corresponds to the Bitter Creek watershed up to the glacial extent, including Goldslide and Otter Creeks.
RSA	The RSA corresponds to the Bitter Creek watershed including the glacial extent and the Bear River watershed from American Creek to Stewart and the northern end of the Portland Canal.
Mine Site TSA	Area bounded by the Cambria Ice Field to the east and south and the tongue of the Bromley Glacier to the north. This includes the proposed underground mine, the temporary waste rock pile footprint, and the areas where the water originates, at or near the Project, to where it drains or discharges. The TSA is drained by the Bitter Creek, and its three uppermost tributaries: Goldslide Creek, Rio Blanco Creek, and Otter Creek.
Bromley Humps TSA	Area comprising all the physical structures and mine activities of the Project around Bromley Humps and surface waters that could be affected by seepage of mine contact water. This includes the TMF, Process Plant, and the Run of Mine (ROM) Stockpile, as well as Bitter and Otter creeks. The Bromley Humps TSA is bounded to the north by an area of low relief located northwest of the TMF North Embankment, where groundwater discharges may be expected, and to the east by the 550 metre contour elevation along the eastern slope of Bitter Creek Valley, which reflects the approximate upper limit at which mine infrastructure along this slope exists.

Figure 10.3-1: Spatial Boundaries for Hydrogeology



10.3.4.2 Temporal Boundaries

The temporal boundaries encompass the periods during which the Project is expected to have potential effects on the Hydrogeology IC. The relevant time periods used for the Hydrogeology Effect Assessment are presented in Table 10.3-4.

Table 10.3-4: Temporal Boundaries for Hydrogeology

Phase	Project Year	Length of Phase	Description of Activities
Construction	Year -1 to Year 1	18 months	Construction activities and construction of: Access Road, Haul Road, power line, declines, power supply to the underground, water management features, water treatment facilities, Tailings Management Facility (TMF), Process Plant, ancillary buildings and facilities; underground lateral development and underground dewatering; ore stockpile and ore processing start-up; and receiving environmental monitoring.
Operation	Year 1 to Year 6	6 years	Ramp up to commercial ore production and maintain a steady state of production, underground dewatering, tailings storage, water treatment, gold ore shipping, environmental monitoring, and progressive reclamation.
Closure and Reclamation, and Post-closure	Year 7 to Year 21	15 years*	Underground decommissioning and flooding; decommissioning of infrastructure at portals, Process Plant, TMF, ancillary buildings and facilities; reclamation, water treatment; removal of water treatment facilities; and receiving environment monitoring.

* Post-closure changes to groundwater will continue until water levels in the mine reach steady state in about 30 years, and monitoring of this component will continue until steady state conditions have been established.

10.3.4.3 Administrative and Technical Boundaries

No administrative boundaries are relevant to the Hydrogeology Effects Assessment.

Technical boundaries for hydrogeology are reflected in the two TSAs described in Section 10.3.4.1 and Table 10.3-3. The Bromley Humps and Mine Site TSAs reflect technical constraints by delineating the area within the LSA where technical and scientific information is available to support modeling.

10.4 Existing Conditions

Section 3.3 of the Project's AIR requests the following information for existing conditions. Specific references are provided for each request in the following list.

- A description of the existing (or baseline) conditions within the study area in sufficient detail to enable potential Project-VC or -IC interactions to be identified, understood, and assessed: please see Sections 10.4.1 and 10.4.3 in this Chapter and Sections 2 and 3 in Appendices 10-A and 10-B (both in Volume 8);

- A description of the quality and reliability of the existing (or baseline) data and its applicability for the purpose used, including any gaps, insufficiencies, and uncertainties, particularly for monitoring activities: please see the "Limitations" discussion in Section 10.4.3.2 and Section 6.9 in Appendix 10-A;

- Reference to natural and/or human-caused trends that may alter the environmental, economic, social, heritage, and health setting, irrespective of the changes that may occur as a result of the proposed Project or other project and/or activities in the area: please see Section 6 in Appendix 12-A on climate change, which is indirectly relevant to hydrogeology;

- An explanation of if and how other past and present projects and activities in the study area have affected or are affecting each VC or IC: please see Section 10.4.2 in this Chapter;

- Documentation of the methods and data sources used to compile information on existing (or baseline) conditions, including any standards or guidelines followed: please see Sections 10.3.1, 10.4.3, and 10.4.4 in this Chapter and Sections 2 and 3 in Appendices 10-A and 10-B;

- Where additional Project and VC- or IC-specific field studies are conducted, the scope and methods to be used will follow published documents pertaining to data collection and analysis methods, where these are available. Where methods used for the assessment deviate from applicable published guidance, the rationale for the variance will be provided in the Application: please see Sections 10.3.1, 10.4.3, and 10.4.4 in this Chapter and Sections 2 and 3 in Appendices 10-A and 10-B; and

- Description of what Traditional Ecological Knowledge (TEK), including Aboriginal Traditional Knowledge, was used in the VC or IC assessment: please see Section 10.3.1 in this Chapter.

10.4.1 Overview of Existing Conditions

The Bitter Creek valley is characterized by rugged, mountainous terrain with steep slopes and elevations ranging between 2,000 and 2,500 meters above sea level (masl); topographic relief of 2 kilometres (km) over a horizontal distance of 6 km is typical. The hydrologic regime is dominated by rapid runoff (from rainfall or snowmelt), very shallow subsurface flow (possibly perched), and surface water. The region is also heavily glaciated and glacial ice persists year-round in the Bitter Creek valley at elevations greater than 600 masl. The Bromley, Bear River, Kitsault and Sutton Glaciers, and the Cambria Icefield cover a total of about 58% of the RSA (Appendix 12-A).

The mountainous terrain has a major influence on the groundwater flow system, causing steep hydraulic gradients that drive groundwater flow from higher to lower elevations. Available data for bedrock groundwater wells in highland areas indicate water tables within mountain bedrock are consistently close to the ground surface (Welch 2012). The water table is generally a subdued replica of topography, with depths to groundwater typically greater in the uplands relative to the valley bottoms.

10.4.2 Past and Current Projects and Activities

Mineral exploration of the Project started in 1989 and has included exploration drilling, construction of an exploration decline, and a bulk sample program. These activities contributed to a better understanding of the Project's hydrogeology but have likely resulted in localized changes in groundwater recharge and discharge patterns and flow directions compared to pre-disturbance conditions. Table 10.4-1 lists the historical activities having potentially interacted with Hydrogeology.

Table 10.4-1: Historical Activities

Timeframe	Mine Site TSA	Bromley Humps TSA
Historical Project Activities (prior to 2016)	Surface drilling on the Marc, AV and JW zones in 1991, 1992, 1993 and 1994. Underground exploration of the Marc zone conducted in 1993 and 1994. Construction of underground exploration adit in 1993, 1994 and 1996. Geotechnical and groundwater studies.	Surface drilling, geotechnical and groundwater studies conducted in 1996.
Current Project Activities (2016)	Underground exploration drilling, geotechnical and groundwater studies.	Surface drilling, geotechnical and groundwater studies.

10.4.3 Project Specific Baseline Studies

10.4.3.1 Data Sources

Historical hydrogeological baseline studies were completed from 1990 to 1992 by Hallam Knight Piésold (HKP 1992) for Bond Gold and then Lac Minerals, from 1993 to 1994 by Klohn-Crippen (Klohn 1994a, 1994b) and from 1993 to 1996 by Rescan (Rescan 1994, 1995) for Lac Minerals, and finally in 1996 by Golder (Golder 1996a, 1996b) for Royal Oak Mines.

Baseline information related to hydrogeology included the installation of wells, hydraulic conductivity testing, measurements of water levels or pressure, and groundwater quality sampling.

Starting in 2003, SRK completed various activities in support of on-going compliance monitoring for the site (SRK 2004 to 2014). These included baseline monitoring of water levels, and flow in the existing decline (2003 – 2006). Baseline studies were re-initiated in June 2014 to address gaps in the existing historical dataset. Starting in 2014, Avison collected water levels in the exiting decline, in piezometers and open holes, and installed water level data loggers to characterize the seasonal groundwater fluctuations. In 2016, SRK conducted packer testing in underground exploration drillholes to refine the characterization of the hydraulic conductivity in bedrock at the Mine Site; Knight Piésold conducted a geotechnical and hydrogeological field investigation at Bromley Humps.

A summary of the activities included in Project specific baseline studies is provided in Table 10.4-2; details of these field programs are provided in Appendices 10-A and 10-B. The groundwater monitoring locations (historical and current) are shown on Figure 10.4-1 and Figure 10.4-2. Further details on the baseline groundwater quality studies are presented in Volume 3, Chapter 11 (Groundwater Quality Effects Assessment) of the Application/EIS.

Table 10.4-2: Baseline Hydrogeological Studies

Studies	Activities
HKP Early 1990s	• Groundwater sample collection at two locations (W6 and W12).
Klohn Crippen 1993 - 1994	• K tests completed at the Mine Site: 4 falling head tests in two surface piezometers (TD93-158 and TD93-159), and 5 packer tests in an underground exploration borehole (MC93-124) drilled into the Marc zone ore body. • Surveys of inflows in the existing decline. • Groundwater sample collected at 24 locations, including 2 underground boreholes (MC-92-124, MC92-76), 2 surface piezometers (TD93-159, TD93-160), 2 discharge locations from the existing decline, and 18 groundwater seeps or springs.
Rescan 1993 - 1996	• Groundwater sample collection at 6 springs (3 near Rio Blanco Creek within the Bitter Creek valley and 3 near the Mine Site), and at W6 and W12.
Golder 1996	• 14 packer tests completed at the Mine Site in 3 underground boreholes, R96-241, R96-244, and R96-U1169, and 42 packer tests completed in the Bromley Humps area in 11 surface geotechnical drill holes, from DT-272 through DT-282. • Installation of 16 piezometers in the Bromley Humps area (drill holes DT-272 through DT-282). • Survey of the exploration boreholes to determine the static water table and potential locations for groundwater sample collection. • Mapping and sampling of the groundwater seeps in the existing decline and measurements of groundwater inflows at 34 underground exploration boreholes.

Studies	Activities
SRK 2003 to 2016	• Establishment of 4 groundwater quality monitoring locations near the historical waste dumps and the underground portal. • Collection of water levels in the exiting decline, in piezometers and open holes, and installation of water level data loggers to characterize the seasonal groundwater fluctuations; • Collection of 9 groundwater samples (as of December 2016) from flowing artesian boreholes and 3 samples from the existing decline located within the Mine Site TSA. The decline samples were collected during periods where no exploration activities were occurring. The surface monitoring wells at the Mine Site continue to be monitored periodically by Avison (Volume 3 Chapter 11). • 10 packer tests completed in 4 underground boreholes to measure the bedrock K around the JW and AV mineralized zones. • Recording of pumping rates and variations of water levels in the decline, observations of underground seeps and collection of 14 groundwater quality samples from the existing decline during dewatering activities.
Knight Piésold 2016	• Drilling and logging of 14 geotechnical drillholes in the Bromley Humps area, including: Standard Penetration Testing (SPT), in-situ hydraulic conductivity testing, installation of 4 standpipe piezometers, installation of 4 groundwater monitoring wells; and installation of vibrating wire piezometers in 6 drillholes. The monitoring wells installed at Bromley Humps in 2016 continue to be monitored periodically by Avison (Volume 3 Chapter 11). • Logging of drill core from 4 historical drillholes (Golder 1996b) located at Bromley Humps. • Laboratory index testing of select SPT samples, laboratory strength testing of select bedrock core samples.

