Appendix 5-C

Brucejack Project Environmental Assessment – Water Management Plan

ERM

Pretium Resources Inc.

BRUCEJACK PROJECT ENVIRONMENTAL ASSESSMENT – WATER MANAGEMENT PLAN

FINAL REPORT

PROJECT No: 1008-010

DATE: June 6, 2014

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PRETIUM RESOURCES INC.

BRUCEJACK PROJECT ENVIRONMENTAL ASSESSMENT

WATER MANAGEMENT PLAN

FINAL

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June 6, 2014
Project No: 1008-010-0404

Ian Chang, Vice President, Project Development
Pretium Resources Inc.
#1600 – 570 Granville Street
Vancouver, B.C., V6C 3P1

Dear Mr. Chang,

Re: Brucejack Project Environmental Assessment – Water Management Plan – FINAL

Please find attached a copy of the above referenced report dated June 6, 2014 summarizing the site-wide water management plan and water balance model results for the Brucejack Project Environmental Assessment. If you have any questions or comments, please do not hesitate to contact the undersigned.

Yours sincerely,

BGC ENGINEERING INC.
per:

Hamish Weatherly, M.Sc., P.Geo
Senior Hydrologist

EXECUTIVE SUMMARY

Pretium Resources Inc. (Pretium) is currently undertaking a Feasibility Study (FS) of the Brucejack gold-silver deposit located in northwest British Columbia, approximately 60 km north of Stewart, British Columbia. BGC Engineering Inc. (BGC) was retained by Pretium to develop a FS-level water management plan and a site-wide water balance for the proposed Brucejack Project. The Brucejack Project proposes to open a 2,700 tpd gold-silver mine that includes an underground mine targeting the gold-silver resource, a plant site and associated facilities.

This report summarizes the results of the site-wide water management plan and water balance model developed for the project area. A water balance model for the Brucejack Project was constructed using a monthly time-step. Water management will be a critical component of the project design in this high precipitation environment.

DESIGN BASIS

A combined total of 18.1 Mt of ore is proposed to be extracted from the underground mine over a 22 year period. Primary processing of the ore will be completed at a plant site on the south side of Brucejack Lake at a nominal mill throughput of 2,700 tpd. As mining progresses, 2.4 Mt of waste rock excavated from the underground mine prior to operations will be deposited into Brucejack Lake along with 9.5 Mt of flotation tailings. About 2.2 Mt of blasted rock from the plant site excavations will also be deposited in the lake during construction. An additional 8.6 Mt of tailings paste backfill and 2.0 Mt of waste rock will be deposited in the underground mine. Of the total processed mineralized material, 8.1% (approximately 1.6 Mt) will be trucked to an off-site facility as concentrate for secondary processing. Approximately 47% of the tailings will be deposited underground as paste backfill, while 53% will be discharged to Brucejack Lake at a maximum depth of 80 m.

WATER MANAGEMENT

Contact runoff is expected from three sources during construction and operations:

1. The upper laydown area where the waste rock transfer and pre-production ore will be stored.
2. The mill building and portal site which requires an extensive cut into bedrock, some of which is currently assumed to be potentially acid-generating material.
3. Groundwater seepage to the underground mine tunnels.

Runoff from the former two sources will be managed by storage and treatment. A contact water pond will be sized to contain runoff from the 24-hour, 200-year return period rainfall event plus snowmelt (~ 33,000 m^3). The contained runoff will be pumped to the water treatment plant for treatment prior to release into Brucejack Lake.

The average water requirement for the Brucejack process plant is 3,134 m^3/d (131 m^3/h) based on a nominal mill throughput of 2,700 tpd. This water is required for the tailings slurry to the lake, the underground paste backfill, the concentrate slurry, and minor evaporative losses within the plant (~ 7 m^3/d). Process water will be sourced from:

- treated underground seepage water;
- ore moisture (~3% by weight); and,
- reclaim from the lake.

Groundwater seepage into the underground workings is expected to vary from approximately 145 to 460 m^3/h through the life of mine. Seepage water will be sent to a water treatment plant for treatment before being sent to the process plant, where its use will be maximized in process. With a settled dry density of 1.46 t/m^3 and a slurry consisting of 65% solids by weight, the paste backfill will expel some water during the curing phase. This additional water is assumed to be pumped out with the seepage water and sent to treatment.

Excess treated groundwater will be used as fluidizing water and discharged to Brucejack Lake at depth. Fluidizing water is required at an average rate of 3,447 m^3/d (144 m^3/h) to maintain flow in the discharge line to Brucejack Lake during periods when thickened tailings are used for backfill paste. Reclaim from the lake is required, as there are periods when the groundwater inflows are predicted to be less than the process requirement.

An average annual flow of 2,472 m^3/h at hydrometric station BJL-H1 has been estimated for the life of mine, an average increase of about 6% above existing conditions (2,324 m^3/h). The increase in flow results from the introduction of tailings slurry water and the displacement of water by the deposition of tailings and waste rock.

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LIMITATIONS

BGC Engineering Inc. (BGC) prepared this document for the account of Pretium Resources Inc. (Pretium). The material in it reflects the judgment of BGC staff in light of the information available to BGC at the time of document preparation. Any use which a third party makes of this document or any reliance on decisions to be based on it is the responsibility of such third parties. BGC accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this document.

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1.0 INTRODUCTION

Pretium Resources Inc. (Pretium) is currently undertaking an Environmental Assessment Study (EA) of the Brucejack gold-silver deposit located in the Coast Mountains of northwest British Columbia, approximately 60 km north of Stewart, BC. The Brucejack Project is situated at 56°28’20”N latitude by 130°11’31”W longitude in the high alpine in the Sulphurets District of the Iskut River region, approximately 30 km west of Bowser Lake and near the western extent of Pretium’s claims in the area (Drawing 01). The project area lies within the drainage basin of the Unuk River.

The Brucejack Project proposes to develop a 2,700 tpd gold-silver mine that includes an underground mine targeting a gold-silver resource, a plant site and associated facilities. BGC Engineering Inc. (BGC) has been retained by Pretium to provide an FS-level water management plan and site-wide water balance model (WBM) for the Brucejack Project.

1.1. Scope of Work

This report describes the water management plan for the Brucejack Project area including the design basis, assumptions, data sources and results of the mine site water balance. The scope of work consists of the following tasks and deliverables:

- Compile and review existing and acquired surface water, climate, groundwater and spatial data (e.g., LiDAR, air photographs, satellite images).
- Assemble a long-term climate dataset for the site that includes estimates of sublimation and evaporation.
- Conduct frequency analyses of annual precipitation and runoff time-series for various return periods and estimate runoff coefficients for undisturbed ground to support the development of a site-wide water balance.
- Develop a deterministic and probabilistic WBM for pre-development, operations and closure.
- Provide recommendations for the site-wide water management plan for the phases of the mine development.

As part of concurrent EA work, BGC is also assessing hydrogeological conditions for the project, including estimated groundwater inflows to the underground workings. A description of the project area geological and hydrogeological setting is provided in BGC (2014).

1.2. Objectives

The Brucejack Project is located in a region characterized by high rates of annual snowfall and rainfall. Several watersheds in the area also have substantial glacial coverage. In this humid climate, water management is an important component of the mine plan during development, operations, closure and post closure. The overall objectives of the water management plan for the Brucejack Project are to:

- Protect ecologically sensitive sites and resources, and avoid harmful impacts on fish and wildlife habitat.
- Provide and retain water for mine operations.
- Manage water to ensure that any discharges are in compliance with the applicable water quality levels and guidelines.
- Provide strategies for water management such as:
  - Protecting disturbed areas from water erosion and collecting surface water from disturbed areas and treating it, if necessary, to meet discharge standards prior to release.
  - Minimizing the use of fresh water though recycling of water wherever possible.
  - Monitoring the composition of release water and treating it to remove or control contaminants as required to meet discharge standards.
  - Constructing diversion channels to direct undisturbed runoff away from mining activities.

1.3. Project Description

Proposed underground mining operations and facilities are located to the southwest of Brucejack Lake in the West Zone and Valley of Kings (VOK) areas. The proposed mining method is underground longhole stoping. An ore processing plant site is proposed to the immediate east of the underground mine footprint. Waste rock and flotation tailings will be deposited into Brucejack Lake at depth, while tailings paste backfill and waste rock will be deposited in the underground mine. The project area currently includes camp and shop facilities, a ventilation shaft, an adit, and approximately 5,300 m of exploratory underground development from previous mining activity conducted by Newhawk between 1985 and 1995 (McLeod, 1999). A portion of the West Zone was previously mined during an advanced exploration program and is accessible from a surface portal when dewatered. Waste rock has been previously deposited in Brucejack Lake. A major reclamation program was completed in 1999 and the property has since been on care and maintenance (McLeod, 1999).

Access is by helicopter or via an existing exploration access road from Highway 37 (Drawing 02). The last section of this access road crosses the Knipple Glacier. A proposed transmission line will connect to the provincial power grid near Stewart, BC (Rescan, 2013a).

2.0 PHYSICAL SETTING

The Brucejack Project area contains glaciated areas and several streams and lakes, the primary of which is Brucejack Lake (Drawing 03 and 04, Figure 2-1). The lake is located within a relatively small sub-basin (9.8 km^2 at the outlet of Brucejack Lake) of the Sulphurets Creek watershed (300 km^2), a tributary to the Unuk River which flows southwest and discharges into the Pacific Ocean, to the northeast of Ketchikan, Alaska.

Figure 2-1. Brucejack Lake looking north. The lake discharges to Sulphurets Creek to the left (southwest) of the photograph. BGC photograph of August 7, 2012.

The hydrology of the project area is characteristic of a snowmelt dominated regime supplemented by glacier melt in the late summer. The project area experiences substantial precipitation with an estimated average annual precipitation of 2,100 mm of which 500 mm is rainfall (Environment Canada, 2012). The majority of precipitation falls as snow from October to May.

Historically at higher elevations, the heavy precipitation and low temperatures led to annual snowfall exceeding annual snowmelt on average, and permanent icefields resulted. It is likely that the icefields in the Brucejack Lake catchment and general area are in a state of net ablation. Lakes and ponds in the vicinity of the project site are covered with ice and snow for approximately eight months. Annual peak flows typically occur in mid to late summer and low flow conditions occur during the winter. The long period of snow and ice cover limits evaporation. Monthly mean air temperatures range from approximately -4°C to -20°C in the winter (November to March) and 5°C to 20°C in the summer (June to September; Rescan, 2013a).

The Brucejack Lake catchment of 11.7 km^2, as measured at hydrometric station BJL-H1, is approximately 27% covered by glaciers (Knight Piésold, 2011), a figure that has been confirmed by BGC using recent aerial imagery. It is not known how much glacier melt contributes to streamflow at the lake outlet. The local terrain is relatively steep with elevations ranging from about 1,325 to 2,390 m above sea level (masl). Physical characteristics of the Brucejack Lake, Sulphurets and Unuk River watersheds are summarized in Table 2-1.

Table 2-1. Physical watershed characteristics.

Watershed[1]	Area[2] (km^2)	Mean Elevation (masl)	Glacier Coverage[3] (%)	Lake Coverage (%)	Tributary to	Rescan Hydrometric Stations	Mean Runoff (mm)[4]
Unuk River	400	1,145	14.5	1.5	Unuk River	UR-H1	2,103
Sulphurets Creek	299	1,438	37.7	0.4	Unuk River	SC-H1	2,376
Sulphurets Lake	84	1,599	48.7	1.3	Unuk River	SL-H1	2,417
Brucejack Lake	11.7	1,644	27	6.2	Sulphurets Creek	BJL-H1	1,779

1 Watershed characteristics reported in Rescan (2013c).

2 Brucejack Lake has a watershed area of 9.8 km^2 at the lake outlet and 11.7 km^2 at the downstream Rescan hydrometric monitoring station BJL-H1 as shown in Drawing 04.

3 The glacier coverage for Brucejack Lake is as reported by Knight Piésold (2011) and calculated by BGC.

4 Mean annual runoff reported from 2008 to 2011 at Rescan hydrometric stations (Rescan, 2013b).

Brucejack Lake has an approximate volume of 30.4 Mm^3 and a maximum depth of 85 m (ERM Rescan, 2013). The watershed area at the outlet of the lake has been estimated by BGC at 980 ha, of which 84 ha is covered by the lake surface. However, this estimated watershed area could be higher or lower, depending on glacier conditions (see Section 3.1).

Approximately 800 m downstream of Brucejack Lake, Rescan Environmental Services Inc. (Rescan) has monitored streamflows at the BJL-H1 hydrometric station since 2007 (Drawing 05). The drainage area at this station is approximately 11.7 km^2. Intervening tributaries between these two locations include Camp Creek (50 ha), VOK Creek (45 ha), and an unnamed creek (50 ha) to the north of Brucejack Creek (Drawing 05).

Groundwater flows from the historic mine adit used to discharge into Brucejack Creek immediately downstream of Camp Creek. However, the adit has been progressively dewatered since November 2011 to gain access to the upper sections of the historic workings. Between November 7, 2011 and February 4, 2012, the adit was dewatered at an average rate of approximately 29 m^3/h (8 l/s). No adit dewatering occurred over the following six months. Dewatering with treatment resumed in September 2012 and continues to this day. The average dewatering rate between September 2012 and January 2014 was approximately 40 m^3/h (11 l/s). Monthly rates are shown in Table 2-2.

Table 2-2. Adit dewatering rates.

Month	Dewatering Rate	
	(m^3/h)	(l/s)
Sep-12	19	5
Oct-12	5	1
Nov-12	2	1
Dec-12	11	3
Jan-13	22	6
Feb-13	25	7
Mar-13	33	9
Apr-13	28	8
May-13	41	11
Jun-13	76	21
Jul-13	83	23
Aug-13	72	20
Sep-13	69	19
Oct-13	72	20
Nov-13	62	17
Dec-13	43	12
Jan-14	39	11

3.0 STREAMFLOW

3.1. Site Data

Rescan has monitored streamflows at the BJL-H1 hydrometric station since mid-2007. Daily flows at this station for the period 2007-2012 are shown in Figure 3-1, while average monthly flows and unit runoff are summarized in Table 3-1 and Table 3-2. Average annual runoff for the period of record is approximately 1750 mm. Streamflows for the November through May period were estimated by ERM Rescan due to the formation of ice on the creek and a deep snowpack, which hinders access to the site.