Figure 10.4-1: Groundwater Monitoring Locations in the Mine Site TSA

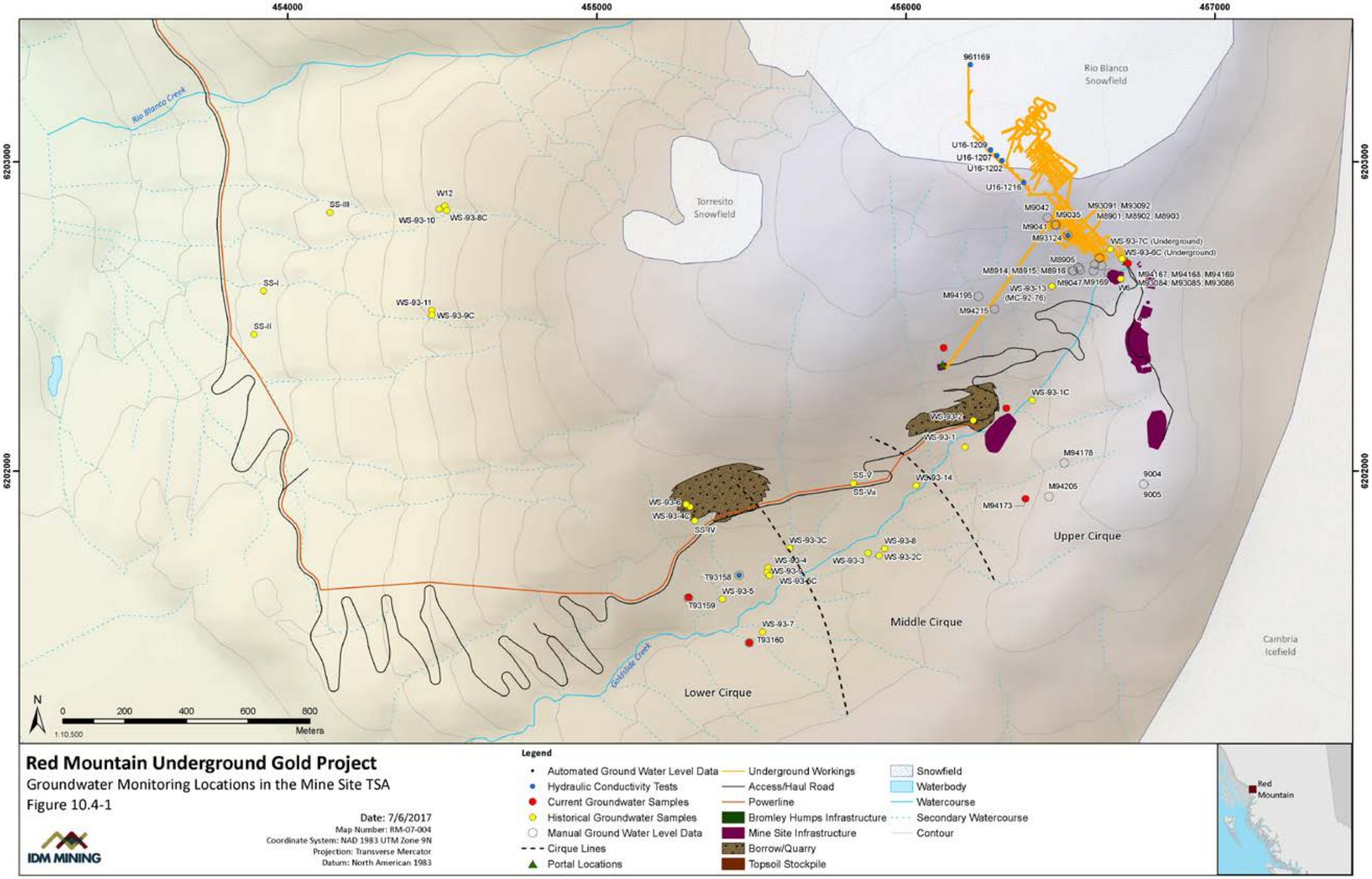
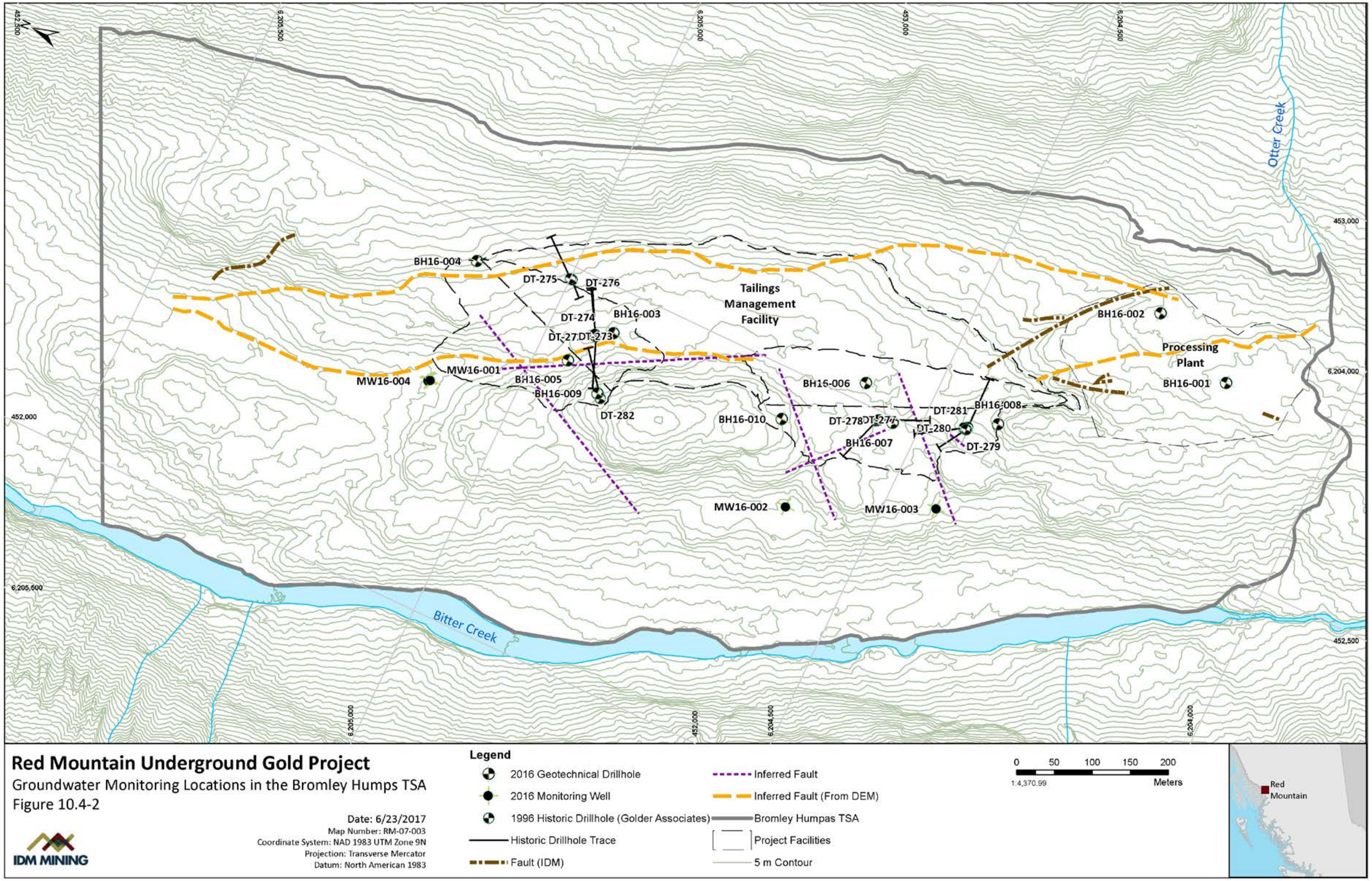


Figure 10.4-2: Groundwater Monitoring Locations in the Bromley Humps TSA



10.4.3.2 Primary Data Collection and Analysis Methods

The methods used to characterize the hydrogeological conditions included the following activities:

- Borehole drilling and logging;
- Installation and development of groundwater monitoring wells;
- Hydraulic conductivity testing (packer tests and slug tests);
- Measurements of groundwater level in boreholes and wells; and
- Measurements of inflow rates and water levels in the existing decline and pressure heads in underground boreholes.

Methodologies for hydraulic testing and piezometer installations by Golder and SRK are provided in Appendix 10-A. Methodologies for hydraulic testing and piezometer installations by KP are provided in Appendix 10-B.

As recommended by guidelines, historical information was reviewed. Data were compiled into spreadsheets and/or databases (i.e. Excel, Access, ArcMap, and Leapfrog) for analyses and mapping. Test analyses were reviewed and verified internally, including methodology, input values, calculations, and interpretations. Groundwater levels recorded by automatic data loggers were compensated for atmospheric pressures and checked against manual groundwater depth measurements. The monitoring measurements were plotted in three-dimensional space based on the high-resolution LIDAR or surveyed collar elevation and IDM's database of drillhole surveys.

10.4.3.2.1 Limitations

The dataset available for hydrogeology has the following limitations:

- There is no pre-disturbance groundwater data within the Mine Site (levels and water quality);
- The baseline groundwater monitoring locations are distributed at and around the key mining areas (i.e., Mine Site and Bromley Humps), adjacent and downgradient to the areas that could be affected by mining operations. However, there is no monitoring wells upgradient of the Upper Portal and upgradient of the TMF because of the topography; i.e., the portal is located under the summit of Red Mountain, and the TMF is below an area that cannot be accessed due to steep topography;
- Methodologies associated with packer tests and piezometer installations by Klohn Crippen are not available in the existing documentation; and
- The groundwater monitoring stations located in the upper cirque area of the Mine Site, i.e., RMS5 (M94173) and RMS7 (M94217), consist of artesian open exploration boreholes. Although these were upgraded and plugged with a pressurized top, mounted

with a pressure gauge, and equipped with a pressure transducer to record the seasonal change in groundwater levels, there are some uncertainties associated with use of exploration boreholes that need to be taken into consideration in the evaluation.

10.4.4 Baseline Characterization

10.4.4.1 Hydrogeology within the RSA and LSA

The primary groundwater flow directions within the RSA and LSA are from the mountain's summits to the Bitter Creek valley, and the secondary flow directions (i.e., localized shallow system) are towards the tributaries of Bitter Creek. The recharge occurs in the highlands in the form of snowmelt or rain infiltration, and the discharges occur as baseflow or sub-stream flow in the Bitter Creek valley and possibly in smaller order streams, gullies, breaks in slope, and geologic discontinuities. Considering the relatively steep topography, some flow systems may be perched and have localized seepage areas.

The BC Ministry of Environment (BC MOE) online British Columbia Water Resources Atlas shows no groundwater resource (i.e., aquifers) within the RSA and no groundwater users close to the site (BC MOE 2016e, 2016f). The nearest groundwater user in the area is the District of Stewart, which is serviced by three wells with capacity for 4,300 cubic meters per day (m^3/day). Given the low population density and the high amount of precipitation, there is the potential for future uses. The closest observation well to the Project within the BC Groundwater Observation Well Network (BC MOE 2017) is over 200 km away near the town of Smithers.

Groundwater is contained either in valley fill deposits or in the fractured rock. In valleys, groundwater fills the glacial and fluvial sandy gravely deposits associated with Bitter Creek, while on the mountain slopes, localized "shallow" groundwater flow system may be present through the relatively thin soil or overburden deposits composed of basal moraine, talus, and slopewash. Groundwater penetrates deep into bedrock through the fractures and joints. These fractured rock systems are expected to be irregularly distributed due to the variability of fractures (Parsons 1994) and to be influenced by major structures or faults that act locally as preferential conduits, impermeable barriers, or both.

Topography, difficulty of access, and weather conditions are major obstacles to the investigation of mountain water systems. While bedrock lithology and major fault zones are mapped, there is typically no information regarding the influences of lithology, faults, and smaller-scale heterogeneities on the subsurface bedrock hydraulic properties; hence regional-scale hydraulic conductivity (K) generalizations are necessary. Water table and hydraulic head data are rare at mountain summits, and stream gauges are limited. This restricts the ability to estimate the actual groundwater recharge rates (R) (Welch, 2012). The magnitude of groundwater recharge or discharge contributions below areas covered with glaciers or ice fields is also uncertain.

10.4.4.2 Hydrogeology of the Mine Site TSA

This section summarizes the current hydrogeological conditions at the Mine Site TSA. Full details on groundwater data, as well as data location maps and analyses, are provided in

Appendix 10-A, which establishes the baseline hydrogeological conditions at the Mine Site and quantifies potential changes to the groundwater system that could occur because of mining.

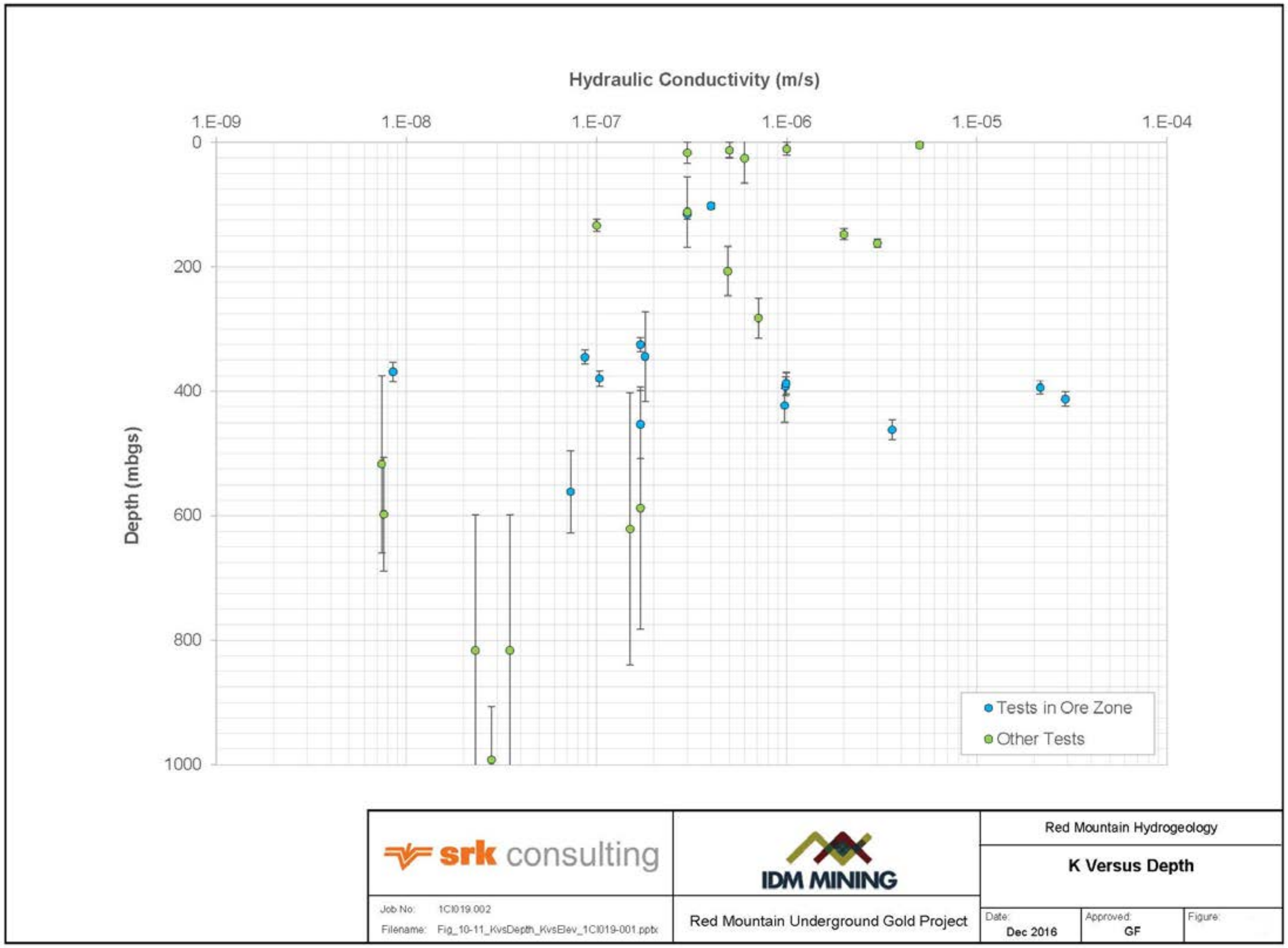
10.4.4.2.1 Hydraulic Conductivity (K)

The Mine Site TSA data set includes 33 K measurements from 10 boreholes measured between 1993 and 2016. The tests were completed in two surface piezometers, three surface boreholes, and five underground boreholes. K data are plotted versus depth in Figure 10.4-3.