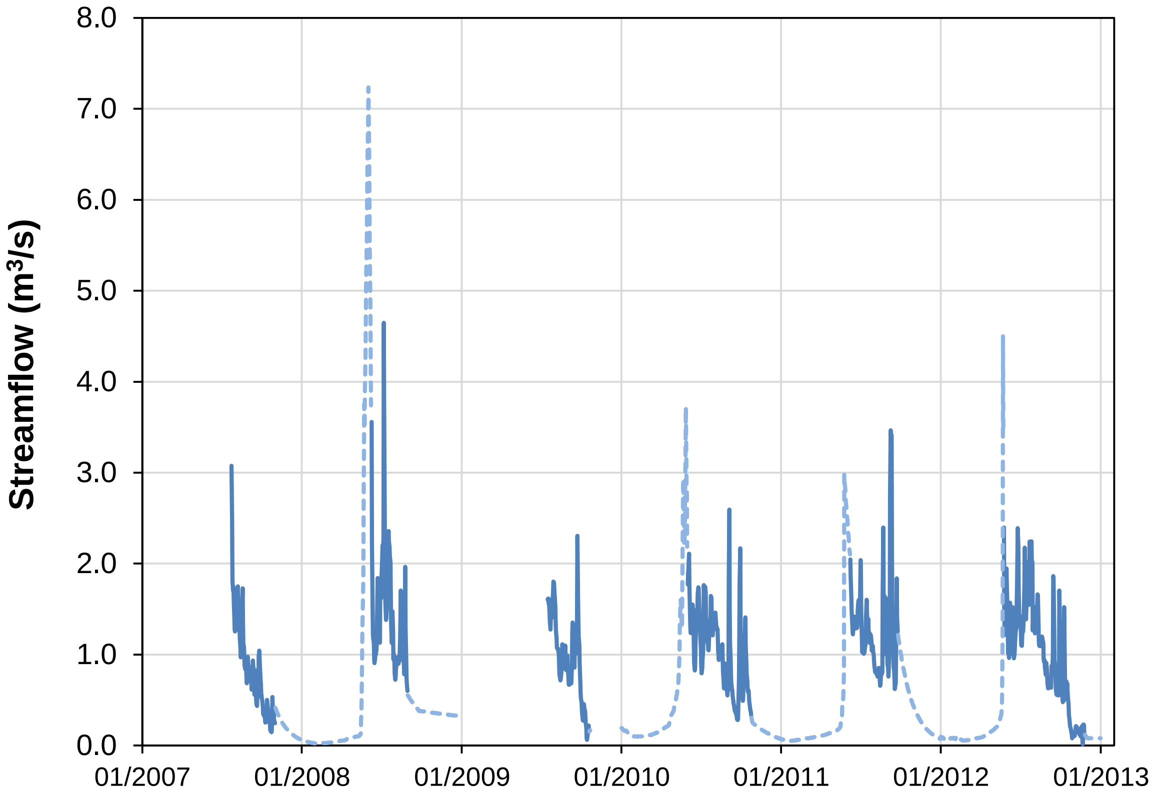


Figure 3-1. Observed and estimated (dashed line) BJL-H1 daily streamflow (2007 to 2012).

Table 3-1. Average monthly flow (m^3/s) at BJL-H1.

Month	2007	2008	2009	2010	2011	2012	Average
Jan		0.040		0.138	0.056	0.081	**0.078**
Feb		0.027		0.102	0.068	0.065	**0.066**
Mar		0.040		0.132	0.090	0.074	**0.084**
Apr		0.073		0.246	0.126	0.126	**0.143**
May		1.946		1.574	0.821	0.890	**1.308**
Jun		2.385		1.433	1.651	1.359	**1.707**
July		1.873		1.287	1.239	1.647	**1.512**
Aug	1.195	1.009	1.011	0.994	1.036	1.168	**1.069**
Sept	0.717	0.442	1.017	0.819	1.387	0.865	**0.874**
Oct	0.328	0.367		0.623	0.682	0.497	**0.500**
Nov	0.272	0.348		0.182	0.280	0.142	**0.245**
Dec	0.105	0.329		0.101	0.115	0.080	**0.146**
Average		**0.740**		**0.636**	**0.629**	**0.583**	**0.644**

Table 3-2. Average monthly runoff (mm) at BJL-H1.

Month	2007	2008	2009	2010	2011	2012	Average	Distr.
Jan		9		31	13	19	**18**	**1.0%**
Feb		5		21	14	14	**14**	**0.8%**
Mar		9		30	21	17	**19**	**1.1%**
Apr		16		55	28	28	**32**	**1.8%**
May		446		360	188	204	**299**	**17.1%**
Jun		528		317	366	301	**378**	**21.7%**
July		429		295	284	377	**346**	**19.8%**
Aug	274	231	231	228	237	267	**245**	**14.0%**
Sept	159	98	225	181	307	192	**194**	**11.1%**
Oct	75	84		143	156	114	**114**	**6.5%**
Nov	60	77		40	62	31	**54**	**3.1%**
Dec	24	75		23	26	18	**33**	**1.9%**
Total		**2008**		**1725**	**1702**	**1581**	**1746**	

Results shown in Table 3-2 are predicated on a watershed area of 11.7 km^2 at BJL-H1. However, this estimated watershed area could be higher or lower, depending on glacier conditions.

Overflow from East Lake, a glacial lake to the east of Brucejack Lake, has been observed to periodically discharge west into Brucejack Lake during snowmelt season (Rescan, 1987). However, East Lake outflows typically drain under Knipple Glacier to the east. Presumably, the flow conduit under the Knipple Glacier can become blocked temporarily by glacier mechanics, allowing East Lake to back-up and overflow into Brucejack Lake. The watershed area draining to East Lake is estimated at approximately 540 ha. Drainage under the glacier appears to occur at a depression (elevation = 1325 m) located to the south of East Lake, as illustrated on Drawing 06.

There is also a watershed area of 320 ha in the southeast portion of the watershed (Drawing 06). This area is mostly glaciated and to date it is been assumed that runoff from this area reports to the lake (e.g., Knight Piésold, 2011; Rescan, 2013c). However, as shown on Drawing 06 it appears that this area drains to the east under Knipple Glacier through the depression at elevation 1325 m, rather than into the lake. Assuming that both East Lake and the 320 ha area on the opposite side of the valley do not report to Brucejack Lake, the drainage area at BJL-H1 would then be 8.5 km^2 and average annual runoff for the period of record (2008, 2010-2012) would then be 2392 mm rather than 1746 mm. This issue is considered further in Section 4.4.3, under a discussion of precipitation at site.

3.2. Synthetic Dataset

Knight Piésold (2011) previously generated a synthetic streamflow dataset at the outlet of Brucejack Lake for the period of 1980 to 2009 by correlating long-term daily flows from the *Surprise Creek* (08DA00) Water Survey of Canada (WSC) Station with concurrent data from Rescan's BJL-H1 hydrometric station records. The data from Surprise Creek were considered most appropriate for use in generating a long-term synthetic flow series to conduct flood frequency analyses for the Brucejack Project area. The Surprise Creek WSC station (56° 6' N, 129° 28' W) is located approximately 50 km southeast of Brucejack Lake in a southeast facing watershed with a drainage basin area of 218 km^2, an estimated glacial coverage of 14%, and a median elevation of 1,400 masl (Drawing 07, Knight Piésold, 2011).

Average monthly flows at Surprise Creek for the period 1967-2012 are summarized in Table 3-3 along with the standard deviation to illustrate the typical range of flows experienced at this station.

Table 3-3. Average monthly streamflow and runoff at Surprise Creek (1967-2012).

Month	Flow (m^3/s)		Runoff (mm)	
	Average	St.Dev.	Average	St.Dev.
January	1.3	0.6	16	7
February	1.1	0.6	13	6
March	1.2	0.7	15	8
April	4.6	4.5	54	53
May	23.0	14.3	283	175
June	45.1	14.0	537	166
July	41.8	13.4	513	164
August	28.9	11.2	355	138
September	20.0	13.4	238	159
October	13.0	14.0	159	172
November	4.8	4.4	57	52
December	2.1	1.1	26	14
Average / Sum	**15.6**		**2265**	

To improve confidence in the seasonal distribution and magnitude of measured streamflows at site, BGC generated a synthetic streamflow time-series for the period 1980 to 2012 using the ranked multiple linear regression analysis method employed by Knight Piésold (2011). The synthetic streamflow generation methodology was derived by Butt (2013). Flows were synthesized by applying monthly regression equations to the long-term record from Surprise Creek. BJL-H1 station has an average runoff rate of 1,746 mm over the period of 2007 to 2012 (Table 3-2). For the period of 2010 to 2012, runoff is 1,669 mm for BJL-H1 compared to 1,719 mm for the synthetic time-series for the same time period, a difference of 49 mm or 3%. From 1980 to 2012, synthetic flows average 1,712 mm. The ranked regression correlations were considered reasonable based on the comparison of the average monthly streamflow series (Figure 3-2).

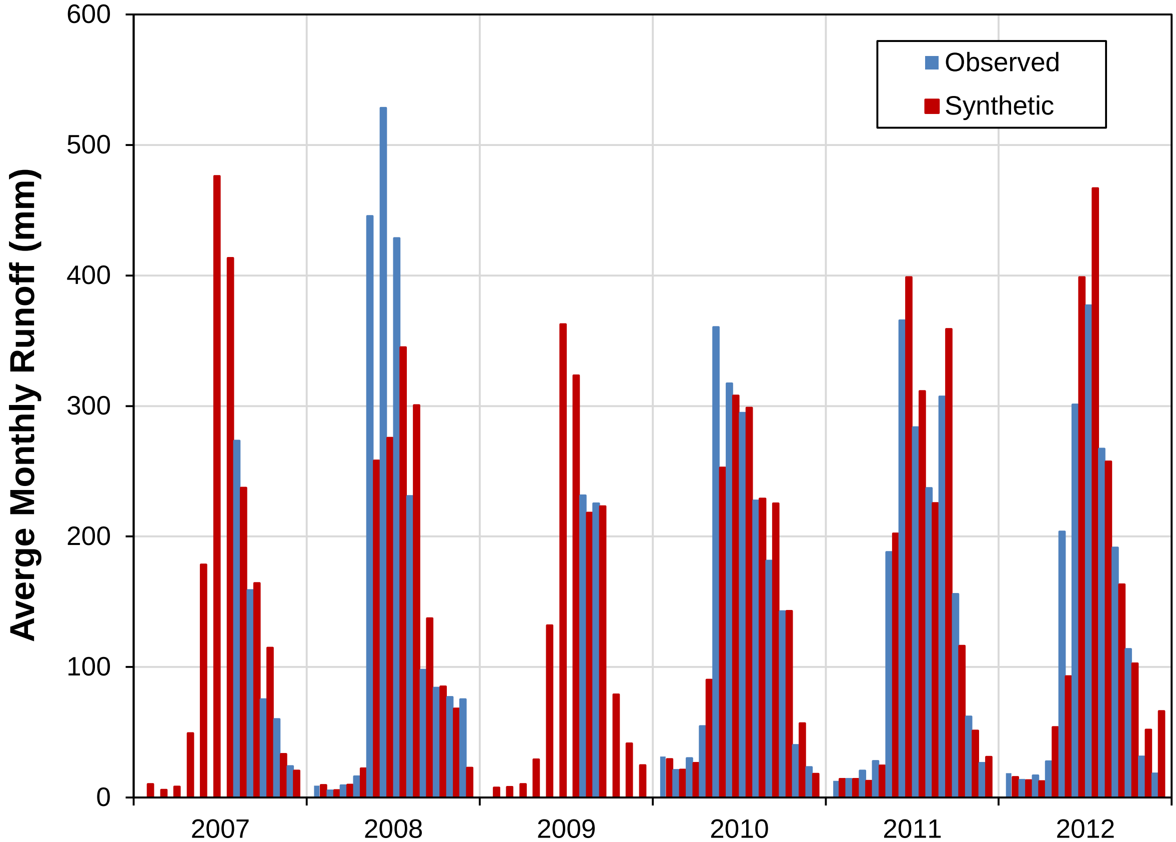


Figure 3-2. Observed and synthetic (ranked regression) average monthly runoff (2007 to 2012).

The synthetic streamflow dataset is not used for further analysis herein, but rather serves as an approximation of the long-term average and variability of streamflows at Brucejack.

4.0 CLIMATE DATA: SYNTHESIS AND ANALYSIS

Meteorological data are required by different project team members involved with the Brucejack feasibility study. Given that these data can be obtained from a number of different sources, it is imperative that a consistent set of values are used by each project team member. Meteorological data are required by BGC for the mine-site water balance and groundwater modelling. This section summarizes the available meteorological data, with a focus on temperature, evaporation, sublimation, and precipitation.

4.1. Stations

Meteorological data have been collected at the site since September 2009 with the installation of a climate station adjacent to the BJL-H1 hydrometric station (Drawing 04) and includes records of air temperature, relative humidity, precipitation, snow depth, barometric pressure, wind speed and direction, net radiation, and global solar radiation measured at hourly or daily intervals (Rescan, 2012). Historic climatic conditions have also been monitored within the region at the *Unuk River Eskay Creek* (#1078L3D) and *Bob Quinn AGS* (#1200R0J) climate stations, both of which are maintained by Environment Canada (EC). The Unuk River Eskay Creek station is located approximately 30 km north of Brucejack Lake while the Bob Quinn AGS station is located approximately 56 km north of the site (Drawing 07; Rescan, 2013a). Table 4-1 provides a summary of local and regional climate stations considered in this study.

Table 4-1. Local and regional climate stations.

Station Name	Latitude	Longitude	Elevation (masl)	Period of Record
Rescan Brucejack Meteorological Station	56° 28' N	130° 12' W	1,360	September 2009 to current
Unuk River Eskay Creek (#1078L3D) Environment Canada Station	56° 39’ N	130° 27’ W	887	November 1989 to September 2010
Bob Quinn AGS (#1200R0J) Environment Canada Station	56° 58’ N	130° 15’ W	610	December 1977 to April 1994

4.2. Temperature

Table 4-2 shows annual average temperatures collected at the Brucejack and Unuk River Eskay Creek stations, as well as output from the ClimateBC climate data model (Wang et al., 2012). ClimateBC is a computer program that extracts and downscales PRISM 1971-2000 monthly climate normal data (800 x 800 m) to scale-free point locations, and calculates seasonal and annual climate variables for specific locations based on latitude, longitude and elevation (optional). ClimateBC covers British Columbia and some surrounding areas. The program uses the scale-free data as baseline in combination with monthly anomaly data of individual years to calculate historical monthly, seasonal and annual climate variables for individual years and periods between 1901 and 2012.

Table 4-2. Observed and scaled monthly average temperatures.

Month	Brucejack Lake (1,360 masl)[1]	ClimateBC Model (1,400 masl)[2]	Unuk River Eskay Creek (887 masl)[3]
	(ºC)	(ºC)	(ºC)
January	-8.2	-9.3	-8.1
February	-6.9	-7.8	-6.0
March	-6.5	-5.7	-4.0
April	-2.6	-1.3	0.5
May	1.7	3.4	4.3
June	4.4	7.1	8.2
July	6.9	9.0	10.2
August	7.5	8.7	10.4
September	4.6	4.8	5.8
October	-1.3	-0.7	0.6
November	-6.2	-7.1	-4.7
December	-8.2	-9.1	-7.0
Average	**-1.2**	**-0.7**	**0.9**

[1] Data collected from the Brucejack meteorological station from 2010 to 2012

[2] Climate normals (1981 to 2010) generated from the ClimateBC climate model (Wang et al., 2012).

[3] Environment Canada Unuk River Eskay Creek climate station (1989 to 2010)

4.3. Potential Evapotranspiration, Lake Evaporation and Sublimation

This section provides estimate of potential evapotranspiration (PET), lake evaporation from the Brucejack Lake, and sublimation.

4.3.1. Potential Evapotranspiration

PET at the site was estimated using available local climate data from the period 2010 to 2012 and the software program REF-ET (Reference Evapotranspiration Calculation Software) Version 3.1.14 (Allen, 2011). REF-ET is a compiled, stand-alone computer program that calculates reference evapotranspiration. Evapotranspiration (ET) is defined as the amount of water that evaporates from vegetation (transpiration) and from the underlying soil. Reference evapotranspiration is defined as the ET that occurs from a standardized “reference” crop such as clipped grass or alfalfa that has an extensive surface, is well-watered, and fully shades the ground.

REF-ET provides calculations that are compatible with United Nations Food and Agriculture Organization (FAO) Irrigation Paper No. 56 (Allen *et al.*, 1998) and with standardized forms of the ASCE Penman-Monteith equation recommended in 2005 by the ASCE Task Committee on Standardized Evapotranspiration Calculations. Reference ET methods calculated include the ASCE and FAO Penman-Monteith equations, and Kimberly Penman, 1948 Penman, and Hargreaves equations.

Required climate inputs to the model include air temperature, wind speed, incoming solar radiation (or sunshine hours), relative humidity, dew point temperature, and atmospheric pressure. The reference ET supplied by REF-ET is considered analogous to PET, as the reference crop is well-watered. Furthermore, many standard hydrology textbooks (e.g., Linsley *et al.*, 1992) state that PET is approximately equal to shallow lake evaporation. Average monthly results for the 2010 to 2012 period are summarized in Table 4-3. Results are based on an average of the equations listed above. Model inputs, most notably temperature, were also averaged over the entire watershed area.

Table 4-3. Average monthly PET and shallow lake evaporation at Brucejack.

Month	REF-ET PET (mm)	Sublimation (mm)	Estimated PET/Sublimation (mm)	Lake Evaporation (mm)
January	8	2	2	0
February	8	2	2	0
March	12	2	2	0
April	20	0	4	0
May	42	0	10	0
June	46	0	23	2
July	46	0	46	6
August	41	0	41	24
September	25	0	25	58
October	16	0	8	94
November	10	2	2	39
December	8	2	2	0
Total	**282**	**10**	**167**	**224**

4.3.2. Brucejack Lake Evaporation

PET values listed in Table are not directly applicable to a deep lake such as Brucejack Lake. Water has a large heat storage capacity compared to air. During the spring and early summer, much of the incoming solar radiation goes into storage in the lake to heat up the water. In contrast, methods that use the net radiation (such as the Penman-Monteith equation) assume that all of the available energy is going into sensible or latent energy. This assumption is reasonable for a vegetated or unvegetated surface (or a small and shallow lake), yet for larger water bodies a significant portion of this incoming energy is used to warm the water. Over a period of months, the amount of error in net radiation methods can be significant as evaporation is over-predicted during the spring and early summer. Because water has a large storage capacity, the temperature of water bodies does not fluctuate considerably through the day in comparison to ambient temperatures. As a result, the amount of available energy at the water surface is nearly constant throughout the day and night, leading to constant evaporation rates for deep lakes. Conversely, in the fall as the lake cools, these methods will underestimate actual evaporation rates.

Monthly average evaporation from Brucejack Lake is shown separately in Table 4-3. These values are based on lake modelling conducted by Lorax (2013) and reflect the heat storage effect noted above.

4.3.3. Sublimation

REF-ET does not account for snow cover; therefore, model results for the watershed during periods of snow cover are not considered reliable. Sublimation losses from the snowpack can occur during the winter when the temperature is less than 0°C and the vapour pressure of the air is less than that of the snow surface. Sublimation from areas without trees is usually less than 1 mm/d, amounting to a total seasonal loss of 10 to 20 mm SWE (Bengtsson, 1980; Bernier 1990; Prevost *et al.*, 1991; Adams *et al.*, 1998). For this study, a monthly sublimation rate of 2 mm was assumed for the months of November to March. Once snowmelt commences, sublimation can continue to occur but evaporation of melt water can also occur.

Evaporation during the snowmelt period (April to June) can be evaluated with equations provided by Kuusisto (1984):

$$E = -0.10T_{\mathrm{d}} + 0.02 \qquad \text{(Eq. 2)}$$

where E is evaporation (mm/12h) and T_{d} (°C) is the daytime dewpoint temperature and,

$$E = 0.44_{\mathrm{d}} \qquad \text{(Eq. 3)}$$

where *d* = saturation deficit of the air (mb).

Using climate data from 2010 to 2012, the average of these two equations yields monthly evaporation of 4 mm and 10 mm for April and May, respectively, during snowmelt. Bare patches at site are expected to occur starting in June. Evaporation from soil begins immediately after the appearance of the first bare spots. The microclimate of these spots differs considerably from that of snow covered areas, as the albedo of bare ground is very low compared to snow. Therefore, the energy surplus of bare ground is high, particularly on sunny days, leading to increased evaporation rates (Kuusisto, 1984). Potential evaporation during June has therefore been estimated as half the PET as estimated using REF-ET. A majority of the snow is assumed to have melted by the end of June, although patches of snow will persist throughout the summer in more shaded areas, as illustrated by Figure 4-1. Based on the above discussion, total annual PET and sublimation at site is estimated at approximately 167 mm.

Figure 4-1. View of Brucejack Lake looking to the northeast. BGC photograph of August 7, 2012.

4.4. Precipitation

4.4.1. Data

The mean annual precipitation for the Brucejack meteorological station is 1,589 mm for the period of January 2010 to December 2012 (Rescan, 2013a; Table 4-4). Mean annual precipitation generated by the ClimateBC climate data model for the 1981 to 2009 climate normals (Wang et al., 2012) exceeds 2,000 mm at an elevation of 1,400 masl as does the annual average precipitation observed at the Unuk River Eskay Creek station (Table 4-4). The Unuk River station is the closest climate station to the project area with a relatively long data record.

The EC climate design for the site also indicates an annual total precipitation of 2,100 mm at an elevation of 1,400 masl (Environment Canada, 2012). EC developed climate design estimates for the site by interpolating from calculated values at surrounding locations.

As most of the precipitation in the coastal mountains is in the form of snow during the winter months, the data collected at the Brucejack station could potentially underestimate precipitation, particularly due to high wind speeds under the gauge. Strong winds in all seasons at high elevations in the project area can lead to significant redistribution of snow (Rescan, 2013a). However, Rescan (2013a) indicated that precipitation values from the Brucejack station were adjusted for undercatch due to wind and missing or invalid data was filled using regression analysis.

Table 4-4. Mean monthly precipitation estimates.

Month	Brucejack Lake (1,360 masl)[1]	ClimateBC Model (1,400 masl)[2]	Unuk River Eskay Creek (887 masl)[3]	Bob Quinn AGS (610 masl)[4]
	(mm)	(mm)	(mm)	(mm)
January	137	322	249	60
February	99	228	214	41
March	114	180	181	27
April	106	129	97	25
May	90	112	88	29
June	84	91	67	34
July	88	117	83	57
August	128	178	139	51
September	367	227	207	86
October	180	346	247	102
November	124	297	215	62
December	72	299	247	69
Total	**1,589**	**2,526**	**2,034**	**643**
Monthly Average	**132**	**210**	**170**	**54**

Notes:

1 Data collected from the Brucejack meteorological station from 2010 to 2012 (Rescan, 2013a)

2 Climate normals (1981 to 2010) generated from the ClimateBC model for latitude (56°28'20"), longitude (130°11'31"W), elevation (1,400 masl) (Wang et., 2012)

3 Environment Canada Unuk River Eskay Creek climate station (1989 to 2010)

4 Environment Canada Bob Quinn AGS climate station (1977 to 1994)

Figure 4-2 compares average monthly precipitation observed at the Unuk River Eskay Creek (1989-2010), the Brucejack meteorological station (2010-2012) and values generated by the ClimateBC model (1981-2010).

Comparing the Unuk River and Brucejack stations indicates a 22% annual difference in average monthly precipitation and a 51% difference during the winter months of November to March on average (Figure 4-2). However, the period of record being compared is significantly different. Unfortunately, the period of overlap of the two stations is very short, consisting only of 2010, and a number of these days are missing in the Unuk River dataset. Comparison of cumulative precipitation for the period May 1 to September 29 indicates that more rainfall was recorded at Brucejack Lake (710 mm) versus Unuk River (502 mm). However, this period of record is too short to develop a statistical relation between the two stations.

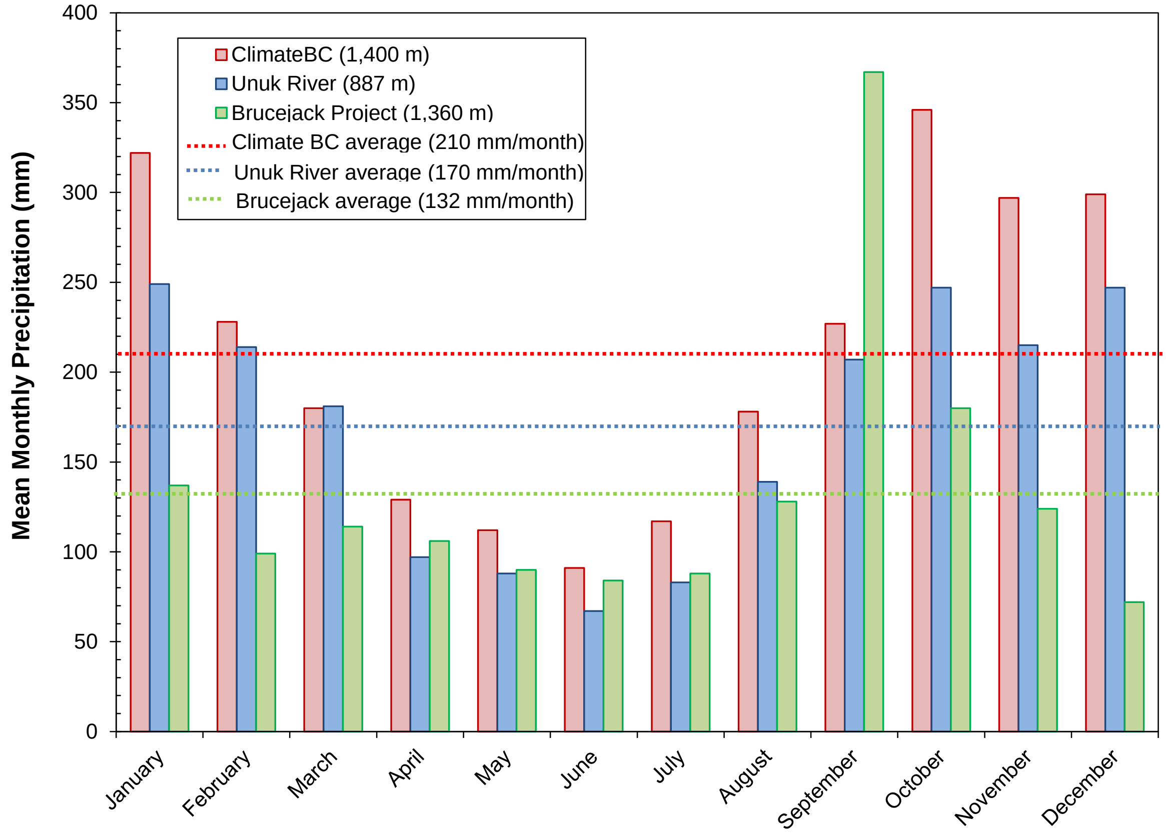


Figure 4-2. Mean monthly precipitation (Brucejack Project, Unuk River and ClimateBC Models).