Key findings from the analysis of K data in the Mine Site TSA are summarized below:

- K in bedrock ranges between 7.4×10^{-9} and 2.9×10^{-5} metres per second (m/s), with a geometric mean of 3.0×10^{-7} m/s, and is interpreted to be primarily related to fractures. All the test intervals were completed in the sub-volcanic porphyry intrusion.
- No strong correlation emerges from the analysis of K, specific mineable zones, and geotechnical data (i.e., Rock Quality Designation (RQD), Fracture Frequency, core photos, and major structures), except for K reduction with depth and elevation.
- There are three tests that suggest the JW mineralized zone, the Marc mineralized zone or the DC fault, and the Rick fault could be characterized by relatively high K. Test #3 in U16-1207 (3.6×10^{-6} m/s) intercepted the JW mineralized zone; Test #5 in MC93-124 (3.0×10^{-6} m/s) intercepted the Marc mineralized zone and the DC fault; and Test #2 in U16-1202 (9.9×10^{-7} m/s) intercepted the Rick fault.
- There is one test that suggests the AV mineralized zone is characterized by a relatively low K (i.e., Test #3 in U16-1216, 8.5×10^{-9} m/s).
- The two tests conducted in U16-1209 measured a K value of approximately 3×10^{-5} m/s in intervals logged with fault/broken zones that are not identified in the current structural model.

Figure 10.4-3: Hydraulic Conductivity (K) in the Mine Site TSA versus Depth



10.4.4.2.2 Groundwater Levels

The Mine Site TSA data set includes static groundwater levels measured between 1993 and 2016 from three shallow surface piezometers, 37 surface exploration boreholes, and from the existing decline. Out of the 41 locations, two water level loggers (Levelogger manufactured by Solinst) were installed in piezometers, two in exploration boreholes, and one in the decline to record the seasonal changes in groundwater levels during baseline conditions. In addition to levels, pressures were recorded in eight underground exploration boreholes between August and September of 1994 and in 16 underground exploration boreholes in September of 1996. Pressure measured in underground boreholes provided anecdotal information on the dynamic levels surrounding the decline during dewatering.

The observations of groundwater levels confirmed that groundwater flow is controlled by topography, with gradients oriented from high elevations towards valleys. The groundwater table at the vicinity of the Red Mountain peak has an elevation of at least 1,875 masl or 252 metres above ground surface (mags). The groundwater table near Goldslide Creek, below the Mine Site, is close to the ground surface, with an average elevation of approximately 1,425 masl or 3 mbgs.

Groundwater levels within the Mine Site show clearly the influence of freshet and a peak in the water table between June and August. Water levels in the existing decline range from an average elevation of 1,800 masl, to 1,846 masl (near the Upper Portal entrance), but have also dropped as low as 1,757 masl on at least one occasion (Pers. comm.; Rob McLeod, IDM, Sep 2016). During the rise in water levels following freshet, the average groundwater inflow rate is estimated at approximately 2,160 m^3/d.

10.4.4.2.3 Pumping Rates and Water Levels during Dewatering Events (1996, 2016)

Water levels and pumping rates were recorded during and after the dewatering events of May 1996, August 2000, and July 2016. Pumping rates were relatively low (i.e., < 90 to 900 m^3/d) prior to the month of June or July, then increased quickly to a peak around mid-August of 2,600 m^3/d for a “cold” year, and 6,050 m^3/d for a “warm” year. Recharge from snowmelt of the Rio Blanco snowfield (Figure 10.4-1) was interpreted to be the primary driver of the magnitude of inflow, hence a warm year leads to higher recharge and higher inflows.

10.4.4.2.4 Hydrogeological Units

There are three types of potential minor aquifers (i.e., overburden, undifferentiated fractured bedrock, and high K fractures or faults) and two types of potential aquitards (i.e., local patches of discontinuous permafrost, low K fractures or faults).

<u>Minor Aquifers</u>

- The overburden cover consists of glacial, eolian, and fluvial deposits with a colluvium cover on many of the steeper slopes. In the Mine Site area, basal moraine, talus, and slopewash generally contain a small percentage of fines due to the short glacial transport distance and water runoff. From literature data, K in glacial till material can vary widely from less than 1×10^{-8} to 5×10^{-6} m/s (Freeze 1979). Depth to bedrock is shallow, specifically 1 to 2 m in thickness.

- The bedrock units (i.e., porphyry intrusion and metasediment) are grouped as one hydrogeological unit because there are no apparent differences of rock type influencing the hydraulic conductivity. K has a geomean of 3×10^{-7} m/s and is interpreted to be primarily related to fractures. K tends to decrease with depth.

- High K fractures or faults are potentially present in the existing decline but not well defined at this stage and with the current dataset. A K of 1×10^{-6} m/s was measured for the Rick fault around the existing decline.

Aquitards (impermeable units)

- Local patches of discontinuous permafrost could be present, although not identified. If present, they will act as an aquitard (impermeable unit) that can limit groundwater recharge.

- Low K fractures or faults are potentially present but not specifically identified with the current dataset. If present, low K fractures or faults could create local impermeable barriers and compartments.

10.4.4.2.5 Groundwater Flow

Groundwater flow at the Mine Site is driven by the relative elevations, with the primary groundwater flow directions from the top of the Red Mountain to the Bitter Creek valley and the secondary flow directions (i.e., localized shallow system) towards the creeks and the Cambria Ice Field. A conceptual model of the groundwater flow in the Mine Site TSA is shown in Figure 10.4-4 in plan and cross-sectional views.

Where present, permeable overburden units likely drain the shallow inflows. In bedrock, groundwater flow paths are controlled by fractures and joints with no apparent distinction between lithologies. Faults may act as preferential conduits, impermeable barriers, or both; however, none of the major structures identified to date have been associated with significant discharge at surface or visible changes in water levels. Furthermore, the observations of seeps at fractures and faults intersecting the existing decline showed that inflows tended to decrease rapidly therefore suggesting that groundwater storage in faults/fractures is limited.

Recharge takes place above approximately 1,100 masl in the form of snowmelt or rain infiltration. The average annual recharge over the Mine Site TSA was estimated as 540 millimetres per year (mm/year). There are pronounced seasonal fluctuations in groundwater levels, and these are greater at higher elevations than at lower elevations. In the area of the existing decline, water levels peak at 1,850 masl between July and August, then slowly decrease to 1,760 m over the course of the winter season and finally recover rapidly with recharge from snowmelt starting around March. Discharges occur at the bottom of the Cambria Ice Field, at lower elevation in the main creeks (i.e., Goldslide Creek and Rio Blanco Creek), and possibly in smaller order streams on the mountain slopes between approximately 950 masl and 1,100 masl (i.e., seepage zone), in gullies, breaks in slope, geologic discontinuities, and in the valley bottom.

The upper sections of Goldslide Creek and Rio Blanco Creek are likely ephemeral, perched above the water table, and fed primarily by glaciers, snowmelt, and/or runoff. It is assumed that the lower sections of the creeks, as well as Bitter Creek in the valley, are fed by groundwater all year round. During the low-flow season (i.e., the winter period), it is assumed that groundwater contributes nearly 100% of the baseflow. During spring, summer and fall, surface runoff and quick flow generated by the snowmelt and/or precipitation dominates.

10.4.4.3 Hydrogeology of the Bromley Humps TSA

This section summarizes the current hydrogeological conditions at the Bromley Humps TSA. Full details on groundwater data, as well as data location maps and analyses are provided in Appendix 10-B, which establishes the baseline hydrogeological conditions in the Bromley Humps area and quantifies the potential changes to the groundwater system that could occur as a result of the TMF.

10.4.4.3.1 Hydraulic Conductivity (K)

The Bromley Humps TSA data set includes 113 K measurements collected from 23 boreholes between 1996 and 2016. K data are plotted versus depth in Figure 10.4-5 and Figure 10.4-6.

The following are the key findings from the analysis of K data for the Bromley Humps TSA:

- The 1996 and 2016 datasets are indicative of a moderately permeable bedrock with some enhanced permeability associated with structures. K ranges between 10^{-9} to 10^{-5} m/s, with a geomean of 3 x 10^{-7} m/s.
- There is a correlation observed between K and depth. K values in the upper 30 m are relatively high with values up to about 1 x 10^{-5} m/s, while K tend to decrease with depth.
- The test intervals intercepting an identified fault zones have values between 4 x 10^{-7} m/s and 1 x 10^{-6} m/s (i.e., faults were noted at DT-277, DT-282, DT-279, BH16-009, BH16-010, and MW16-002).

Figure 10.4-4: Conceptual Hydrogeological Model for the Mine Site TSA

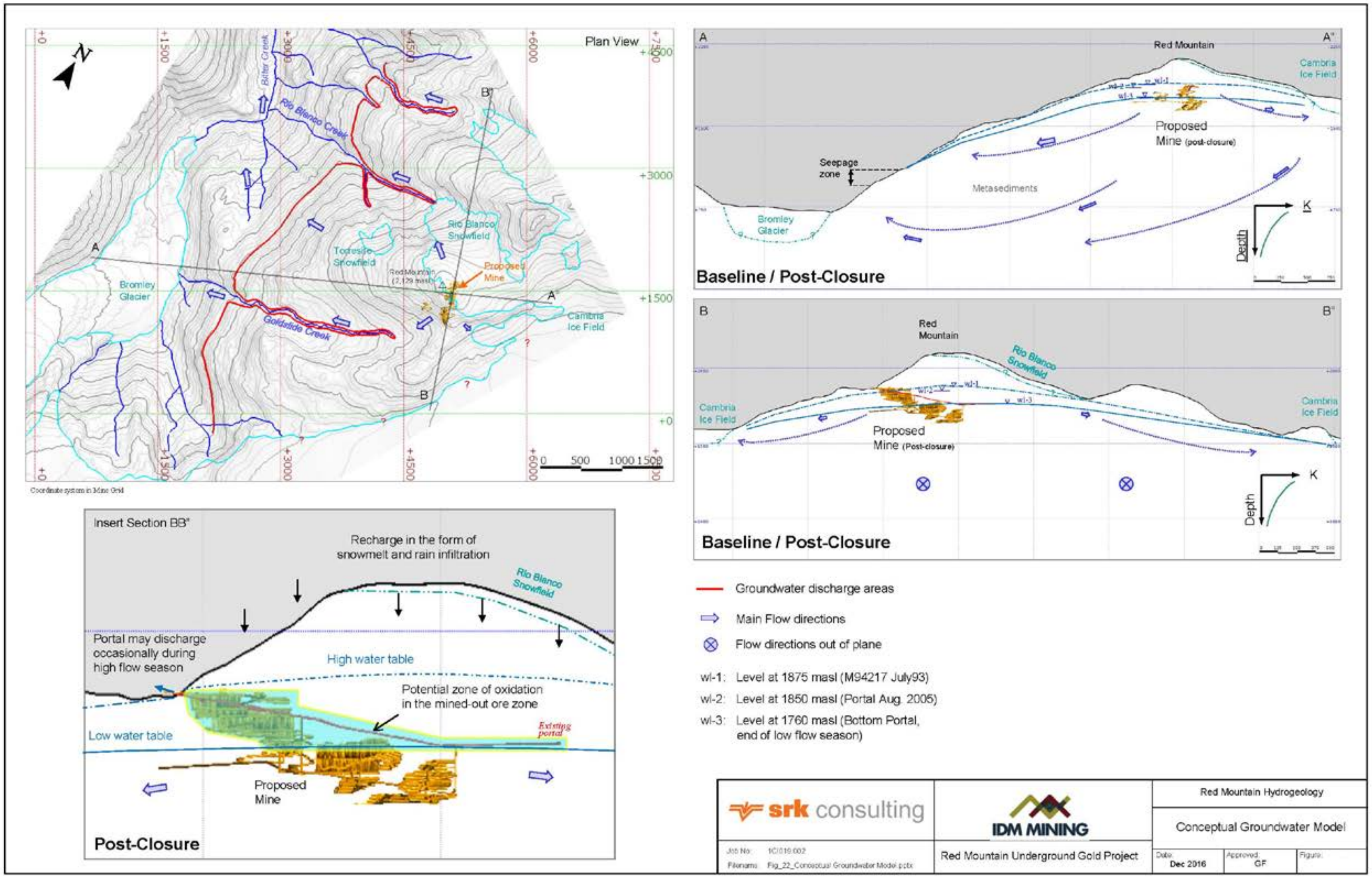
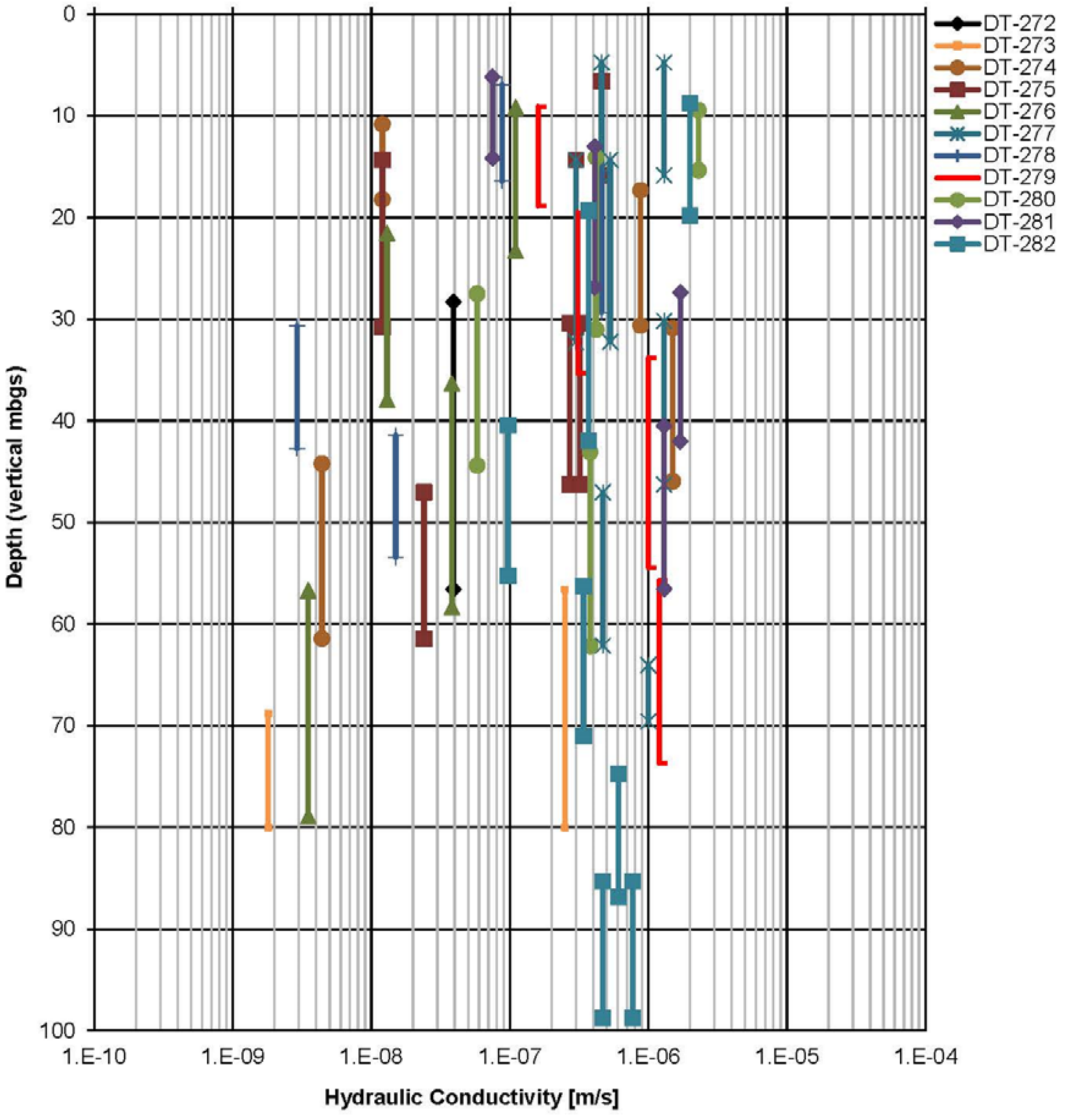