4.4.2. 2011-2012 Site Precipitation

The observed average annual precipitation for the 2011 to 2012 hydrologic years (October 1 to September 30) at the Brucejack climate station is 1490 mm. In comparison, the annual observed runoff from the BJL-H1 station for the same period is 1663 mm (see Section **Error! Reference source not found.**). This difference suggests that:

- the site climate station is underestimating precipitation;
- there are strong orographic effects at the mine site; and/or
- there is a significant contribution of runoff from glacial melt.

All of the above factors, or a combination thereof, are possible reasons for the observed discrepancy between observed precipitation and runoff, as discussed further below.

Underestimate of Precipitation

In April 2011, a snow course station (SC-02) was established by Rescan near the Brucejack Lake meteorological station, to determine average snow depths and snow water equivalent (SWE). Sampling was performed in April 2011, 2012, and 2013 to record peak SWE levels in each year (Rescan, 2013c). Snow cores were taken at 20 m intervals along a 200 m transect at specific courses. The sampling site was judged to be most representative of the area, with snow relocation believed to be at a minimum. Average snow depths and average SWEs were then calculated for the snow course.

In addition, BGC conducted a snow survey at 23 locations in the Brucejack Lake watershed (Drawing 08) on May 3, 2012. That survey consisted of a random set of locations to gain a better understanding of the areal distribution of the snowpack, recognizing that the location of SC-02 may be biased in some way and may not be representative of watershed conditions on average. Only sites that could be accessed safely were sampled. Higher elevations in the watershed are associated with avalanche hazards and thus could not be sampled. The 2012 BGC survey was conducted following a period of minor snowmelt, so results may not be representative of maximum snowpack levels. The wider area surveyed in 2012 may also not be representative of average watershed conditions, as it is also biased toward lower elevations.

In 2013, Rescan (unpublished data) conducted snow surveys at snow courses SC-02 and SC-03 (a new station located closer to the camp), as well as the 23 locations surveyed by BGC in 2012. All snow survey results are summarized in Table 4-5. Snow water equivalent values are compared to annual runoff and precipitation, and snowfall for the coincident period of the snow surveys.

Table 4-5. Observed Brucejack annual runoff, precipitation and snow water equivalent.

Hydrologic Year[1]	Runoff (mm)	Precip (mm)	Snowfall (mm)	Rescan Snow Survey (SC-03)		Rescan Snow Survey (SC-02)		BGC Snow Survey	
				Date	SWE (mm)	Date	SWE (mm)	Date	SWE (mm)
2008	1,931	-	-			-	-	-	-
2009	n/a[2]	-	-			-	-	-	-
2010	n/a[2]	1,885	-			-	-	-	-
2011	1,663	1,738	512			April 15	943	-	-
2012	1,662	1,242	566			April 4	1,341	May 3	534
2013	-	574[3]	471[3]	April 22	950	April 22	865	April 25	566

Note: Runoff, precipitation and snow survey data are as reported by Rescan (2013a, 2013c).

1. The hydrologic year starts in October. Hydrologic year 2011 covers the period October 1, 2010 to September 30, 2011.
2. Streamflow data are only available in 2009 from July 16 to October 21.
3. Precipitation and snowfall data from Brucejack climate station for period of October 1, 2012 to April 28, 2013 only as provided by Rescan on April 29, 2013.

Table 4-5 indicates that there is considerable variation between the SWE surveys themselves and snowfall recorded at the climate station. Snow course SC-02 over-estimates SWE relative to the climate station, while the 23 random sampling locations are roughly consistent with the climate station. At this time, no strong conclusion can be reached with respect to the climate station and snow survey results. The ideal scenario would be to measure SWE throughout the Brucejack watershed before the onset of spring. However, a significant portion of the watershed is inaccessible during periods of snow cover due to avalanche hazards.

Orographic Effects

Orographic effects are commonly observed in mountainous areas, with precipitation increasing with elevation. However, whether orographic effects are an important factor at Brucejack Lake cannot be determined with the available climate data for the region.

Glacier Melt

Given that about one-quarter of the watershed is covered by glaciers, glacier melt is likely a source of runoff, particularly during summers of above average temperature and below average rainfall. However, with the current data it cannot be established that glacier melt has been a significant source of runoff in recent years. For example in the 2012 hydrologic year, precipitation of 1242 mm was measured versus an observed runoff of 1662 mm. If this difference could be attributed to glacier melt alone, the inference is that there was over 1000 mm of glacier melt (given that only 27% of the basin is glaciated), which does not account for potential evapotranspiration (PET) losses. It is highly unlikely that glacier melt of this magnitude occurred in 2012. As illustrated by Figure 2-1, there were still significant patches of snow cover at lower elevations in the first week of August 2012.

4.4.3. Analysis

The paucity of precipitation data in the region and the short period of site-specific data makes it difficult to estimate annual precipitation at site. However, streamflow data can also be used to estimate precipitation. Given an estimated potential evapotranspiration (PET) of approximately 170 mm/yr (as described in Section 4.3), runoff for the site is expected to be 170 mm less than precipitation over an annual period assuming that PET is maximized and glacier melt is not a significant contributor to runoff. This line of reasoning has been applied to several sources of runoff, as described below.

Regional Analysis

Rescan (2013b) analyzed annual runoff from a number of regional Water Survey of Canada (WSC) hydrometric stations and stations installed as part of the adjacent KSM gold project. In that report, they suggest that average annual runoff for the Brucejack Lake watershed can be estimated using the following relation:

$$\text{Annual runoff} = 232.7786e^{0.0013x} \qquad \text{(Eq. 4-1)}$$

where x = median watershed elevation. Using a median watershed elevation of 1540 m, average annual runoff at Brucejack is then estimated at 1723 mm. This value is consistent with average annual precipitation on the order of 1900 mm, assuming that PET is maximized and glacier melt is not a significant contributor to runoff.

Gauged Streamflows

Average annual runoff observed at BJL-H1 for the period August 2007 to December 2012 is 1732 mm (Section **Error! Reference source not found.**). Assuming that PET is maximized and glacier melt is not a significant contributor to runoff, the conclusion again is that average annual precipitation is on the order of 1900 mm. However, it should be cautioned that with the short period of site record, it cannot be determined if the 2007-2012 period is characterized by below, average or above average precipitation at the study site.

Conversely, as noted in Section 3.2, the watershed area reporting to BJL-H1 could be as low as 8.5 km^2 and the resulting average annual runoff would be 2392 mm. Assuming that PET is maximized, average annual precipitation would then be on the order of 2560 mm, which coincidentally is close to the average value of 2526 mm obtained from the ClimateBC model. However, this higher runoff value is inconsistent with measured precipitation and SWE at site.

Regression Correlation

BGC has also generated a synthetic streamflow dataset for BJL-H1 using ranked regression correlation (see Section **Error! Reference source not found.**). That analysis suggests that the long-term average annual runoff at BJL-H1 is 1712 mm (assuming a watershed area of 11.7 km^2), again indicating that annual precipitation could be on the order of 1,900 mm.

4.4.4. Summary

The above discussion highlights that there is uncertainty regarding the average annual precipitation estimate for Brucejack Lake that cannot be resolved at this point in time. Therefore, a range of precipitation values will be utilized for the water balance analysis considered in this report with average annual precipitation at site assumed to fall within the range of 1900 mm to 2034 mm. The upper end of this average precipitation estimate is based on the observed data from the Unuk River station and is not scaled for orthographic effects, as there is currently no strong evidence to suggest that there is an orographic effect in this particular area. The Unuk River station is judged to be a suitable proxy given the close proximity to Brucejack Lake, coupled with the lack of a long-term climate dataset at Brucejack Lake and variable snowfall measurements. The lower end of the estimate, 1900 mm, is based on the site and regional streamflow data, as described above.

When considering wet periods, frequency analyses for various durations have been conducted using the Unuk River precipitation data. Conversely, when considering dry periods, frequency analyses were conducted using the Unuk River precipitation data, but scaled down to yield an average annual precipitation of 1900 mm. Results of the precipitation frequency analysis are presented in the next section.

There is currently uncertainty with the watershed area reporting to BJL-H1. If the watershed area was only 8.5 km^2, the implication is that average annual runoff and precipitation at site are on the order of 2400 mm and 2560 mm, respectively. With this interpretation, the observed precipitation and SWE at site would then have to be significantly under-estimated (Table 4-5). Such an explanation is possible for a remote weather station, but the SWE estimates should be relatively robust, particularly the distributed surveys of 2012 and 2013. Therefore, it is currently assumed that the watershed area reporting to BJL-H1 is 11.7 km^2. For the purposes of modelling streamflows, an estimate of the average annual precipitation is less important than observed streamflow data. The water balance model described in Section 5 and Appendix A is calibrated to streamflow with precipitation as an input. Therefore, whether the model is calibrated to a smaller watershed area and higher precipitation or a larger watershed area and smaller precipitation is irrelevant – the key output is simulated streamflow that is consistent with observed data.

Having confidence in precipitation estimates becomes more important when evaluating peak flows and runoff volumes for drainage ditches and collection ponds. Therefore, it is recommended that a site visit be conducted in June 2014 to evaluate runoff patterns at the east end of Brucejack Lake. The purpose of the site visit would be to try and confirm the watershed area reporting to BJL-H1.

4.4.5. Precipitation Return Period

Rainfall amounts at Brucejack for various durations and return periods are summarized in Table 4-6. The 24-hour totals include an adjustment factor (1.13) of the published daily maxima. The daily precipitation data from Unuk River are for a fixed time interval and as such, are expected to rarely yield the true maximum rainfall amount for a 24-hour period. Studies compiling thousands of rainfall datasets indicate that multiplying the results of a frequency analysis of annual maximum rainfall amounts for a fixed time interval of any duration from 1 to 24 hours by 1.13 will yield values closely approximating those obtained from an analysis based on true maximum (Hershfield, 1961). Frequency results are based on an average of the following probability distributions: Generalized Extreme Value (GEV), Log Pearson Type III (LP3), Pearson Type III (P3) and Log Normal Type III (LN3).

Table 4-6. Rainfall estimates for various return periods and durations.

Return Period (years)	24-hr Rainfall (mm)	2-day Rainfall (mm)	3-Day Rainfall (mm)	5-Day Rainfall (mm)	10-day Rainfall (mm)
2	65	81	96	122	155
5	92	111	126	155	195
10	110	128	145	175	219
25	132	150	168	197	247
50	148	166	184	212	266
100	163	182	200	226	285
200	179	197	216	239	302

Frequency results for wet and dry annual precipitation are summarized in Table 4-7.

Table 4-7. Annual precipitation estimates.

Return Period (years)	Annual Precipitation (mm)	
	Dry	Wet
2	1,900	2,110
5	1,730	2,340
10	1,600	2,460
25	1,450	2,580
50	1,345	2,650
100	1,240	2,710
200	1,145	2,770

Again, the period of rainfall data at Brucejack is insufficient to determine the intensity of short duration rainfall at various durations and frequencies (IDF). The closest Environment Canada station with IDF data is located at the Stewart Airport (#1067742) to the south (Drawing 07). Table 4-8 summarizes the published IDF data for this station for the period 1978-2005.

Table 4-8. Rainfall intensity-duration-frequency data for Stewart Airport (#1067742).

Duration	Rainfall (mm)						
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	200-yr+
5 min	2.0	3.1	3.7	4.5	5.1	5.7	6.4
10 min	2.9	3.9	4.5	5.3	5.9	6.5	7.2
15 min	3.4	4.4	5.1	5.9	6.5	7.1	7.8
30 min	4.7	5.7	6.4	7.3	7.9	8.5	9.2
1 hr	7.1	8.3	9.0	10.1	10.9	11.6	12.5
2 hr	11.5	13.8	15.4	17.3	18.8	20.2	21.9
6 hr	26.6	32.7	36.8	41.9	45.7	49.4	53.7
12 hr	43.3	54.0	61.1	70.1	76.8	83.4	90.9
24 hr	69.0	88.7	101.7	118.2	130.0	142.5	156.2

+ The published IDF data only extend to a 100-year return period. 200-year values were interpolated using a log-log relation.

BGC then compared the 24-hour rainfall frequency estimates for Stewart Airport (Table 4-8) to those at Brucejack (Table 4-6). The 24-hour rainfall estimates at Brucejack are on average 9% higher than at Stewart. Therefore, the IDF data of Table 4-8 were upward adjusted by 9% for application to site, as summarized below.

Table 4-9. Rainfall intensity-duration-frequency data estimates for Brucejack Lake.

Duration	Rainfall (mm)						
	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	200-yr
5 min	2.2	3.4	4.0	4.9	5.5	6.2	6.9
10 min	3.2	4.2	4.9	5.8	6.4	7.1	7.8
15 min	3.7	4.8	5.5	6.4	7.1	7.7	8.5
30 min	5.1	6.2	7.0	7.9	8.6	9.2	10.0
1 hr	7.7	9.0	9.8	11.0	11.8	12.6	13.5
2 hr	12.5	15.0	16.7	18.8	20.4	21.9	23.7
6 hr	28.9	35.5	40.0	45.5	49.6	53.7	58.4
12 hr	47.0	58.7	66.4	76.1	83.4	90.6	98.8
24 hr	65	92	110	132	148	163	179

These IDF data are required for the sizing of diversion channels around the plant site.

4.5. Average Monthly Climate Data

Assumed average monthly climate data for the Brucejack Project are summarized in Table 4-10.

Table 4-10. Average monthly climate data.

Month	Average Temperature (°C)[1]	Average Precipitation		Average PET (mm)[4]
		Lower End (mm)[2]	Upper End (mm)[3]	
January	-9.3	233	249	2
February	-7.8	200	214	2
March	-5.7	169	181	2
April	-1.3	91	97	4
May	3.4	82	88	10
June	7.1	63	67	23
July	9.0	78	83	46
August	8.7	130	139	41
September	4.8	193	207	25
October	-0.7	231	247	8
November	-7.1	201	215	2
December	-9.1	231	247	2
Average/ Total	**-0.7**	**1,900**	**2,034**	**167**

1 Based on ClimateBC normals (1981-2010) for an elevation of 1400 m

2 Scaled down precipitation from Environment Canada Unuk River Eskay Creek climate station (1989 to 2010)

3 Observed precipitation from Environment Canada Unuk River Eskay Creek climate station (1989 to 2010)

4 Estimated using climate data collected from the Brucejack meteorological station from 2010 to 2012

5.0 WATER BALANCE MODEL OVERVIEW

The following sections provide an overview of the WBM developed for the Brucejack Project and outlines the key assumptions that were used as input. Results and a water management strategy for all phases of mining are presented in Section 6.0.

5.1. Overview

The WBM developed for the Brucejack Project employs a monthly time-setup and is set-up in Excel™, which facilitates its use and review by others. Data for the water balance comes from a variety of sources including:

- underground mine design and mill feed rates (Section 5.2);
- site-specific and long-term climate dataset for the proposed mine area, including precipitation, potential evaporation and temperature (Section 4);
- precipitation frequency analysis (Section 4);
- drainage areas and runoff coefficients (Section 5.6 and Appendix A);
- estimated groundwater inflows and seepage rates (Section 5.5);
- process plant water balance model (including freshwater make-up requirement) (Section 5.4); and
- assumed tailings densities and properties.

Information for the water balance was compiled from feasibility-level work conducted by Tetra Tech (TT), AMC, Rescan and BGC. The WBM can be set-up to evaluate various precipitation conditions including:

- average conditions;
- variable precipitation conditions based on a historic dataset (deterministic dataset); and
- a specific return period for a given year (e.g. a 200-year wet year in Year 15 of operations).

In addition, the WBM has been replicated in GoldSim by Lorax (2014) to allow for an evaluation of water quality.

5.2. Design Basis

A majority of the Brucejack Project infrastructure is located to the southwest of Brucejack Lake in the Brucejack Lake and Brucejack Creek watershed (Drawing 09). Primary processing of the ore will be completed at a plant site southwest of Brucejack Lake.

The mine operating life is estimated at 22 years. Rates of ore processing are expected to vary on an annual basis during operations; however, a mill feed rate of 2,700 tpd was assumed for the WBM based on a site-wide process water balance provided by TT on March 9, 2013. As mine development progresses, 2.4 Mt of waste rock excavated from the underground mine prior to operations will be deposited into Brucejack Lake along with 9.5 Mt of flotation tailings during operations. About 2.2 Mt of blasted rock from the plant site excavations will also be deposited in the lake during construction. An additional 8.6 Mt of tailings paste backfill and 2.0 Mt of waste rock will be deposited in the underground mine.[1] Of the total processed mineralized material, 8.1% (approximately 1.6 Mt) will be trucked to an off-site facility as concentrate for secondary processing. Table 5-1 summarizes the project design criteria related to water management.

Table 5-1. Design basis.

Item	Criteria
Total Ore resource	18.1 Mt
Nominal Mill Throughput	2,700 tpd
Life of Mine	22 years
Ore Tonnage to Export	1.6 Mt assumed 8.1% of mill feed goes to concentrate
Waste Rock Tonnage	4.6 Mt deposited in Brucejack Lake prior to operations 2.0 Mt deposited in the underground during mine life
Flotation Tailings Tonnage	9.5 Mt deposited in Brucejack Lake
Paste Backfill Tonnage	8.5 Mt deposited in underground mine
Brucejack Lake catchment	9.8 km^2
Brucejack Lake volume	30.4 Mm^3

5.3. Model Components

Components of the Brucejack Lake mine site water balance are summarized in Table 5-2 along with a water balance flow schematic in Figure 5-1. Water inflows and losses are defined with respect to the indicated infrastructure.

The various elements of the WBM are discussed in further detail in the following sections, but contact water will be generated by groundwater inflows to the underground workings as well as surface runoff from around the plant site, which will be directed to a contact water pond. Both sources of contact runoff will be pumped to a water treatment plant (WTP) with the treated effluent discharged to Brucejack Lake (Figure 5-1). Treated effluent from the sewage treatment plant (STP) will also be discharged to Brucejack Lake. During construction, effluent from the WTP and STP will be discharged to Brucejack Creek downstream of the lake outlet but upstream of monitoring point BJ200 m D/S.

[1] Information received from AMC and TT on May 2, 2013 indicated that the volume of thickened tailings to be placed in the lake is approximately 9.5 Mt and the volume of paste backfill is approximately 8.5 Mt for the 22 year life of mine. BGC assumed these volumes for the WBM.

Table 5-2. Components of the Brucejack Lake mine site water balance.

Water Inflows	Water Losses
Process Plant	
Process requirement via water treatment plant	Concentrate moisture
Ore moisture	Evaporative mill losses
Reclaim from Brucejack Lake	Tailings slurry water
Fluidizing Water	Paste backfill
Brucejack Lake	
Tailings slurry water	Void losses
Undisturbed runoff (includes groundwater inflows)[1]	Reclaim to process plant
Water displaced by tailings and waste rock	Discharge to Brucejack Creek
Fluidizing water	
Water Treatment Plant (WTP) effluent	
Sewage Treatment Plant (STP) effluent	
Runoff from quarry	
Water Treatment Plant	
Excess groundwater inflows to underground mine	Discharge to Brucejack Lake
Contact water pond	
Underground Mine	
Groundwater inflows to underground mine	Void losses
Paste backfill	Excess to WTP plant

[1] Includes incident precipitation within lake footprint and lake evaporation.

Of note in Figure 5-1 is the delineation of catchments between the outlet of Brucejack Lake and BJL-H1. On the south side of Brucejack Creek, both Camp Creek (50 ha) and VOK Creek (45 ha) discharge into the creek (Drawing 05). On the north side, an unnamed tributary with an area of 50 ha discharges to Brucejack Creek. These tributaries have been isolated in the WBM as a cone of depression will develop around the underground workings, as the groundwater table drops below the lowest level of mining. This lowering of the groundwater table will result in reduced baseflows in Camp Creek, VOK Creek, and Brucejack Creek during construction and operations. As this reduction in baseflow is spatially variable, it is important to segregate the individual flows in the WBM. This segregation is also important from a water quality monitoring perspective (contact vs non-contact). The two additional areas shown on Figure 5-1, and labelled as “Other”, represent intervening slopes (10 ha above BJ200 m D/S and 17 ha below BJ200m D/S) located between the three tributaries.

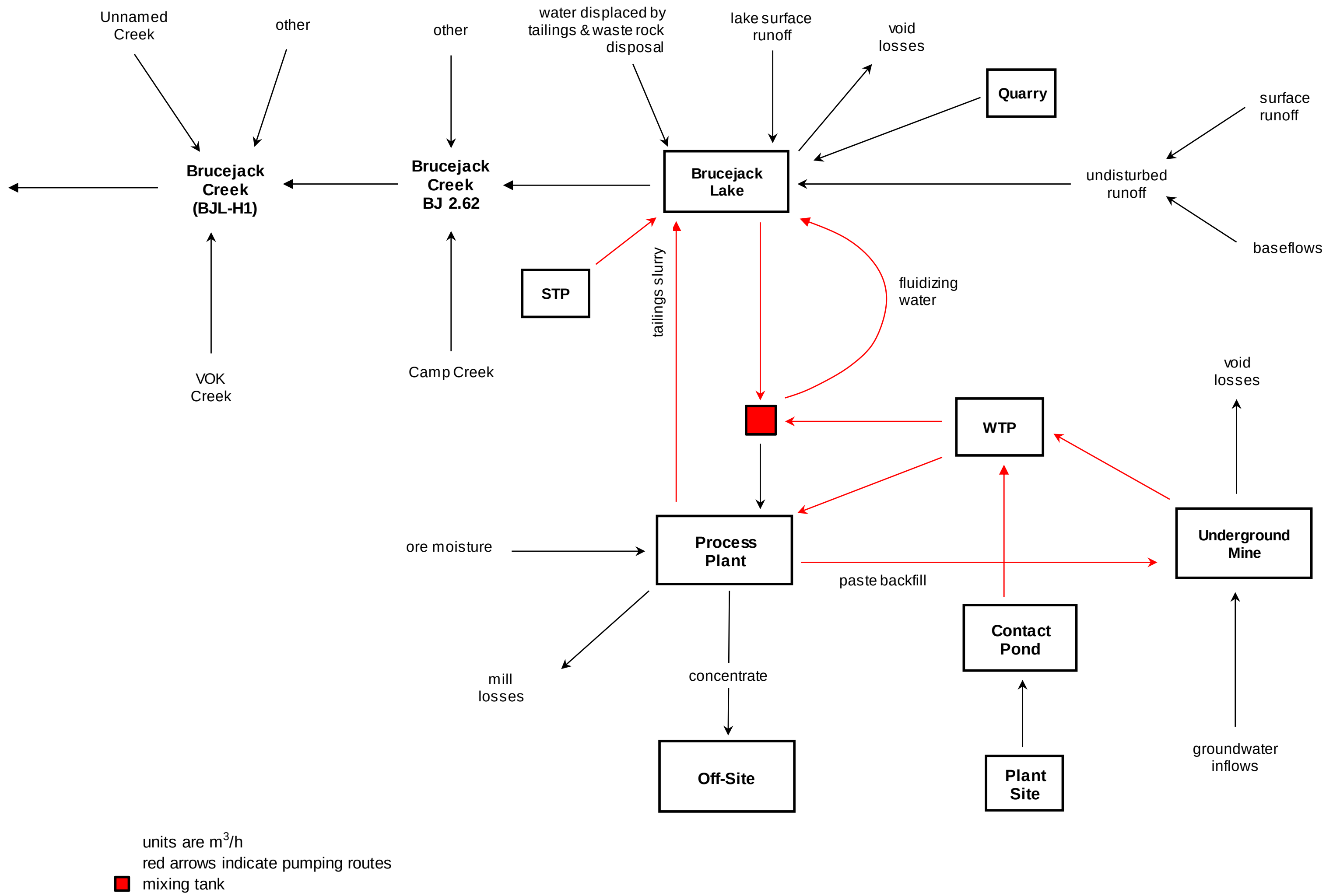


Figure 5-1. Brucejack Lake water balance model flow schematic during operations.

5.4. Process Parameters

The latest process water balance was prepared by TT and provided to BGC on May 25, 2014. This water balance was prepared based on a nominal ore throughput of 2,700 tpd. Based on the process water balance and accounting for the change in tailings balance, the following assumptions are utilized in the WBM as summarized in Table 5-3.

Table 5-3. Process plant input assumptions for 2,700 tpd.

WBM Component	Assumption	
Solids		
Mill feed)	2,700 tpd	
Concentrate	219 tpd	
Flotation tailings	1,307 tpd	
Paste backfill tailings (including 5-6% bonder)	1,245 tpd	
Water		
Flotation tailings	35% (by weight)	
	2,427 m^3/d	101 m^3/h
Paste backfill	65% (by weight)	
	670 m^3/d	28 m^3/h
Concentrate	88% (by weight)	
	30 m^3/d	1.3 m^3/h
Mill losses (evaporation in concentrator)	7 m^3/d	0.3 m^3/h
Total process water requirement	3,134 m^3/d	131 m^3/h
Fluidizing water	3,447 m^3/d	144 m^3/h
Water Source		
Ore initial moisture content	3.0% (by weight)	
	81 m^3/d	3.4 m^3/h

The above values assume that there is co-deposition of the paste backfill and the flotation tailings in Brucejack Lake. However, tailings will either be diverted to the paste backfill plant or diluted and sent to Brucejack Lake, but never concurrently. A constant flow is required through the pipeline at all times to keep the deposit at the end of the outfall fluidized; however, the tailings line to the lake will be operational less than 50% of the time. Therefore, when the thickened tailings are used in the backfill plant, flow will be maintained with fluidizing water, which will be sourced from excess underground seepage water and reclaim water from the surface of Brucejack Lake. The average fluidizing water requirement is 3,447 m^3/d (144 m^3/h).

5.5. Groundwater Inflows

A base case transient predictive simulation using 2-month stress periods was used to evaluate the groundwater flow system throughout proposed mining operations at the Brucejack Project (BGC, 2014). The simulation was based on the 22-year underground mine plan received from AMC Consultants on July 3, 2013 (AMC, 2013). The information provided with the 22-year mine plan included annual mined volumes and approximate mined elevations on an annual basis for the West Zone, Valley of Kings (VOK) Zone, and Galena (GAL) Zone, as well as an annual waste schedule. The production and waste schedules were combined with the stope plan received from AMC Consultants on February 27, 2013, and the development plan received from AMC Consultants on July 8, 2013 and updated on December 6, 2013, to develop mine sequencing for the predictive simulation. The model is used to predict groundwater inflows to the underground workings, as well as groundwater flows in the larger watershed. The model assumes that dewatering of the underground workings commence two years prior to the start of mining (Years -2 and -1).

Groundwater inflows to the underground workings have been estimated by BGC (2014) for a number of scenarios: a base case run followed by a sensitivity analysis that involved changing several parameters. The sensitivity run where the hydraulic conductivity, *K*, was increased by a factor of 5 and the recharge doubled resulted in the highest predicted inflows. The lowest predicted inflows were generated by reducing *K* by a factor of 5. Table 5-4 summarizes the estimated average annual groundwater inflows, although the input to the WBM is on a monthly basis based on output from the transient groundwater flow simulation (2-month stress period). The rate of groundwater inflow to the underground workings is predicted to remain relatively stable throughout the development of the mine (Figure 5-2).

Numerical groundwater modeling of the site indicates that during mine operations, the natural groundwater flow pattern will be altered and a cone of depression will form around the underground workings, as seepage water is pumped from the underground and used in processing (BGC, 2014). In response, the baseflow inputs to Brucejack Lake, Brucejack Creek, Camp Creek and VOK Creek will also be altered during this period. These altered baseflows are summarized in Table 5-5, as average values over the life-of-mine. Figure 5-3 also shows the monthly change in baseflow for two locations: Brucejack Lake and Brucejack Creek above BJ200 m D/S. The WBM accounts for these predicted reductions in baseflow.