Figure 10.4-5: Hydraulic Conductivity (K) in the Bromley Humps TSA versus Depth (1996 Site Investigation)



NOTES:

1. HYDRAULIC CONDUCTIVITY DATA FROM GOLDER (1996). ALL RESULTS FROM IN-SITU PACKER TESTS.
2. SEE TABLE B1 IN APPENDIX B FOR PACKER TEST RESULTS SUMMARY.

IDM MINING LTD.

RED MOUNTAIN UNDERGROUND GOLD PROJECT

BEDROCK HYDRAULIC CONDUCTIVITY WITH DEPTH
(1996 SITE INVESTIGATION)

Knight Piésold
CONSULTING

P/A NO.
VA101-594/04

REF. NO.
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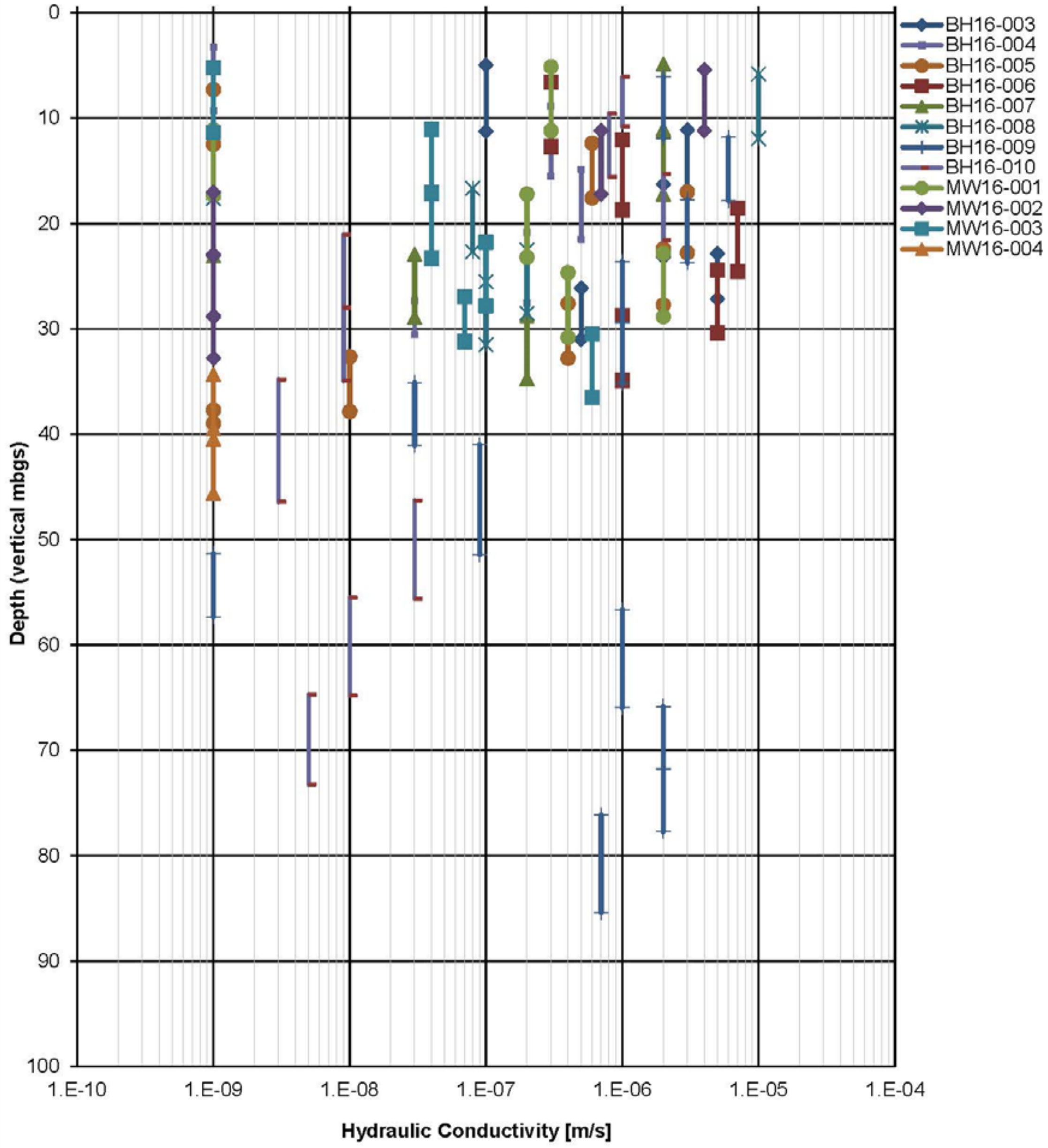
Figure 10.4-6: Hydraulic Conductivity (K) in the Bromley Humps TSA versus Depth (2016 Site Investigation)



NOTES:

1. HYDRAULIC CONDUCTIVITY DATA FROM GOLDER (1996). ALL RESULTS FROM IN-SITU PACKER TESTS.
2. TESTS REPORTED AS NO TAKE IN KP (2016) ASSIGNED AS 1E-9 m/s.FOR PLOTTING PURPOSES.
3. SEE TABLE B2 IN APPENDIX B FOR PACKER TEST RESULTS SUMMARY.

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RED MOUNTAIN UNDERGROUND GOLD PROJECT

BEDROCK HYDRAULIC CONDUCTIVITY WITH DEPTH
(2016 SITE INVESTIGATION)

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10.4.4.3.2 Groundwater Levels

Water levels were collected in 1996 and 2016. The 1996 levels were measured at all the installations, during drilling, and at the end of the site investigation (Golder 1996a); these manual measurements are the only recorded water levels from the 1996 installations. The 2016 levels included measurements from all the new installations; i.e., four monitoring wells, four standpipe piezometers, and seven vibrating wire piezometers in six drill holes. Water level loggers (Mini-divers manufactured by Van Essen) were installed in three monitoring wells and four standpipe piezometers.

The observations of groundwater levels confirmed that groundwater flow is controlled by topography with the flow towards Bitter Creek. The groundwater table elevations in the TMF area range between 375 masl and 475 masl. Relatively deep water levels (greater than 30 mbgs) and downward gradients were observed during drilling and from monitoring sites. The relatively rapid response to rainfall events noted at almost all the installations suggest there is substantial local meteoric recharge (including both rainfall and snowmelt). Groundwater level increases of over 5 m were recorded (BH16-001, BH16-007, MW16-002, and MW16-004) and daily precipitation totals of up to 65 mm (regional Terrace A station) were recorded indicating relatively high local recharge rate.

The reported substantial changes in groundwater level over short distances are consistent with a groundwater flow regime influenced by structures. Therefore, structures are expected provide preferential groundwater seepage pathways away from the TMF.

10.4.4.3.3 Hydrogeological Units

Bromley Humps has no major aquifer, three types of potential minor aquifers (i.e., overburden, undifferentiated fractured bedrock, and high K fractures or faults), and potentially low K structures that could act as aquitards.

Minor Aquifers

- The overburden cover consists of colluvium and glacial moraine deposits. It is sparse and, where encountered, generally thin (average thickness of 1.8 m).
- The bedrock units (i.e., mainly siltstone with intrusions of gabbro, quartz monzonite, and Goldslide porphyry) are grouped as one hydrogeological unit because there are no apparent differences of rock type influencing K. K has a geomean of 3×10^{-7} m/s, is interpreted to be primarily related to fractures, and tends to decrease with depth. The shallow bedrock has more permeability with values up to about 1×10^{-5} m/s in the upper 30 m.
- Permeable structures have been identified with K values up to 1×10^{-6} m/s.

Aquitards (impermeable units)

- Low K fractures or faults are potentially present but not specifically identified with the current dataset. If present, low K fractures or faults could create local impermeable barriers and compartments.

10.4.4.3.4 Groundwater Flow

Groundwater flow is driven by the relative elevation. The system is conceptualized as an upper vertical flow regime below which a regional sub-horizontal flow regime is present; the primary groundwater flow directions (i.e., regional deep system) are from upslope to the Bitter Creek valley and the secondary flow directions (i.e., localized shallow system) towards depressions in the topography. A groundwater mound is expected below Bromley Humps resulting in shallow flow from the crest of Bromley Humps to the northeast and southwest toward the TMF area. Deep groundwater flows under the TMF area towards Bitter Creek. The conceptual flow regime is shown on Figure 10.4-7 and Figure 10.4-8.

The deep groundwater system is recharged on the slopes above the TMF as well as locally in the TMF area. Local recharge enters the shallow groundwater regime and migrates downwards and laterally. The relatively recent glaciation and permafrost action likely resulted in disturbances of the near surface bedrock that potentially enhanced permeability and effective porosity, allowing higher recharge rates during rain and snowmelt events, particularly on this terrace like feature. Local recharge in the TMF area was estimated as 4 L/s based on an assumed recharge rate of 1,000 mm/year and the approximate surface area of the plateau.

Most groundwater bypassing or originating in the TMF area is expected to discharge into Bitter Creek. There may also be local discharges to nearby unmapped channels, to seeps or springs located low in the relief area to the northwest of the TMF area, and to seeps or springs along the slope above Bitter Creek. Groundwater flow migrating from upslope of the TMF area was estimated to be about 16 L/s, while groundwater flow past the TMF North and South Embankment areas was estimated to be 4 L/s each, and groundwater migrating from upslope that bypasses the TMF area was estimated to be 12 L/s. These rates were estimated using Darcy's Law and the following assumptions:

- K of 1×10^{-6} m/s based on the expected upper bound for the bulk value of the bedrock, 1×10^{-6} m/s for the South Embankment and a slightly higher value of 3×10^{-6} m/s for the North Embankment.

- An upslope hydraulic gradient of 0.7 m/m, which represents an average slope of the ground above the TMF, assumed to be equivalent to the water table. The hydraulic gradient was estimated as 0.2 m/m for the North Embankment and 0.5 m/m for the South Embankment.

- An upslope area of about 22.5 km^2 based on a length of 750 m (approximately the lateral extent of the TMF) and a thickness of 30 m of rock (assuming the upper rock will be the most permeable and therefore dominant flow path). The areas for the North and South embankments were assigned based on the approximate length of each alignment and a thickness of 30 m. The groundwater bypass area assumes that half of the flow discharging below the embankments originates from local recharge.