Table 5-4. Estimated average annual groundwater inflows to underground workings.

Year	Underground Groundwater Inflows (m^3/h)		
	Base Case	**High K, High Recharge**	**Low K**
-2	158	373	88
-1	187	485	93
1	178	509	88
2	171	508	85
3	170	506	83
4	177	516	86
5	179	527	86
6	175	524	84
7	202	564	108
8	259	715	136
9	226	688	100
10	226	690	100
11	219	679	95
12	223	683	99
13	225	689	100
14	225	687	100
15	224	689	97
16	222	682	99
17	224	684	100
18	228	696	101
19	204	655	88
20	215	668	94
21	217	669	96
22	217	669	97
Average	**206**	**615**	**96**

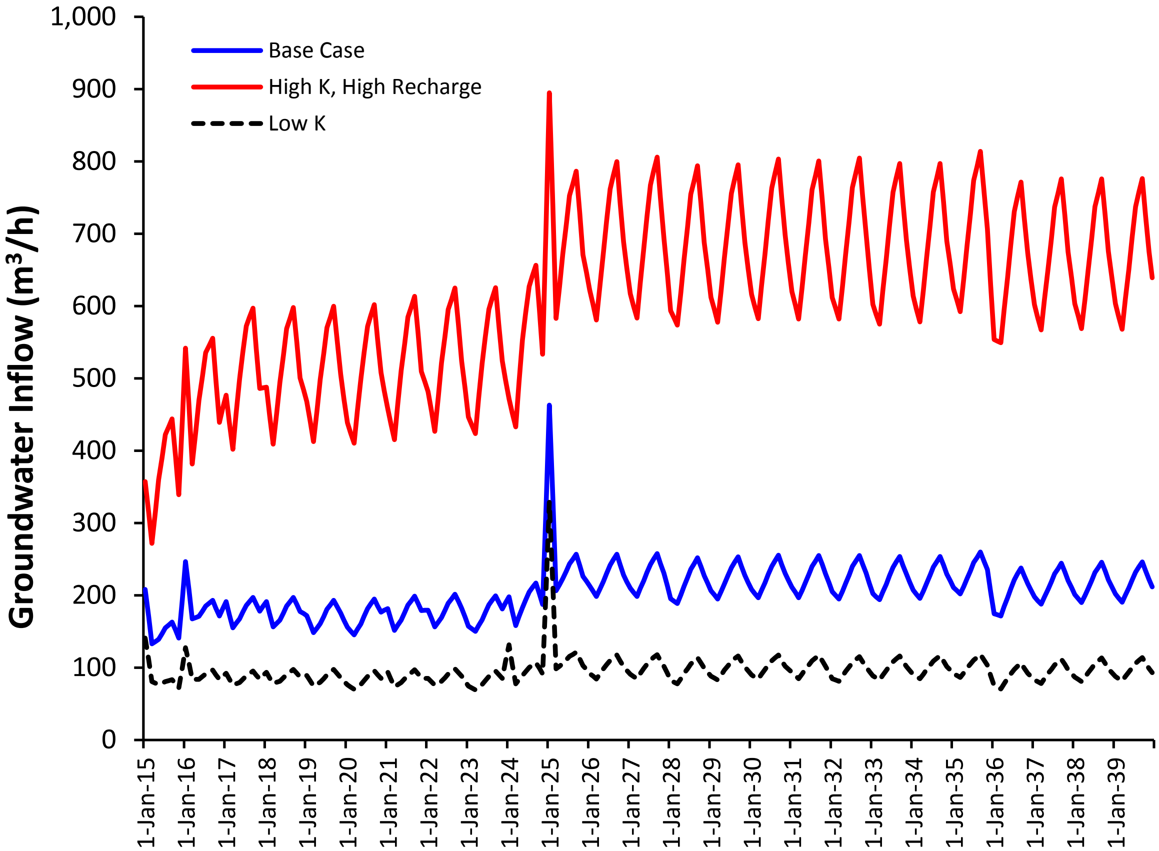


Figure 5-2. Estimated monthly groundwater inflows to underground workings (after BGC, 2014).

Table 5-5. Change in annual average groundwater flow over the life-of-mine.

Groundwater Discharge Location	Undisturbed (m^3/h)	Disturbed (m^3/h)
Brucejack Lake	269	257
Camp Creek	4	0
Unnamed Creek	34	28
VOK Creek	8	1
Brucejack Creek (above BJ200 m D/S)	43	4
Brucejack Creek (below BJ200 m D/S)	15	12

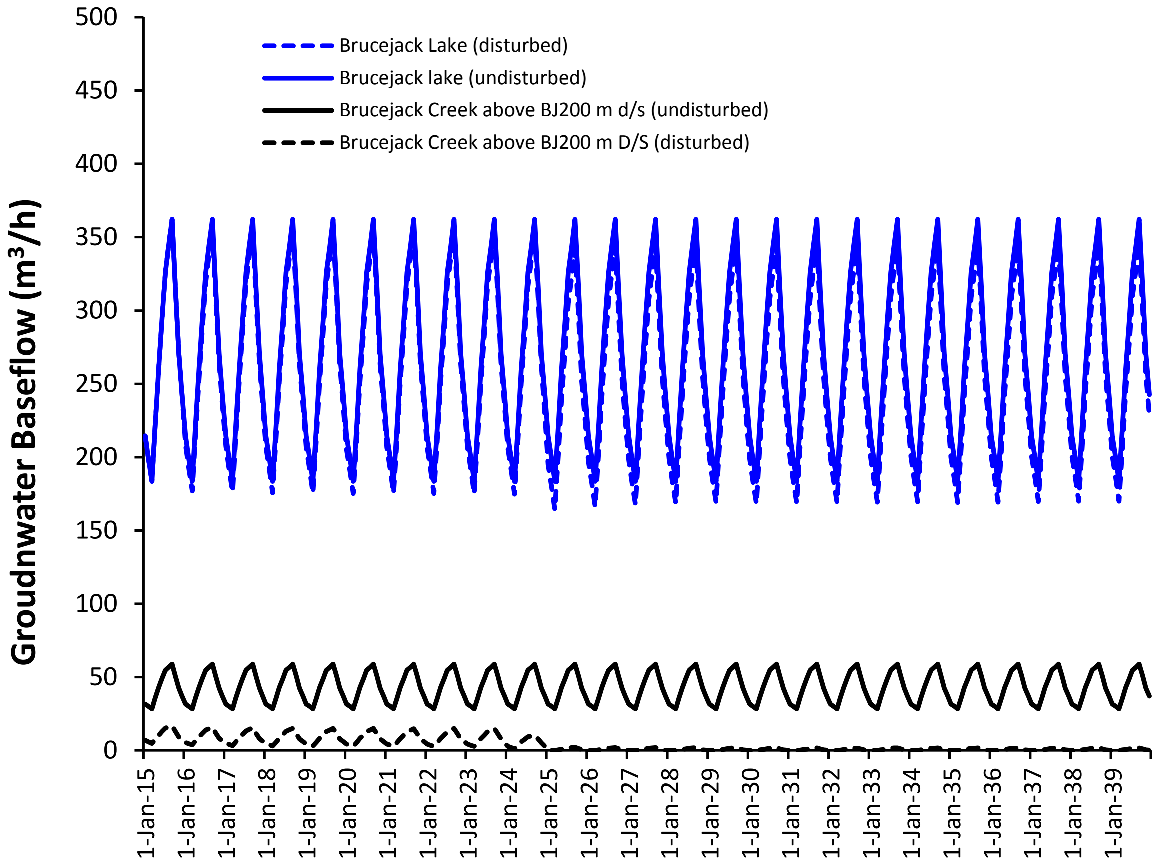


Figure 5-3. Estimated monthly change in groundwater flows for baseflows discharging into Brucejack Lake and Brucejack Creek above BJ200 m D/S.

5.6. Runoff Calculations

5.6.1. Undisturbed Ground

Monthly runoff from undisturbed ground was estimated using a calibrated version of the Vandewiele *et al.* (1992) model. The model structure and calibration procedure are provided in Appendix A. The Vandewiele *et al.* (1992) parameters calibrated to BJL-H1 streamflow were then applied to the water balance to predict runoff at the outlet of Brucejack Lake and BJL-H1 during mine operations. Monthly estimated flows at BJL-H1 based on the calibrated Vandewiele *et al.* (1992) model for average, 10-year dry, 10-year wet and 200-year wet conditions are summarized in Table 5-6. For the 10-year dry and wet scenarios, it was assumed that average precipitation conditions prevailed in the previous year (i.e. average soil moisture conditions). For the 200-year wet year, it was assumed that the previous year had above average precipitation (5-year return period). Of note is that during an exceptionally wet year, not all of the snowpack melts resulting in lower than expected flows.

Table 5-6. Monthly estimated flows at BJL-H1 for undisturbed conditions.

Month	Runoff (mm)				Flow (m^3/s)			
	Average	10-Year Dry	10-Year Wet	200-Year Wet	Average	10-Year Dry	10-Year Wet	200-Year Wet
January	22	22	22	24	0.095	0.094	0.097	0.103
February	18	17	18	19	0.085	0.084	0.087	0.092
March	16	16	16	16	0.069	0.069	0.069	0.071
April	28	28	28	29	0.127	0.126	0.129	0.133
May	148	145	154	160	0.647	0.633	0.674	0.700
June	406	392	431	445	1.831	1.771	1.946	2.010
July	373	363	391	400	1.628	1.584	1.707	1.749
August	362	168	426	448	1.581	0.735	1.861	1.956
September	214	165	426	456	0.964	0.743	1.921	2.060
October	94	88	110	111	0.409	0.382	0.479	0.486
November	33	32	37	37	0.150	0.143	0.167	0.169
December	28	27	30	30	0.121	0.116	0.131	0.132
Total/ Average	**1740**	**1461**	**2089**	**2177**	**0.642**	**0.540**	**0.772**	**0.805**

5.6.2. Contact Runoff

Contact runoff is expected from three sources during construction and operations:

- The upper laydown area where the pre-production ore will be located.
- The mill building and portal site which requires an extensive cut into bedrock some of which is currently assumed to be potentially acid-generating (PAG) material.
- Groundwater seepage to the underground mine tunnels.

Runoff from the plant site excavation and waste rock stockpiles will be managed by storage and treatment. Collection ditches along with a contact water pond will be used to contain runoff associated with the 24-hour, 200-year return period rain-on-snow event. These collection ditches are being designed by TT. Additional details are provided in Section 6.

5.7. Additional Assumptions

The following is a list of additional assumptions used in the Brucejack Lake mine site water balance:

- An estimated 4.6 Mt of waste rock will be removed and deposited directly into Brucejack Lake (approximately 2.2 Mt of which will be rock from the mill pad) prior to mine life and an additional 2.0 Mt of waste rock will be placed in the underground during mine life.

The water balance accounts for the lake water displaced by this deposition (assuming a settled dry density of about 2 t/m^3) and the tailings deposition.

- The flotation tailings in Brucejack Lake have an assumed final settled dry density of 1.6 t/m^3 (G. Norton, ERM Rescan, pers. comm.) and a solids specific gravity of 2.68. Void losses (i.e. water retained in the voids of the tailings sand) are then estimated using the following equation:

$$void\ loss = \left(\frac{1}{\rho} - \frac{1}{SG}\right) \cdot mill\ throughput$$

where ρ = tailings settled dry density and SG = specific gravity.

- The settled dry density of the paste backfill is 1.46 t/m^3 for the underground mine deposition with a solids specific gravity of 2.71 (Aran, 2013). Based on these properties and a backfill slurry that is 65% solids by weight, the paste backfill will expel some water during the curing phase. It is conservatively assumed that this bleed water will report to the underground sumps and require treatment.
- Runoff from East Lake was assumed to not contribute flow to Brucejack Lake, except for sensitivity analyses. A watershed area of 9.8 km^2 for the outlet of Brucejack Lake and an area of 11.7 km^2 for BJL-H1 was adopted.
- Runoff from the proposed quarry (area = 4 ha) is included in the WBM. However, this runoff will not be captured, as water quality issues are not currently anticipated[2].

[2] This assumption still needs to be verified by the geochemical assessment.

6.0 WATER MANAGEMENT PLAN

This section provides an overview of the water management plan for Brucejack Lake during construction, operations, and closure. During construction and operations it is assumed that contact water can be discharged to the environment following treatment. For closure and post-closure, it has been assumed that the contact water will be of suitable quality for discharge without treatment, although this assumption needs to be verified by concurrent water quality modelling being conducted by Lorax.

6.1. Construction

The current schedule shows that on-site construction will occur over an approximate two-year period. Early works around the site would commence in the 3rd quarter of Year -2 and include:

- site preparation for a mill pad, operations camp, site water management, construction laydown area, explosives storage and substation;
- site roads;
- transmission line;
- initial underground mine development; and
- operations camp.

Construction of required water management structures would be complete by November of Year -2. Full project execution would commence near the end of the 1st quarter of Year -1 and would include construction of:

- underground infrastructure to support full operations;
- the mill, warehouse and administration buildings;
- switchyard and substation;
- pipelines – tailings and reclaim, mine WTP effluent, STP effluent; and
- shops and additional ancillary infrastructure.