Figure 10.4-7: Conceptual Baseline Piezometric Contours and Flow Direction for the Bromley Humps TSA (Plan View)

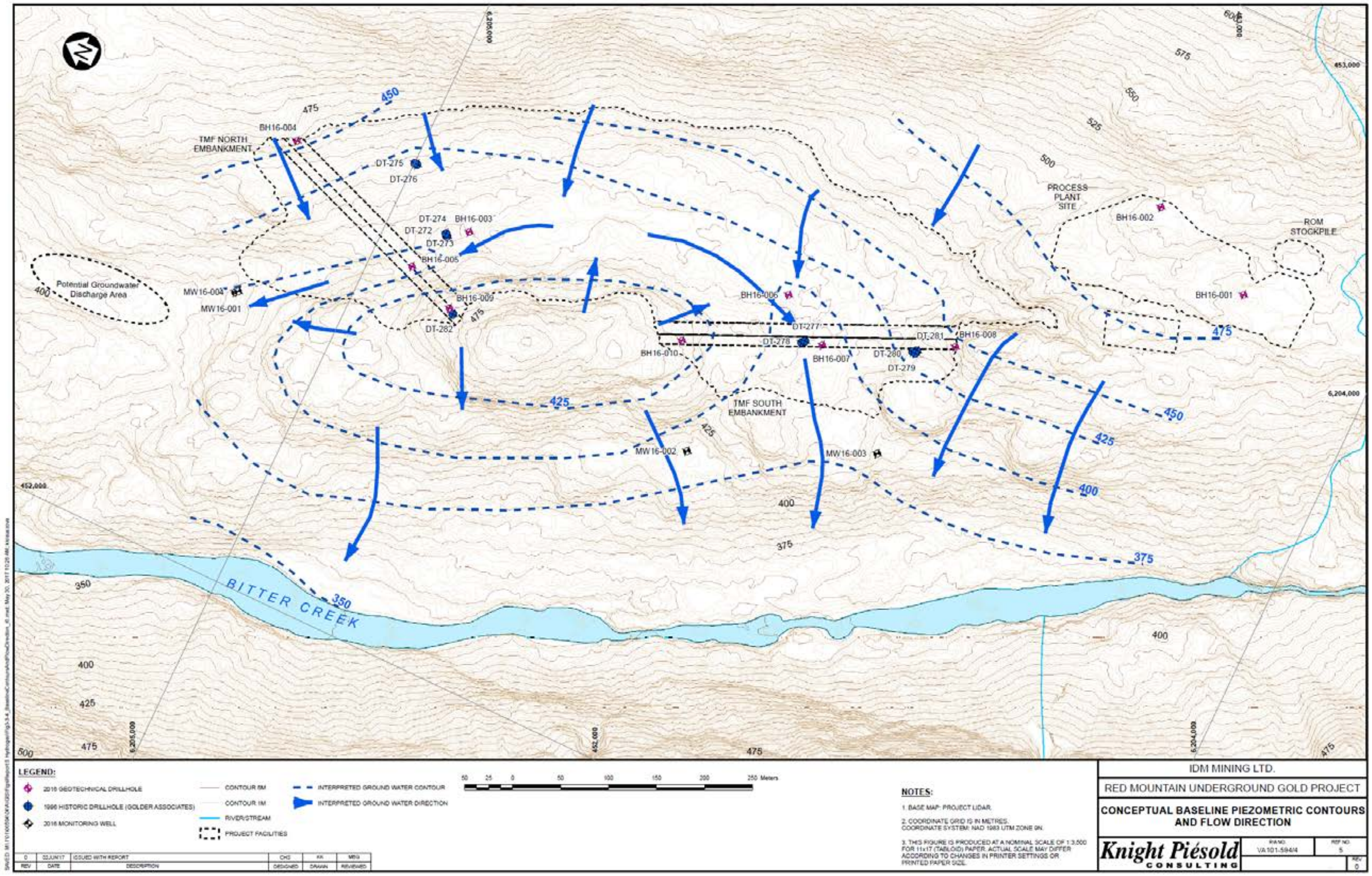
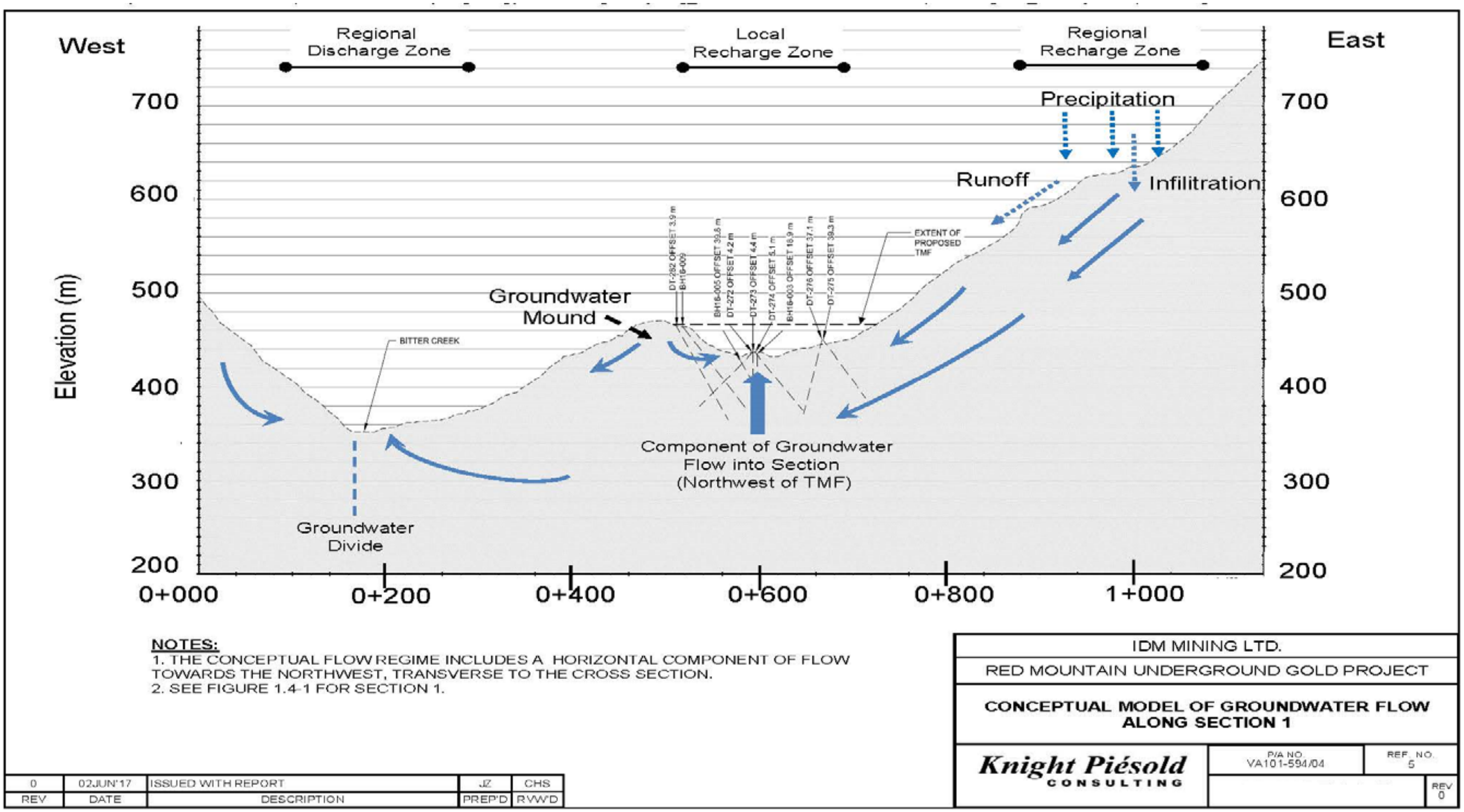


Figure 10.4-8: **Conceptual Groundwater Flow for the Bromley Humps TSA (Cross Section)**



NOTES:
1. THE CONCEPTUAL FLOW REGIME INCLUDES A HORIZONTAL COMPONENT OF FLOW TOWARDS THE NORTHWEST, TRANSVERSE TO THE CROSS SECTION.
2. SEE FIGURE 1.4-1 FOR SECTION 1.

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10.5 Potential Effects

10.5.1 Methods

A scoping exercise was undertaken to identify the Project components and activities that could be expected to interact with Hydrogeology and cause a potential effect to the groundwater flow system. The potential interactions were identified based on professional experience with other mining projects in BC and through multi-disciplinary consultation with external consultants working on behalf of IDM.

The feedback received during IDM's consultation efforts (as outlined in Table 10.3-1) informed the scoping and identification of potential interaction and effects on Hydrogeology.

10.5.2 Project Interactions

Table 10.5-1 presents the Project components/activities and the expected degree of interaction with Hydrogeology. Key interactions have been bolded.

Table 10.5-1: Potential Project Interactions, Hydrogeology

Project Component or Activity	Potential Effect / Pathway of Interaction with Hydrogeology
Construction Phase	
Excavate and secure Lower Portal entrance and access tunnel.	**Changes to site drainage patterns and subsurface characteristics due to construction works; changes to groundwater flow caused by dewatering.**
Construct Mine Site water management infrastructure including talus quarries and the portal collection pond, dewatering systems, and water diversion, collection and discharge ditches and swales.	Changes to subsurface characteristics due to construction works; changes to site drainage patterns and groundwater flow caused diversions and infiltration through and mounding of water table underneath organics stockpiles.
Install and fill Fuel Tanks at Mine Site.	Changes to site drainage patterns due to construction works and diversions; changes to subsurface characteristics and groundwater flow caused by water management activities.
Construct other Mine Site ancillary buildings and facilities.	Same as above.
Discharge of water from underground workings at the Mine Site.	**Changes to subsurface characteristics and groundwater flow caused by mining and dewatering.**
Initiate underground lateral development and cave gallery excavation.	**Same as above.**

Project Component or Activity	Potential Effect / Pathway of Interaction with Hydrogeology
Temporarily stockpile ore at the Mine Site	Changes to site drainage patterns, subsurface characteristics and groundwater flow caused by deposition of material and water management activities and infiltration and mounding of water table underneath stockpiles.
Install construction and permanent ventilation systems and underground water pumps.	Changes to site drainage patterns due to construction works and diversions; changes to subsurface characteristics and groundwater flow caused by water management activities.
Transport and deposit waste rock to the Waste Rock Storage Area (WRSA).	Changes to site drainage patterns, subsurface characteristics and groundwater flow caused by deposition of material and water management activities and infiltration and mounding of water table underneath stockpiles.
Clear and prepare the Tailings Management Facility (TMF) basin and Process Plant site pad.	Changes to site drainage patterns due to construction works and diversions; changes to subsurface characteristics and groundwater flow caused by water management activities.
Excavate rock and till from the TMF basin and local borrows/quarries for construction activities (e.g. dam construction for the TMF).	Changes to site drainage patterns due to construction; changes to groundwater flow through changes to local scale flow or drainage pathways.
Establish water management facilities including diversion ditches for the TMF and Process Plant.	Changes to site drainage patterns due to construction works and diversions; changes to subsurface characteristics and groundwater flow caused by water management activities.
Construct the TMF.	Changes to site drainage patterns, subsurface characteristics, and groundwater flow due to construction works.
Construct the Process Plant and Run of Mine (ROM) Stockpile.	Changes to watercourses and site drainage patterns due to construction and diversions; changes to subsurface characteristics due to construction and deposition of material, changes to groundwater flow paths caused by infiltration and mounding of water table underneath ore stockpile.
Construct water treatment facilities and test facilities at Bromley Humps.	Changes to site drainage patterns, subsurface characteristics, and groundwater flow due to construction works.
Operation Phase	
Continue underground lateral development, including dewatering	**Changes to subsurface characteristics and groundwater flow caused by mining and dewatering.**
Haul waste rock from the declines to the WRSA for disposal (waste rock transport and storage).	Changes to site drainage patterns, subsurface characteristics and groundwater flow caused by deposition of material and water management activities and infiltration and mounding of water table underneath WRSA.
Extract ore from the underground load-haul-dump and transport to Bromley Humps to ROM Stockpile (ore transport and storage).	Changes to subsurface characteristics and groundwater flow caused by infiltration through and mounding of water table underneath ore stockpile.
Pump process water from the TMF (reclaim water) to supply the Process Plant.	Changes to groundwater flow caused by infiltration underneath the facility.

Project Component or Activity	Potential Effect / Pathway of Interaction with Hydrogeology
Pump tailings and waste water to the TMF for disposal.	Same as above.
Progressively reclaim disturbed areas no longer required for the Project.	Changes to site drainage patterns due to reclamation activities; changes to groundwater flow through changes to local scale flow or drainage pathways.
Install bulkhead(s) in the declines and ventilation exhaust raise.	**Changes to subsurface characteristics and groundwater flow because of the bulkhead installation.**
Closure and Reclamation Phase	
Flood underground.	**Changes to groundwater flow because of flooding.**
Decommission and reclaim Lower Portal area and Powerline.	Changes to site drainage patterns due to decommissioning activities; changes to groundwater flow through changes to local scale flow or drainage pathways.
Decommission and reclaim Haul Road.	Same as above.
Decommission and reclaim all remaining mine infrastructure (Mine Site and Bromley Humps, except TMF) in accordance with the Closure and Reclamation Chapter (Volume 2, Chapter 5).	Same as above.
Conduct maintenance of mine drainage, seepage, and discharge.	Changes to subsurface characteristics and groundwater flow caused by maintenance work and infiltration through water management features.
Remove discharge water line and water treatment plant.	Changes to site drainage patterns due to decommissioning activities; changes to groundwater flow through changes to local scale flow or drainage pathways.
Decommission and reclaim Access Road.	Same as above.
Post-Closure Phase	
Flood underground.	**Changes to groundwater flow because of flooding.**

10.5.3 Discussion of Potential Effects

Potential activities that are likely to influence groundwater flows include development, dewatering and reflooding of the underground mine resulting from modifications to the subsurface characteristics and groundwater flow. The key issue from a groundwater quantity perspective is potential effects on groundwater discharges into nearby creeks. The specific activities that fall within this group are:

- Excavate and secure Lower Portal entrance and access tunnel;
- Initiate and continue underground lateral development and cave gallery excavation, including dewatering and discharge of water from underground;

- Install bulkhead(s) in the declines and ventilation exhaust raise; and
- Flood underground.

The TMF will be fully lined. Unless there are defects through the high-density polyethylene (HDPE) geomembrane, there will be no leakage under the facility. The upper bound seepage losses through the TMF geomembrane liner during operations was calculated to be minimal, less than 0.2 L/s (Appendix 10-B). Given the relatively small footprint area of the TMF, the potential decrease in recharge is not expected to have an appreciable effect on downgradient groundwater flow. Therefore, further assessment is not warranted.

All other activities listed in Table 10.5-1 are anticipated, based on professional judgment, to have limited localized effects to the hydrogeology and no adverse effect. Therefore, further assessment is not warranted.

10.5.3.1 Changes to Subsurface Characteristics and Groundwater Flow

During mining operations, the effects on the groundwater flow system will be dominated by underground water management, drilling, blasting, excavation, and backfilling activities. Drilling, blasting, excavation, and backfilling activities may enhance the hydraulic conductivity and lead to increased drawdown near the mine during operations and through to post-closure. The deepest mine excavation will be at an elevation of approximately 1,636 masl[1]. The Lower Portal will provide access to the lower levels of the underground workings located at an approximate elevation of 1,710 masl. Dewatering activities will result in a drawdown of the water table that will gradually expand over time if dewatering continues. The changes in groundwater levels and flow may induce a seasonal reduction of the groundwater discharges (i.e., baseflow) to Goldslide Creek and Rio Blanco Creek. Conversely, inflows reporting to the underground mine will need to be discharged to the environment. The potential effects of these activities on Hydrogeology were evaluated using a numerical groundwater model, as described in Appendix 10-A. A summary of the predictive results is provided in Section 10.7 of this Chapter. In the Hydrogeology Effects Assessment, the effect of groundwater changes to baseflow is evaluated independently from the effect of discharges from the mine into the creeks. The Hydrology Chapter (Volume 3, Chapter 12) integrates the predictions of groundwater discharges from the mine to evaluate the combined effects of the changes to baseflow combined with discharges of the water management system to the creeks.

At closure, a hydraulic bulkhead will be constructed in the lower access ramp, and pumps/drains will be shut off to allow reflooding of the mine. As the mine floods, the drawdown induced during operations will decrease, and the reductions in baseflow to nearby streams will diminish over time.

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[1] Elevations reported herein are based on the pre-feasibility level mine plan and differ slightly from the current mine design. For example, the Lower Portal elevation is now at an elevation of 1710 masl. The differences are not expected to result in an appreciable difference in the results of numerical modelling or other methods used to evaluate the potential effects of mine development.

At post-closure, the groundwater system at the Mine Site will return to near baseline conditions. There may be a small zone of residual drawdown remaining due to the changes of hydraulic properties in the mine and if there are surface openings at crown pillars.

10.6 Mitigation Measures

10.6.1 Key Mitigation Approaches

Results from the review of best management practices, guidance documents, and mitigation measures conducted for similar projects, as well as professional judgment for the Project-specific effects and most suitable management measures, were considered in determining the mitigation measures. The approach to the identification of mitigation measures subscribed to the mitigation hierarchy, as described in the Environmental Mitigation Policy for BC (http://www.env.gov.bc.ca/emop/).

Potential Project-related changes to Hydrogeology will be reduced through mitigation measures, management plans, and adaptive management. If mitigation measures were considered entirely effective, potential Project-related effects to the Hydrogeology IC were not identified as residual effects.

Specific mitigation measures were identified and compiled for each category of potential effect on Hydrogeology and presented in this section. For the purposes of this assessment, mitigation measures included any action or Project design feature that will reduce or eliminate effects to the Hydrogeology IC. Key approaches include:

- Design Mitigation; and
- Best Management Practices (BMPs).

Technical and economic feasibility constraints dictated the highest level on the hierarchy that could be achieved for each potential effect and the identification of mitigation measures for managing these effects.

During the Construction and Operation Phases, no specific mitigation measures are proposed or currently planned to limit inflows to the mine workings, although backfilling may result in a slight decrease in inflows and therefore drawdown. However, there are opportunities for adaptive management if inflows are greater than expected. The monitoring of the mine inflows and groundwater monitoring stations during operations will be used to evaluate whether additional measures are needed as mining continues. Potential mitigation measures include the application of shotcrete to seal exposures of materials, the construction of additional plugs and seals (e.g. grouting) in the underground workings, or barriers to limit the movement of groundwater.

For post-closure conditions, the long-term mitigation strategy to limit effects on Hydrogeology is the installation of hydraulic plugs at all three portal locations to allow flooding of the underground workings and re-establish the pre-mining conditions. Plugging of the underground workings and subsequent flooding will:

- Prevent discharge of mine influenced groundwater out of the decline;

- Permit re-establishment of near pre-mining groundwater levels; and

- Limit potential for long-term metal leaching and acid rock drainage (ML/ARD) of backfilled rock.

As described previously, the TMF will be fully lined during operations and will be covered with a liner and soil cover at closure to minimize infiltration of water from the TMF to the groundwater system.

10.6.2 Environmental Management and Monitoring Plans

The management of water on site, including groundwater, will be guided by several Environmental Management Plans (EMPs), which will define the standard operating procedures, the BMPs, the adherence to existing environmental regulations, and the use of appropriate design criteria. The list below compiles the EMPs with a potential linkage to the Hydrogeology IC:

- Aquatic Effects Management and Response Plan;
- Groundwater Monitoring Plan;
- Site Water Management Plan;
- Material Handling and ML / ARD Management Plan; and
- Measures outlined in Mine Closure and Reclamation (Volume 2, Chapter 5).

EMPs are discussed in detail in Volume 5, Chapter 29.

10.6.3 Effectiveness of Mitigation Measures

The anticipated effectiveness of mitigation measures to minimize the potential for significant adverse effects is evaluated and classified as follows within this section:

- Low effectiveness: Proposed measure is experimental or has not been applied in similar circumstances.

- Moderate effectiveness: Proposed measure has been successfully implemented but perhaps not in a directly comparable situation.

- High effectiveness: Proposed measure has been successfully applied in similar situations.

- Unknown effectiveness: Proposed measure has unknown effectiveness because it has not been implemented elsewhere in a comparable project or environment.

The key measures proposed for mitigating potential effects on the Hydrogeology IC from changes to subsurface characteristics and groundwater flow, along with mitigation effectiveness and uncertainty, are outlined in Table 10.6-1. This table also identifies the residual effects that will be carried forward for residual effects characterization and significance determination.

Backfilling is not expected to have an appreciable effect on inflows but is important for maintaining the stability of the mine and therefore integrity of the surrounding rock. As a mitigation measure, it is considered to have a relatively low degree of effectiveness. In contrast, the hydraulic plug is expected to have a high degree of effectiveness in restoring groundwater levels to current conditions. Hydraulic plugs have been implemented and proposed and a number of other underground mine sites and are viewed as a proven technology for limiting flow from underground mine. Therefore, there is a reasonably high degree of confidence in the effectiveness rating for this mitigation measure. The timing for the mitigation measures to become effective is expected to be immediate upon implementation.

Table 10.6-1: Proposed Mitigation Measures and their Effectiveness

VC/IC	Potential Effects	Mitigation Measures	Rationale	Applicable Phase(s)	Effectiveness[1]	Uncertainty[2]	Residual Effect
Hydrogeology	Changes to subsurface characteristics and groundwater flow	The mining method being employed is longhole stoping utilizing cemented rock fill as a structural backfill and backfilling of waste rock material. The mining and backfilling will be designed such that interaction with the hydraulic regime is minimized. Surface disturbance by mining will be limited to the Upper Portal, Lower Portal, and Vent Portal.	Maintains stability of the mine and integrity of the surrounding rock	Operation	Low	Low	Yes
		Hydraulic plugs will be installed and the underground will be flooded to prevent continued geochemical reactivity of the fractured zone.	Limits flow from the underground mine and restores groundwater levels to pre-disturbance conditions	Closure and Reclamation Post-closure	High	Low	Yes

[1] Effectiveness: Low = measure unlikely to result in effect reduction; Moderate = measure has a proven track record of partially reducing effects; High = measure has documented success (e.g., industry standard; use in similar projects) in substantial effect reduction

[2] Uncertainty: Low = proposed measure has been successfully applied in similar; Moderate = proposed measure has been successfully implemented, but perhaps not in a directly comparable situation; High = situations proposed measure is experimental, or has not been applied in similar circumstances

10.7 Residual Effects Characterization

This section summarizes the analyses and results used to quantify the residual effects identified in Table 10.7-1 and, more specifically, the residual effect on groundwater baseflow. Since this chapter focuses on the groundwater flow system as an effect pathway to the aquatic environment, the residual effects on Hydrology and Surface Water Quality resulting from changes in groundwater flow are presented in Volume 3, Chapters 12 and 13, respectively. In those chapters, a site-wide water and load balance is used to evaluate the effects of Project related changes in groundwater flow in the Mine Site TSA and Bromley Humps TSA on the hydrology and water quality at local and regional scales (i.e., LSA and RSA).

10.7.1 Summary of Residual Effects

Through consideration of potential effects and mitigation measures, the only residual effect associated with the Hydrogeology IC relates to changes to subsurface characteristics and the measurement indicator groundwater flow caused by the mine development and dewatering, as identified in Table 10.7-1.

10.7.2 Methods

10.7.2.1 Residual Effects Criteria

The residual environmental effects are characterized using the criteria and general definitions presented in Volume 3, Chapter 6. Further details specific to the hydrogeological effects are summarized in Table 10.7-1.

Table 10.7-1: Characterization of Residual Effect on Hydrogeology

Criteria	Interaction with Hydrogeology
Magnitude	The reduction of creek baseflow was evaluated using similar criteria as those defined for hydrology (Volume 3, Chapter 12). Further rational for these flows are presented in Volume 3, Chapter 12. **Negligible**: a decrease of less than 10% **Low**: a decrease of 10-20% **Moderate:** a decrease of 20-40% **High:** a decrease of more than 40% Changes in baseflow are evaluated at GSC2 on Goldslide Creek, RBC02 on Rio Blanco Creek, and BC08 on Bitter Creek (Figure 12.3-1 in Volume 3 Chapter 12). Increases in creek baseflows of less than 15% are also considered to be negligible given that seasonal flows in the creeks are orders of magnitude higher than baseflow values.

Criteria	Interaction with Hydrogeology
Geographical Extent	Geographic extent of potential effects were defined relative to the study boundaries defined in Section 10.3.4.1, as follows: **Discrete:** effect is limited to the TSA. **Local:** effect is limited to the LSA. **Regional:** effect occurs throughout the RSA. **Beyond regional:** effect extends beyond the RSA.
Duration	**Short-term (ST):** effect lasts less than 18 months (during the Construction Phase of the Project). **Long-term (LT):** effect lasts greater than 18 months and less than 22 years (encompassing Operation, Reclamation and Closure, and Post-Closure Phases). **Permanent (P):** effect lasts more than 22 years.
Frequency	**One time**: effect is confined to one discrete event. **Sporadic**: effect occurs rarely and at sporadic intervals. **Regular**: effect occurs on a regular basis. **Seasonal / Continuous**: effect occurs seasonally or constantly (i.e., year-round).
Reversibility	**Reversible**: effect can be reversed. **Partially reversible**: effect can be partially reversed. **Irreversible**: effect cannot be reversed, is of permanent duration.
Direction	**Positive:** the residual effect has a beneficial effect (not assessed for significance). **Neutral:** the residual effect has a neutral effect (not assessed for significance). **Negative:** the residual effect has a negative effect (assessed for significance).
Context	**High**: the receiving environment has a high natural resilience to imposed stresses and can respond and adapt to the effect. **Neutral**: the receiving environment has a neutral resilience to imposed stresses and may be able to respond and adapt to the effect. **Low**: the receiving environment has a low resilience to imposed stresses and will not easily adapt to the effect.

10.7.2.2 Likelihood

Likelihood refers to the probability of the predicted residual effect occurring and is determined per the attributes listed in Table 10.7-2. The probabilities are based on qualitative judgment and common understanding of the hydrogeological system within the profession.

Table 10.7-2: Attributes of Likelihood

Likelihood Rating	Quantitative Threshold
High	More than 50% chance of effect occurring
Moderate	Equal chances of occurring or not occurring
Low	Less than 50% chance of effect occurring

10.7.2.3 Confidence and Risk

Confidence, which can also be understood as the level of uncertainty associated with the residual effects assessment (including significance determination), is a measure of how well residual effects are understood and the quality of the input data. The reliability of data inputs and analytical methods used to predict Project effects, confidence regarding the effectiveness of mitigation measures, and certainty of the predicted outcome are all considered. Confidence definitions are provided in the Effects Assessment Methodology Section of the Application/EIS (Volume 3 Chapter 6, Table 6.10-1).

10.7.2.4 Analytical Assessment Technique

The analyses of the Project's residual effects in the Mine Site TSA were performed with a predictive three-dimensional groundwater flow model, calibrated to baseline conditions, and used to evaluate:

- The quantities of groundwater intercepted by the mine and ultimately discharged from the mine during operations;
- The potential changes to creek baseflows during operations and at post-closure;
- The potential contribution of mine affected groundwater to creek baseflows at post-closure, and
- The range of water level conditions in the mine at post-closure.

Details on these analyses are provided in Appendix 10-A.

10.7.3 Potential Residual Effects Assessment

The results of the residual Project effect analyses for the Operations Phase were as follows:

- The mine inflows during operations were predicted to reach an annual average rate of about 3,810 m^3/d in Year 2 and then decrease from this point onward to about 2,640 m^3/d (i.e., Base Case). Under more conservative assumptions (i.e., Upper Case), the inflow predictions were respectively 6,400 m^3/d and 4,400 m^3/d. As discussed previously, the effects of groundwater discharges from the mine to surface water hydrology are further evaluated in Volume 3, Chapter 12.

- Mine dewatering at end of operations was predicted to extend over an area of 3.8 km^2 and a depth of 210 m at the vicinity of the Lower Portal entrance (Figure 10.7-1). This is considered to be insignificant in terms of groundwater usage since there are no groundwater resources in use close to the site.

- The model predicted a maximum average monthly reduction in baseflow during operations of about 3 to 4% at downstream stations located in Goldslide Creek at GSC02 and Rio Blanco Creek at RBC02 and 1% in Bitter Creek at BC08 (the farthest downstream station in the Red Mountain Cirque TSA). The maximum reductions were calculated to occur between March and May, at the end of the low-flow winter conditions. It must be noted that the reductions to baseflow in Goldslide and Bitter Creeks will be more than offset by the discharges to these streams (Volume 3, Chapter 12).

During operations, the residual effect on hydrogeology has a negligible magnitude because the decrease in baseflow is less than 10%. The geographic extent is discrete, because the effect is limited to the TSA. The duration is long-term, because the effect lasts throughout operations. The frequency is continuous because dewatering occurs year-round. The effect is reversible, because the effect is reversed when dewatering stops at the end of operations. The direction is negative and context is neutral.

The results of the residual project effect analyses for the Closure and Reclamation and Post-Closure Phases were as follows:

- The model predicted an increase in baseflows at downstream stations located in Goldslide Creek (GSC02, +5 to 10%), Rio Blanco Creek (RBC02, +6 to 12%), and Bitter Creek (BC08, +1 to 5%) post-closure.

- The model indicated that it would take 20 to 40 years for water levels in the mine to recover to steady state conditions. After this period, the system will have recovered to baseline conditions and the groundwater level in the mine will be expected to fluctuate seasonally. Backfilled mine workings above an elevation of 1,790 masl (the Upper Portal elevation) will remain above the zone of seasonal fluctuation.

- In terms of potential post-closure discharge of groundwater from the flooded mine into surface water, the model predicted that water from the reflooded mine will flow through the surrounding bedrock and discharge to Goldslide, Rio Blanco, or Bitter Creeks after a minimum of about 5 years for Goldslide Creek, 40 years for Rio Blanco Creek, and 90 years for Bitter Creek (see Figure 10.7-2 and Figure 10.7-3).