Mine operations would then commence in the 3rd quarter of Year 1. During construction, water management will include the following:

- Fresh water diversion channels will be constructed around the plant site. Diversions are required for the operations camp, laydown area, and garbage and incinerator area. Water management for the plant site (diversion channels, culverts) has been designed by TetraTech. The diverted water will either discharge to Brucejack Lake or downstream of the lake into Brucejack Creek.
- Groundwater from the underground workings will be pumped to a water treatment plant (WTP) and treated before being discharged into Brucejack Lake. The WTP has been designed with an initial capacity of 400 m^3/h and will be scaled up as needed over the life-of-mine.
- Runoff from the plant site excavation and from the ore stockpile will be captured by a perimeter ditch system, diverted to a contact water pond, and pumped to the WTP for

treatment prior to release to Brucejack Lake. Additional details are provided in Section 0.
- Some of the waste rock deposited in Brucejack Lake is suspected to be PAG. Therefore, sufficient cover over the deposits must be maintained to limit exposure to air.
- Reclamation material stockpiles will be seeded and silt fences will be installed around the perimeter of stockpiles to prevent erosion during construction and operations.
- A 500 person camp will be required for the construction period. Assuming an effluent rate of 0.227 m^3/person/d (Sylvia Van Zalingen, Pretium, pers. comm.), total daily effluent is estimated at approximately 5 m^3/h. A sewage treatment plant (STP) will be constructed to handle this effluent, which will be discharged into Brucejack Creek downstream of Brucejack Lake during construction (and into the lake during operations).

Perimeter water diversion and sediment collection structures will be established as a first step to work activities. In addition to perimeter diversion ditches, small-scale runoff collection and treatment measures may be used locally. Work areas will be isolated from water flow paths.

Non-contact water will be routed around the site by freshwater diversion channels that will be constructed around the operations camp, plant site and laydown area, and garbage and incinerator area. These channels will typically follow access roads or the base of rock cuts. Channels will have a trapezoidal shape with a bottom width of about 2.5 m, and side slopes of 2H: 1V. The ditches are designed for the 200-year return period peak instantaneous flow (rain-on-snow event) and a high-density polyethylene (HDPE) geomembrane liner will be placed under the channels as required to prevent leakage. A 300 mm (minimum) thick cushion layer of 30 mm minus granular material (<10% passing 0.75 mm) will be placed under the liner. Channels will be armoured as required to prevent damage from erosion and equipment used to maintain and clean out the channels. The contact water collection ditches will drain to the contact water collection pond, which will also be lined. Water in the pond would be treated in the WTP and discharged directly to Brucejack Lake during construction.

6.2. Operations

6.2.1. Water Use and Management

During operations, the average water requirement for the Brucejack process plant is 3,134 m^3/d (131 m^3/h) based on a mill throughput of 2,700 tpd. This water is required for the tailings slurry to the lake, the underground paste backfill, the concentrate slurry, and minor evaporative losses within the plant (~ 7 m^3/d). The process water will be sourced from:

- treated underground seepage water
- ore moisture
- reclaim from the lake.

During operations, water management will include the following:

- Non-contact water (freshwater) will be directed away from the site via diversion channels around the plant site, operations camp, laydown area, and garbage and incinerator area. The diverted water will either discharge to natural drainages or to Brucejack Lake.
- Contact water from the upper laydown area (including storage pads for waste rock transfer and pre-production ore) and mill building/portal site will be contained in lined perimeter collection ditches. Contact water will first be directed to the lined collection pond, then pumped to the WTP for treatment prior to use as process water or directly released to Brucejack Lake.
- Approximately 47% of the tailings will be deposited underground as paste backfill, while 53% will be discharged sub-aqueous at a maximum depth of 80 m in Brucejack Lake.
- Reclaim from the lake is required, as there are periods when the groundwater inflows are predicted to be less than the process requirement.
- Tailings will either be diverted to the paste backfill plant or diluted and sent to Brucejack Lake, but not concurrently. A constant flow is required through the pipeline at all times to keep the deposit at the end of the outfall fluidized; however, the tailings line to the lake will be operational less than 50% of the time. Therefore, when the thickened tailings are used in the backfill plant, flow will be maintained with fluidizing water, which will be sourced from excess treated underground seepage water and reclaim water from the surface of Brucejack Lake.
- Groundwater seepage to the underground mine will be pumped to the WTP for treatment. Priority of use for this treated water is:
  - The process plant;
  - Fluidization water when there are excess amounts remaining after process plant requirements; and
  - Excess treated groundwater will be discharged to Brucejack Lake at times when the tailings slurry is also being discharged, as there is no on-site storage for the treated water.
- Given a settled dry density of 1.46 t/m^3 and a slurry consisting of 65% solids by weight, the paste backfill will exude some water during the curing phase. This additional water is assumed to be pumped out with the groundwater seepage water and sent to treatment.

6.2.2. Water and Sewage Treatment Plants

The WTP will initially be constructed as two independent trains, each capable of treating up to 200 m^3/h, for a total capacity of 400 m^3/h. The treated water will be used in process to the extent possible, with any excess treated water being used as fluidizing water for the tailings line to the lake. It is anticipated that the WTP will be used year round. The system will be scaleable such that additional units can be added if required.

It is currently assumed that the treated effluent from the STP will be at the same rate as the construction period: 5 m^3/h.

6.2.3. Potable Water

There will be three potable water supply systems: one located in the mill/administration complex to service the mill building and camp, a second at the Knipple Transfer Area, and a third during the construction stage for the Tide Lake Staging Area. Potable water will be supplied from wells or surface water, as appropriate for each site, and will be treated to achieve the necessary quality for human consumption.

The camp water requirements will be approximately 115 m^3/d during construction (and less during operation) based on an average usage rate of 230 L/d per person and a camp population of up to 500 people. The existing exploration camp has an ozone/UV potable water treatment package sized to service 180 people. This camp will be used during the construction period in addition to the new camp.

6.2.4. Plant Site Runoff

As noted previously, contact water will be generated from:

- The upper laydown area where the pre-production ore and waste rock transfer will be stored.
- The mill building and portal site which requires an extensive cut into bedrock some of which is currently assumed to be potentially acid-generating (PAG) material.

Runoff from these two areas will be captured by a perimeter ditch system (Drawing 10) and conveyed to a stormwater pond with sufficient capacity to contain the 24-hour, 200-year return period rainfall event plus snowmelt. The 24-hour, 200-year rainfall has been estimated at 179 mm while snowmelt potential was calculated using the rain-on-snow equations described in the USACE's 'Runoff from Snowmelt' engineering manual (1998). For open or partially forested basin areas, snowmelt is calculated as:

$$M = (1.33 + 0.239kv + 0.0126P_r) \cdot T_a + 2.3 \qquad \text{[Eq. 6-1]}$$

where M = snowmelt (mm/day), k = basin wind coefficient, v = wind velocity at a 15 m height (km/h), P_r = daily rainfall (mm), and T_a = mean temperature of the saturated air (^oC). BGC assumed that a rain-on-snow event was most likely to occur in October and used the average maximum daily temperature and wind speed for that month in Equation 6.1, as recorded at the site climate station. Using values of 12.1 m/s, 5.6^oC and 179 mm for wind velocity, temperature, and daily rainfall, respectively, potential snowmelt was estimated at 41 mm. Therefore, the total rain-on-snow depth was estimated at 220 mm.

Assuming a runoff co-efficient of 0.9, the required live storage volume for the contact pond is estimated at 33,000 m^3. The layout of the pond is provided in Drawing 10. The contained runoff will be pumped to the WTP at a maximum rate of 200 m^3/h, which is sufficient to prevent the pond from overtopping for 200-year return period rainfall events up to 10 days duration, assuming that there is not additional snowmelt beyond the first day. A high-density polyethylene (HDPE) geomembrane liner will be required for:

- the storage pond;
- under the pre-production ore storage; and
- the diversion ditch that parallels Access Road 01.

A 300 mm (minimum) thick cushion layer of 30 mm minus granular material (<10% passing 0.75 mm) will be required under the liner. Appropriate armouring will be placed over the liner to protect it from erosion and damage by equipment. Sludge from the pond will be excavated periodically and transported to the paste plant for inclusion in the paste product.

6.2.5. Flotation Tailings

The tailings distribution system is being designed by Rescan. The following is an excerpt from the FS text:

> "The thickened tailings slurry will be discharged to the bottom of 85 m deep Brucejack Lake when not used for paste backfill (about 50% of the time). For discharge to the lake, the tailings slurry will be first pumped to an agitated slurry mixing tank at approximately 65% solids by weight and there diluted to 35% solids by weight with water. The dilute slurry will then be pumped overland a distance of 525 m and then underwater along the lake bed another 445 m to the discharge point. There will be one duty pump and one standby pump to permit an immediate switch over when necessary. Much of the pipeline alignment may be subject to the risk of impact by avalanches. Therefore, a significant portion of the overland pipeline section will be trenched and backfilled. The pipeline will also have a continuous downward slope from the mill building to the lake shore to ensure that the line drains during shutdowns.
>
> At the lake shore the pipeline will divide into two parallel pipelines. The primary pipeline will discharge at 80 m and the secondary pipeline will discharge at 60 m. The pipelines will be switched if and when the back-pressure associated with the growing deposit approaches the upper operating range of the discharge pump.
>
> Air/vacuum valves will be installed at critical points along the pipeline to prevent the possibility of air entering the underwater section. A large volume of air entering the underwater section could potentially float sections of the pipeline. The valves will primarily function during start-up and shut-down.
>
> Prior to tailings discharge, a small quantity of coarse sand and gravel will be placed at the terminus of the outfall. Through operations, tailings solids will further accumulate and cover

> the discharge point. This feature will act as a filter to prevent suspended solids from entering the upper layers of the lake's water column and from subsequently being discharged into Brucejack Creek.
>
> There will be a constant flow through the pipeline at all times to keep the deposit at the end of the outfall fluidized. When the thickened tailings are used in the backfill plant, flow will be maintained with water. The overall footprint of the tailings at the end of 22 years occupies most of the lake bottom, to a depth of approximately 48 m at its edge and a depth of 38 m at the apex of the deposition cone."

Previous Rescan designs for discharging tailings through a deposit have been demonstrated to be effective in reducing total suspended solids (TSS) (Rescan, 2013d). A potential concern remains however that there may be some re-suspension of fine tailings particles during lake turnover, potentially resulting in elevated TSS concentrations at the outlet. To minimize this potential, flocculant will be added to the tailings slurry. Lorax (2013) conducted hydrodynamic modelling to evaluate the potential for re-suspension of the tailings. In the absence of flocculant, the model predicts significant suspended particle concentrations in the lake surface, with a median surface layer TSS concentration of 8 mg L^{-1} (maximum = 40 mg L^{-1}). In contrast, the results for scenarios with flocculant addition predict that tailings particles will not migrate into the surface layer of the lake if the minimum particle diameter is greater than or equal to 5 µm.

As a further contingency to flocculant addition, Rescan (2013d) evaluated additional mitigation options to prevent discharges of water with elevated TSS at the lake outlet. A turbidity curtain across the lake outlet is one of the mitigation options being planned for (Drawing 10).

6.3. Closure

The underground workings will be flooded at closure to minimize development of acid rock drainage and associated leaching of metals. The adits will need to be sealed to allow the mine workings to flood.

At the moment it is assumed that by the end of the closure phase, water treatment will no longer be required and all facilities not required for ongoing monitoring would be closed. The contact water pond will be backfilled and reclaimed. A diversion ditch is present that will direct water from the cut face above the plant site and adit. The ditch will cut across the backfilled pond and discharge into Brucejack Lake. The end of post-closure represents a "walk-away" state with the only ditch remaining being the one that carries water from the cut face to the lake. All roads will be reclaimed and culverts removed such that the ditch will cut across the roads on its way to the lake.

7.0 WATER BALANCE MODEL RESULTS

7.1. Base Case Results

Water balance schematics for the mine for existing conditions and during construction, operations and closure are shown in Figures 7-1 to 7-4. Values shown are average flows (m^3/h). Note that values shown on Figure 7-3 are lower than values provided in Table 5-3, as the proposed ore tonnage varies from year to year and averages less (2250 tpd) than the nominal throughput of 2700 tpd that the Table 5-3 calculations are based on.

An average annual flow of 2,472 m^3/h at BJL-H1 has been estimated over the LOM, an average increase of 6.4% above existing conditions (2,324 m^3/h). The increase in flow results from the introduction of tailings slurry water and the displacement of water by the deposition of tailings and waste rock. In the WBM, outflows from Brucejack Lake are assumed to be of suitable water quality for discharge to Brucejack Creek following treatment of the underground mine and surface contact water.

Estimated average monthly changes in flow at BJL-H1 over the life-of-mine (LOM) are summarized in the table below. These changes assume average precipitation conditions, and will vary from year to year depending on the mine schedule. As a percentage, changes in flow are most apparent during the winter months.

Table 7-1. Average changes in streamflow at BJL-H1 over the life-of-mine.