- The maximum contributions to creeks' baseflow are about 55% in Goldslide Creek at GSC09, 10% in Goldslide Creek at GSC02, 6% in Rio Blanco Creek at RBC02, and 2% in Bitter Creek at BC08. The predictions for BC08 are conservative as they do not account for additional unaffected baseflows from underneath the Cambria icefield. The effect of groundwater from the reflooded mine on water quality in Goldslide, Rio Blanco, and Bitter Creeks is evaluated in Volume 3, Chapter 13.

During the Closure and Reclamation and Post-Closure Phases, the residual effect on hydrogeology is negligible because the increase in baseflow is less than 15%. The geographic extent is discrete, because the effect is limited to the TSA. The duration is permanent, because the effect lasts from Closure and Reclamation onward. The frequency is continuous because the effect occurs year-round. The effect is irreversible because the effect is permanent. The direction is negative, and the context is neutral.

Further details, including the following, regarding changes to hydrogeology and groundwater flow regimes can be found in Volume 8, Appendix 10-A:

- The quantity of groundwater intercepted by the mine during operation and until end-of-mine;
- The maximum reduction in groundwater base flow in creeks throughout the Project life;
- The quantity of groundwater losses from the flooded mine and the percent flow contribution of mine contact groundwater to creek base-flows at Post-Closure;
- The groundwater pathways and travel times from the mine components to the creeks; and
- The time required to reach Post-Closure conditions.

Overall, and at the scale of the LSA and RSA, the residual effect on Hydrogeology is expected to be limited to a negligible reduction in baseflow in Goldslide Creek, Rio Blanco Creek, and Bitter Creek during operations, which will be offset by the discharges to these streams. At post-closure, the effect on baseflow will be reversed and will consist of a negligible increase in baseflow in Goldslide Creek, Rio Blanco Creek, and Bitter Creek.

Figure 10.7-1: Predicted Drawdown at the Underground Mine

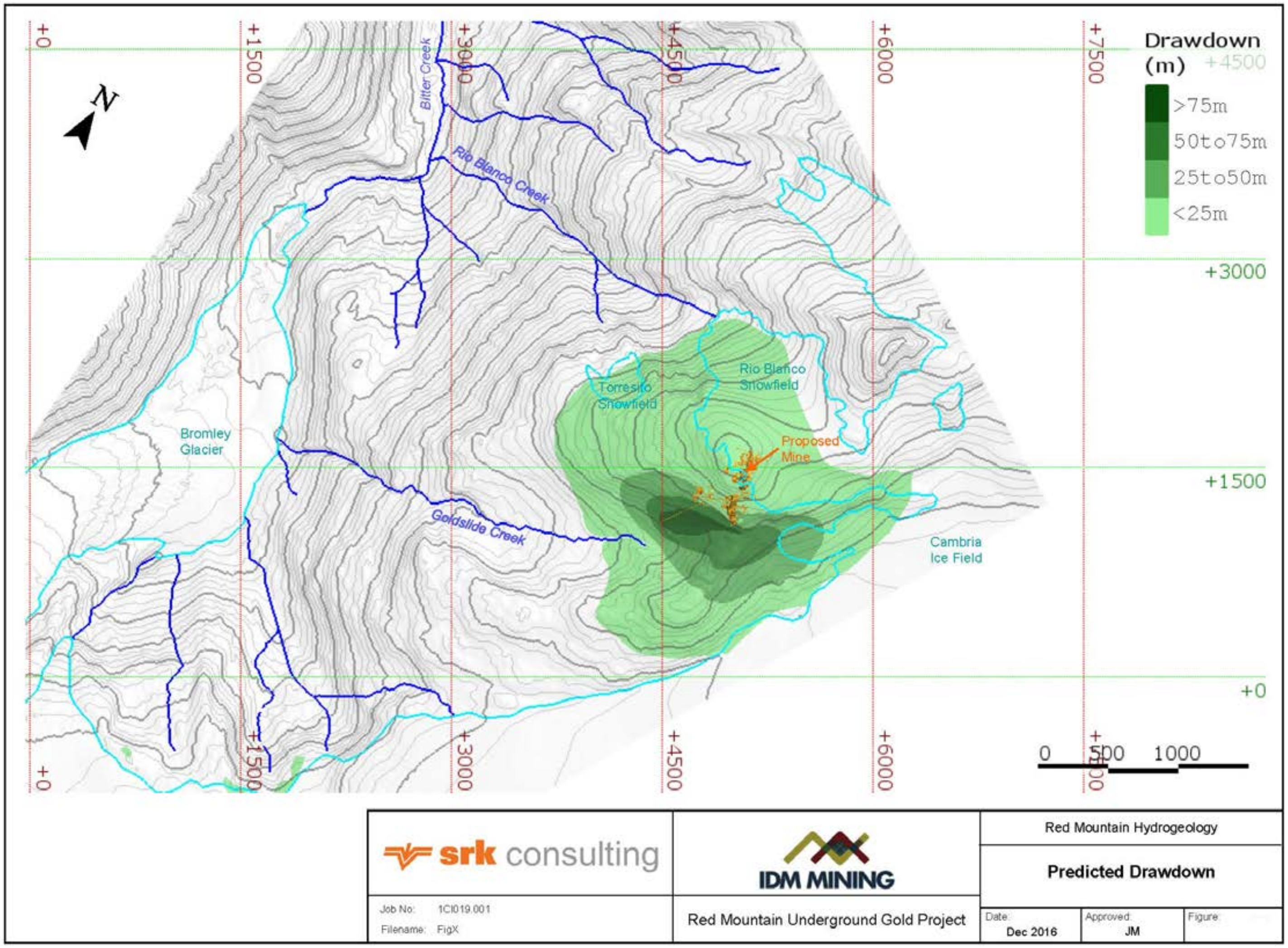


Figure 10.7-2: Particle Paths from the Mine to the Surface Water Receptors

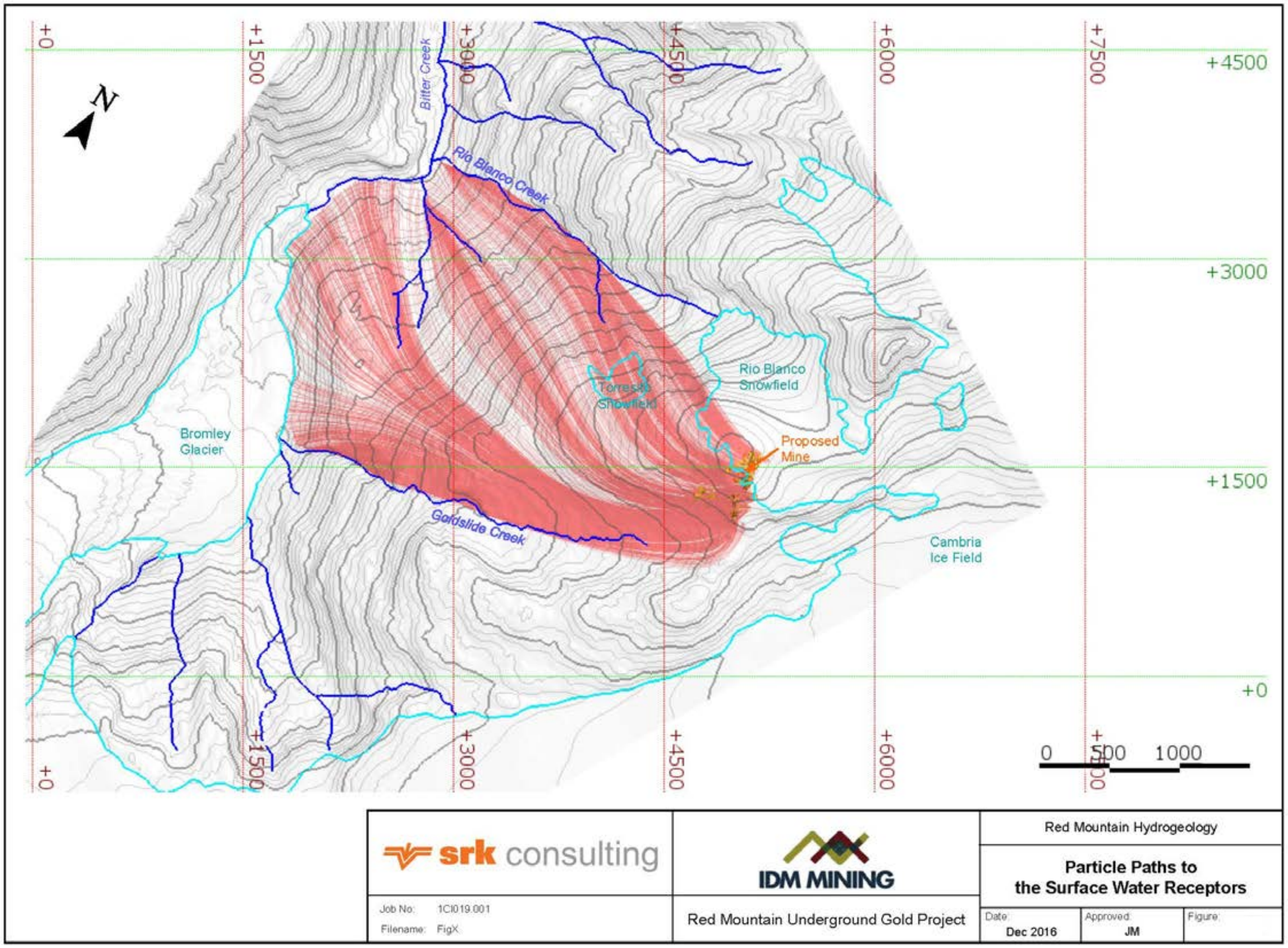
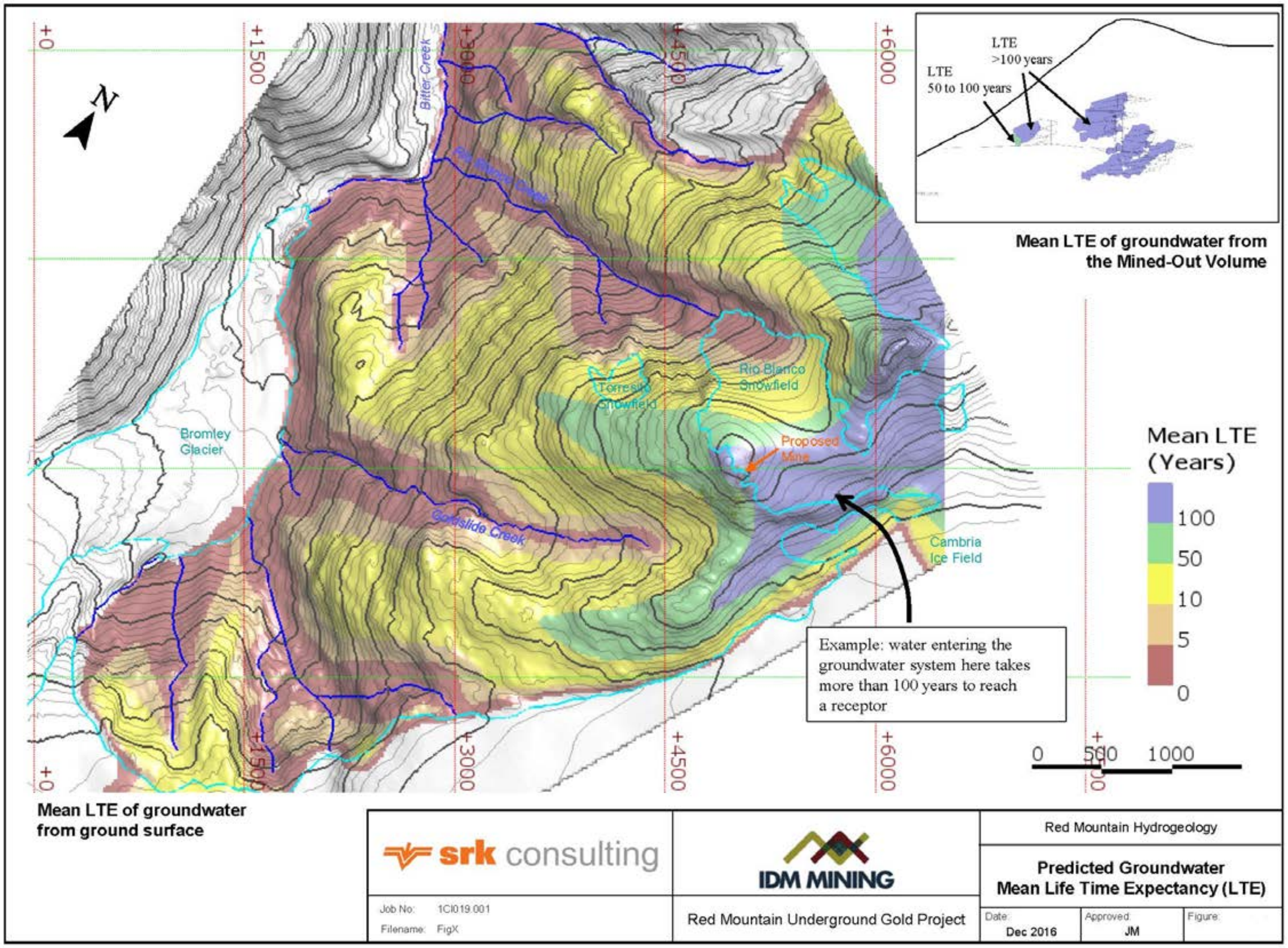


Figure 10.7-3: Predicted Groundwater Mean Life Time Expectancy (LTE) in the Mine Site TSA



10.7.4 Summary of Residual Effects Assessment

A summary of the residual effects assessment is provided in Table 10.7-3 based on the discussion in Section 10.7.3.

Table 10.7-3: Summary of the Residual Effects Assessment to the Hydrogeology

Residual Effect	Project Phase	Mitigation Measures	Summary of Residual Effects Characterization Criteria		Likelihood
Changes to subsurface characteristics and groundwater flow	O	Utilization of cemented rock fill as a structural backfill and backfilling of waste rock material.	Magnitude: Geo. extent: Duration: Frequency: Reversibility: Direction: Context:	Negligible Discrete Long-Term Continuous Reversible Negative Neutral	High
	CR, PC	Installation of a hydraulic plug in the lower access decline to allow flooding of the underground workings and re-establish the pre-mining conditions.	Magnitude: Geo. extent: Duration: Frequency: Reversibility: Direction: Context:	Negligible Discrete Permanent Continuous Irreversible Negative Neutral	High

Note: O, Operation phase; CR, Closure and Reclamation phase; PC, Post-closure phase

Confidence is considered moderate because:

- The final calibrated models reproduced the regional hydrogeological system reasonably well, with a steady-state normalized root mean squared error (NRMSE) for calculated versus observed hydraulic heads of 5.1%. NRMSE values less than 10% are commonly considered to be an acceptable level of model calibration. Seasonal water level variability at each of the four monitoring stations were consistent with the measured transient levels.

- Sensitivity analyses described in Section 6.8 of Appendix 10-A indicate that the uncertainty of the model outputs is tied to the characterization of the hydraulic conductivity field, the seasonal recharge rate R, and the determination of structures acting as major conduits. The model was developed based on the available data. At the scale of the mine site, the model simulates reasonably well the site observations and the regional behaviour of the groundwater system

- There are significant uncertainties with respect to groundwater recharge or discharge below areas covered with glaciers and the presence of geological structures (i.e., if and where large-scale fractures and faults are connected and where they act as a conduit or as a barrier to flows). These uncertainties are tied to the physical constraints of the site and cannot be easily verified from field investigations.

- Residual effects can be predicted to occur with a high degree of certainty, but factors influencing the timing, magnitude, and direction of these effects are difficult to predict accurately.

- Groundwater systems in fractured and faulted terrain are heterogeneous, more effectively understood at larger spatial scales. Prediction of residual effects at small scales are therefore uncertain. Observations of site-specific conditions allow adjustment of predictions based on professional judgment, but do not allow more precise predictions.

10.8 Cumulative Effects

10.8.1 Review Residual Effects

The only residual effect associated with the Hydrogeology IC relates to changes to subsurface characteristics and groundwater flow caused by the mine development and dewatering. The residual effect will consist of a modification to the groundwater baseflows in the creeks, predicted to be of negligible magnitude during the operations and negligible at post-closure. The effects are limited geographically to the Red Mountain Cirque TSA. Furthermore, during operation, changes to groundwater baseflow will be offset by the discharges from the mine water management system.

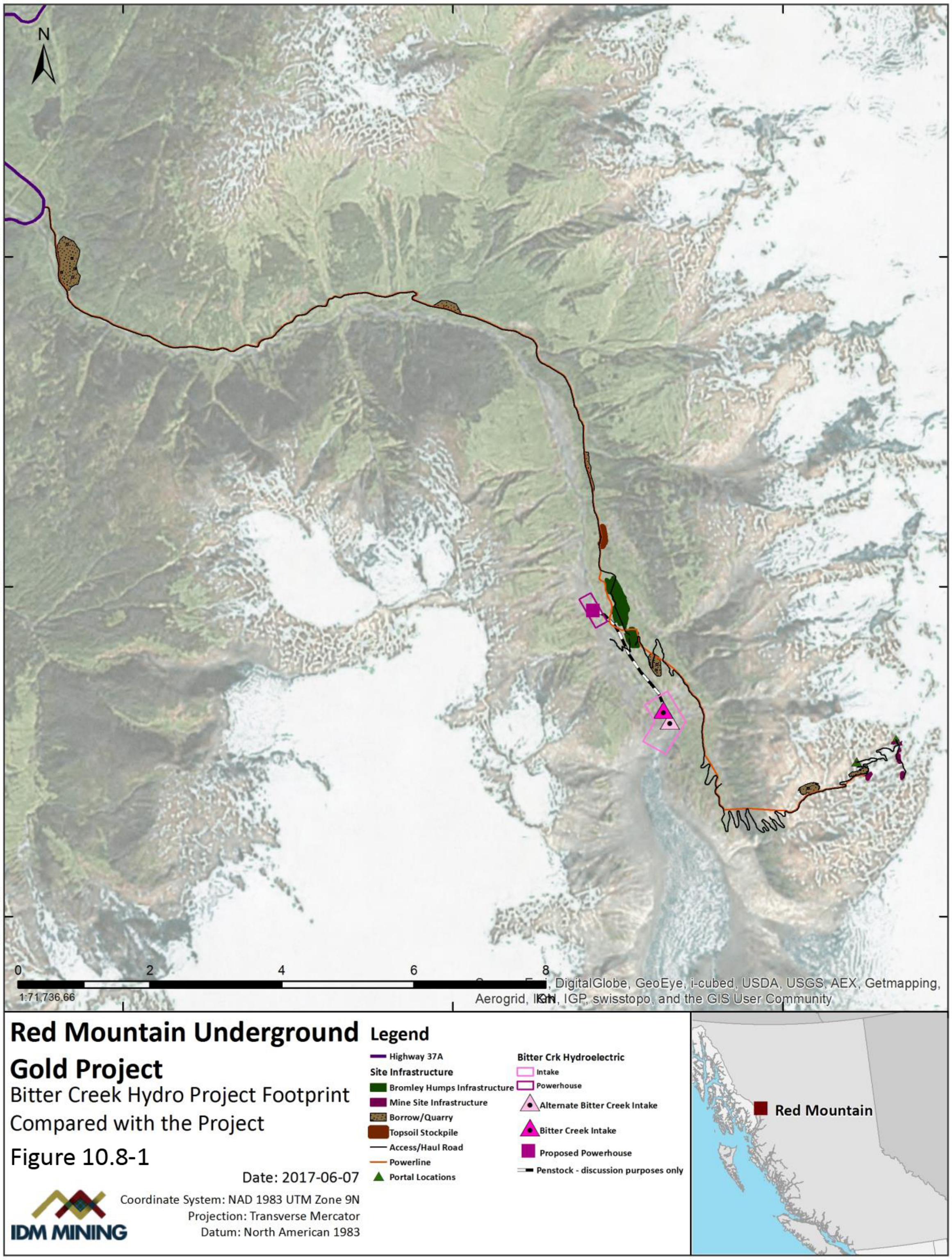
10.8.2 Cumulative Effects Assessment Boundaries

The cumulative effects assessment boundaries are identical to the spatial and temporal boundaries defined in Section 10.3.4 of this Chapter.

10.8.3 Identifying Past, Present, or Reasonably Foreseeable Projects and/or Activities

Other projects within the spatial boundaries of the cumulative effects assessment are limited to the Bitter Creek Hydro Project, as shown in Figure 10.8-1. The Bitter Creek Hydro Project involves the construction of an intake and diversion structure in the Bitter Creek valley, near the Red Mountain Cirque and Bromley Humps TSAs. A detailed description of the proposed Bitter Creek Hydro Project, including anticipated duration, is provided in the Past and Current Projects section of the Effects Assessment Methodology Chapter (Volume 3, Chapter 6).

Figure 10.8-1: Bitter Creek Hydro Project Footprint Compared with the Project



10.8.4 Potential Cumulative Effects and Mitigation Measures

10.8.4.1 Changes to Groundwater Flow

The changes to the flow in Bitter Creek from the Bitter Hydro Project could potentially affect groundwater baseflow near the creek.

10.8.5 Cumulative Effects Interaction Matrix

Table 10.8-1: Interaction with Effects of other Past, Present, or Reasonably Foreseeable Future Projects and Activities

Residual Effects of the Project	Future Projects and Activities
	Bitter Creek Hydro Project
Changes of Groundwater Flow	Y

Notes:
Y = Yes, interaction exists between the residual effect of the Project and the other past, current, or future project/activity
N = No, interaction does not exist between the residual effect of the Project and the other past, current, or future project/activity

10.8.6 Cumulative Effects Characterization

10.8.7 Changes to Groundwater Flow

Potential changes to groundwater baseflow caused by the Project are predicted to be low to negligible. The changes to hydrogeology caused by the Bitter Creek Hydro Project components are expected to be negligible because the changes in water levels in Bitter Creek, and the interactions with groundwater (i.e., infiltration of water from or drainage of groundwater to the project components) is expected to only affect the hydrogeology in the immediate vicinity of the Bitter Creek valley. The difference in groundwater elevations between the mountain’s top and the Bitter Creek valley is at least 1,100 m (i.e., approximately 1,760 masl minimum at the Red Mountain top; 500 masl at the south end and 350 masl at the north end of the Bitter Creek Hydro Project). Even a change of several meters in the water levels of the Bitter Creek would not modify significantly the gradients driving groundwater baseflows into Bitter Creek.

If the Bitter Creek Hydro Project was in operation when the mining started, the combined effect of these two projects to the groundwater baseflow in Bitter Creek would be expected to be negligible during operations and at post-closure.

10.8.8 Summary of Cumulative Effects Assessment

Table 10.8-2: Summary of Residual Cumulative Effects Assessment

Project Phase	IC	Residual Cumulative Effect	Characterization Criteria	Likelihood	Confidence
O	Hydrogeology	Changes to groundwater baseflows in Bitter Creek	Magnitude: Negligible Geo. extent: Discrete Duration: Long Term Frequency: Continuous Reversibility: Reversible Context: Neutral	High	Moderate
CR, PC			Magnitude: Negligible Geo. extent: Discrete Duration: Permanent Frequency: Continuous Reversibility: Irreversible Context: Neutral		

10.9 Follow-up Program

IDM has identified a follow-up strategy to evaluate the accuracy of effects predictions and effectiveness of proposed mitigation measures in regards to Hydrogeology. The strategy focuses on implementation of the Site Water Monitoring Program contained within the Site Water Management Plan (Volume 5, Chapter 29.18). The purpose of this program is to minimize the effects of the Project's activities on surface and groundwater, monitor the results of mitigation to ensure effectiveness, and adaptively manage for any unanticipated effects resulting from the Project.

The Site Water Management Plan involves the implementation of widely recognized BMPs and the development of procedural mitigation measures during Project planning to minimize anticipated effects. The monitoring program is intended to detect unanticipated effects where adaptive management protocols will be triggered. Many mitigation measures have already been implemented during the planning stages of the Project. These include Project design such as site selection, selection of best available technologies to-date for Project infrastructure and mining equipment, and a commitment to progressive reclamation.

If original predictions of effects and mitigation effectiveness are not as expected, adaptive management principles and strategies will be implemented. Adaptive management will require consideration of monitoring results, management reviews, incident investigations, shared traditional, cultural, or local knowledge, new or improved scientific methods, regulatory changes, or other Project-related changes. Mitigation and monitoring strategies for groundwater will be updated to maintain consistency with action plans, management plans, and BMPs that may become available during the life of the Project. Key stakeholders, Aboriginal Groups, and government agencies will be involved, as necessary, in developing effective strategies and additional mitigation.

The follow-up strategy will also incorporate means to evaluate the effectiveness of implemented mitigation. Adaptive management principles rely on this evaluation to assess whether further mitigation is required to achieve desired outcomes. IDM will report on Project mitigation and monitoring activities related to the site water monitoring program section(s) of reporting requirements stipulated in operational permits.

IDM will review the results of the monitoring program on a frequency to be stipulated by future permit conditions and develop a detailed report on trends in monitoring indicators. Statistical analyses of the monitoring results will be performed, where appropriate.

10.10 Conclusion

Mine Site

Alteration to the hydraulic conductivity from mining and dewatering activities will cause a drawdown of the water table centred about the underground workings that will gradually expand over time for as long as dewatering continues. The extent and maximum drawdown (3.8 km^2 and 210 m depth at the vicinity of the Lower Portal entrance) are insignificant in terms of groundwater usage since there are no groundwater resources in use close to the site. The changes in groundwater levels and flow may induce a seasonal reduction of the groundwater discharges (i.e., baseflow) of about 3 to 4% at downstream stations located in Goldslide and Rio Blanco Creeks and 1% in Bitter Creek. The maximum reductions are calculated to occur between March and May, at the end of the low-flow winter conditions.

At closure, the installation of a hydraulic plug in the lower access decline will prevent the direct discharge of mine influenced groundwater out of the decline, allow flooding of the underground workings for the re-establishment of the pre-mining conditions and limit potential for ML/ARD of backfilled rock. Modelling indicates that water levels are expected to reach steady-state conditions after a period of 20 to 40 years.

Post-closure, flow from the flooded workings is expected to migrate through fractured bedrock and discharge to surface water receptors after a minimum of about 5 years for Goldslide Creek, 40 years for Rio Blanco Creek, and 90 years for Bitter Creek. The maximum contributions to creeks' baseflow are about 55% in Goldslide Creek at GSC09, 10% in Goldslide Creek at GSC02, 6% in Rio Blanco Creek at RBC02, and 2% in Bitter Creek at BC08. The predictions for BC08 are conservative as they do not account for additional unaffected baseflow from underneath the Cambria icefield.

Cumulative effects to Hydrogeology are expected to be negligible in the LSA and RSA.

Bromley Humps

The TMF will be a fully lined facility hence there will be no leakage under the facility unless there are defects through the HDPE geomembrane. The upper bound seepage losses through the TMF geomembrane liner during operations is calculated to be less than 0.2 L/s. Given the relatively small footprint area of the TMF, the potential decrease in recharge at this location is not expected to result in a noticeable change in the groundwater flow regime.

At closure, the TMF will be covered with a geomembrane liner and soil cover to minimize infiltration. A permanent spillway from the TMF will be established. All infrastructure will be removed and disturbed sites re-graded to natural slopes.

Residual Effects

Hydrogeology (i.e., groundwater flow system) forms an effect pathways to the aquatic environment, such that residual effects caused by the Project to Hydrogeology can potentially effect the aquatic environment. There is no residual effect expected for Hydrogeology beyond the limits of the Mine Site TSA. The residual effect for Hydrogeology in the Mine Site TSA (i.e. changes to subsurface properties and groundwater flow) have been integrated to the site-wide water and load balance model to evaluate the significance of these effects to the aquatic environment. The linkages to other components include the surface Hydrology (Volume 3 Chapter 12), Surface Water Quality (Volume 3 Chapter 13), Aquatic Resources (Volume 3 Chapter 17), and Fish and Fish Habitat (Volume 3 Chapter 18).

The results of the Hydrogeology Effects Assessment show that there will be no effects to Hydrogeology outside of Canada.

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