Month	Streamflow (m^3/h)		Change in flow	
	Existing	LOM	(m^3/h)	%
January	342	496	153	45%
February	307	450	143	47%
March	248	381	134	54%
April	458	600	142	31%
May	2,329	2,516	187	8%
June	6,593	6,732	139	2%
July	5,860	6,016	155	3%
August	5,690	5,834	144	3%
September	3,471	3,617	145	4%
October	1,474	1,619	145	10%
November	539	680	141	26%
December	434	582	148	34%
Average	**2,324**	**2,472**	**148**	**6.4%**

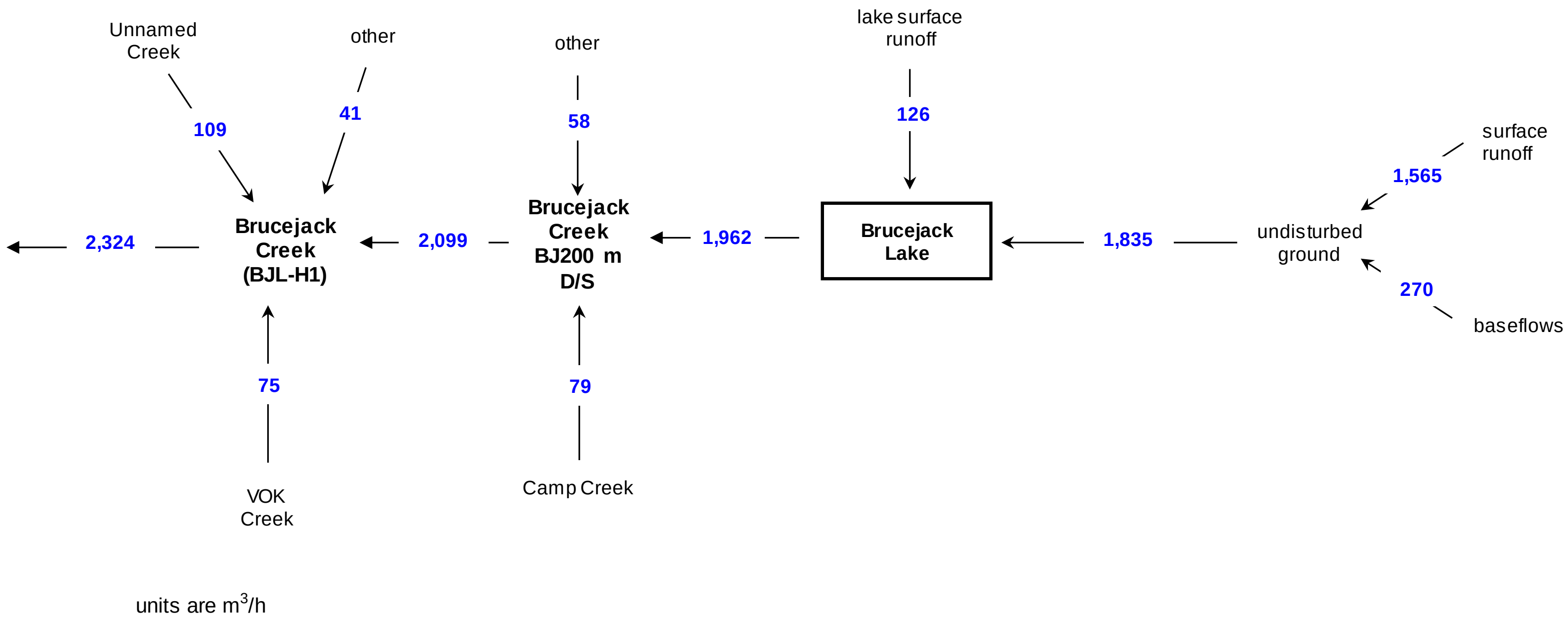


Figure 7-1. Brucejack Lake water balance model schematic for undisturbed conditions (average precipitation).

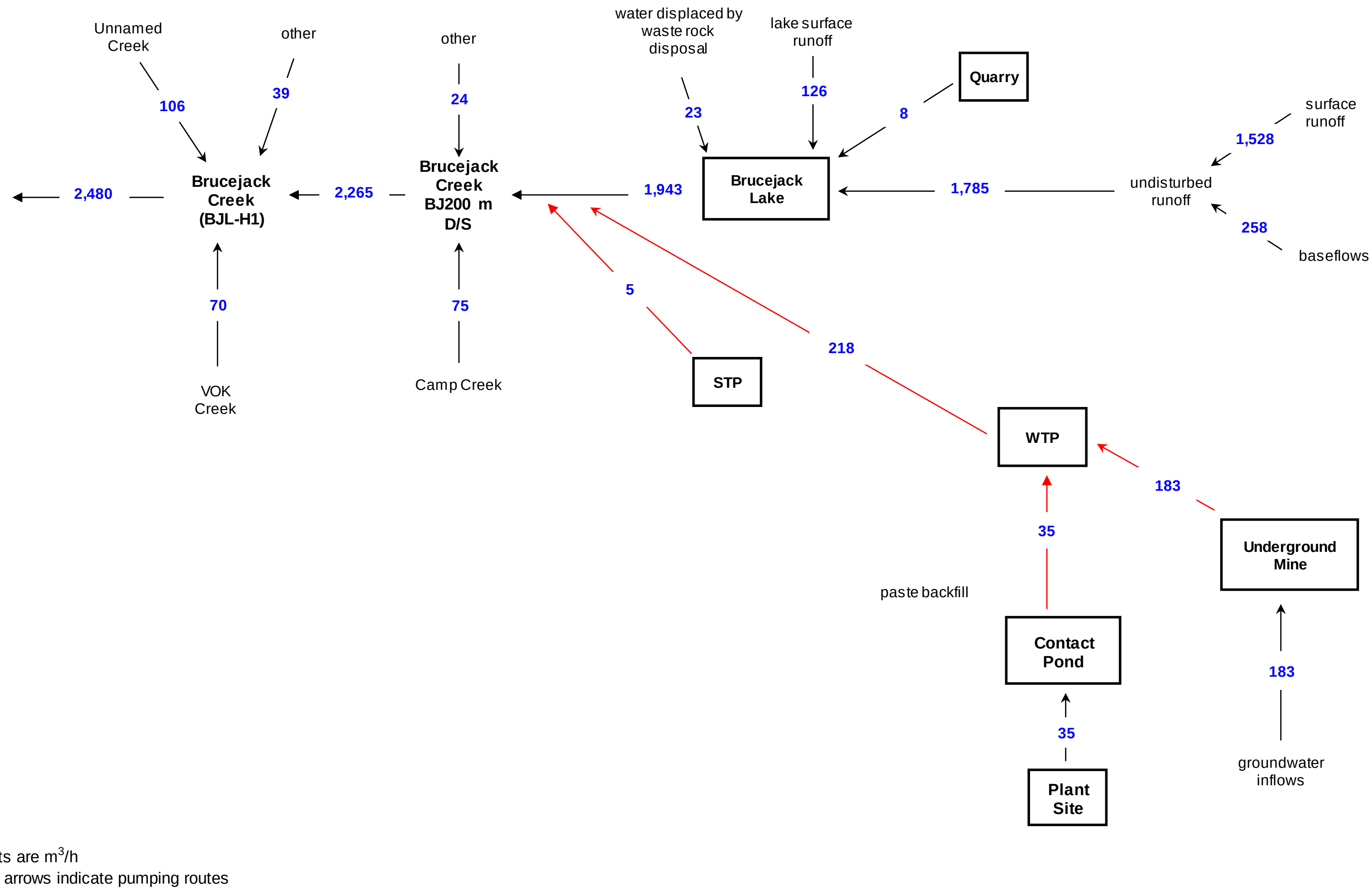
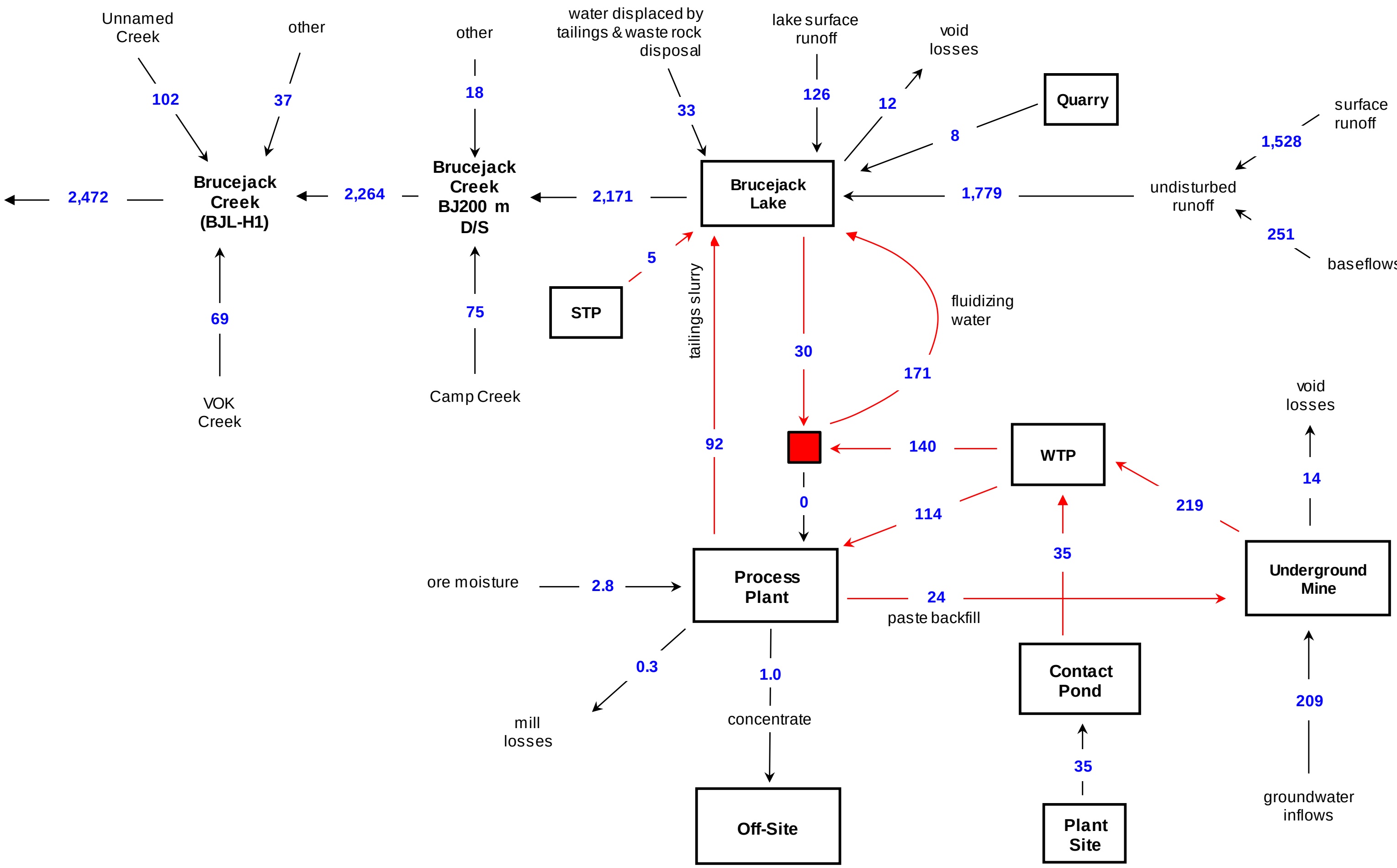


Figure 7-2. Brucejack Lake water balance model schematic for construction (average precipitation).



units are m^3/h
red arrows indicate pumping routes
mixing tank

Figure 7-3. Brucejack Lake water balance model schematic for operations (average precipitation). Values shown are averaged over the life-of-mine.

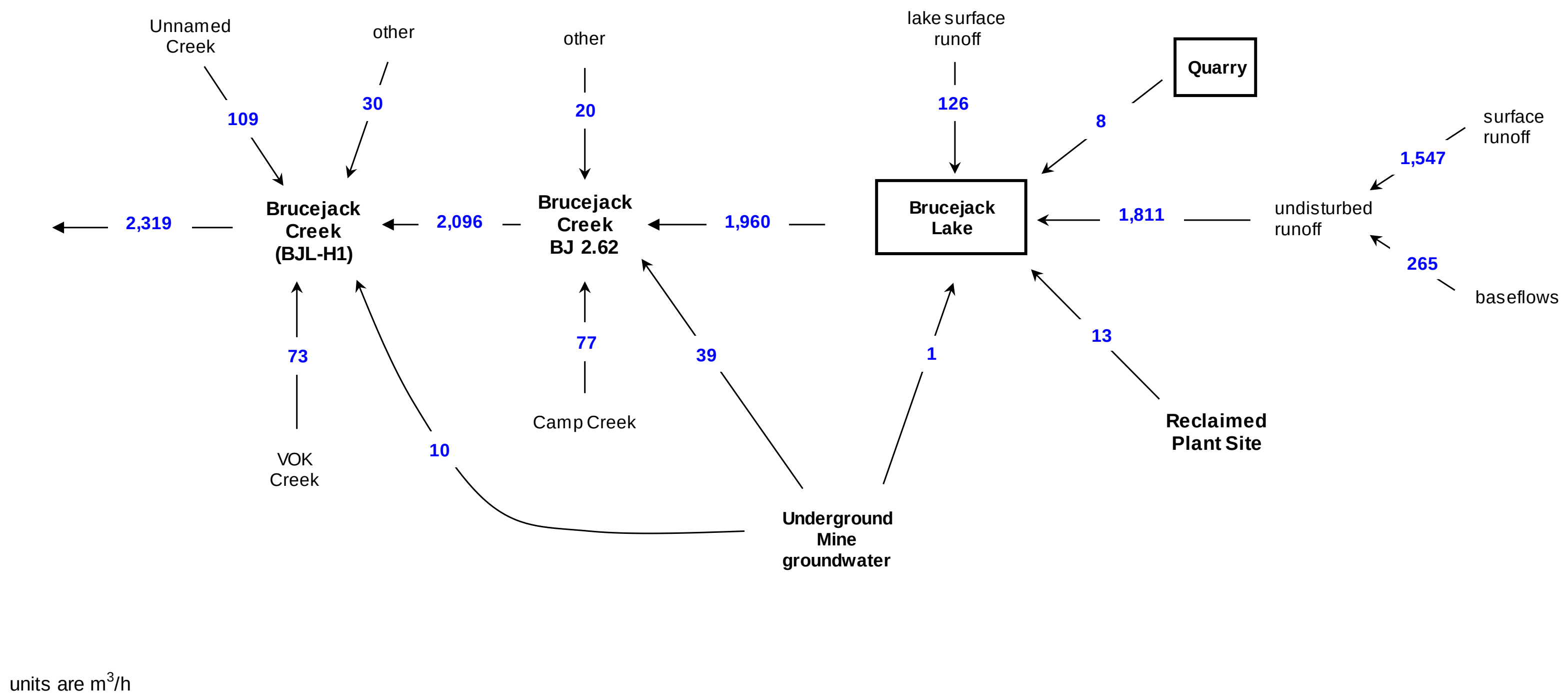


Figure 7-4. Brucejack Lake water balance model schematic for closure (average precipitation).

Figure 7-4 demonstrates that flows in Brucejack Creek return to pre-disturbance levels during the closure and post-closure periods. The estimated flow at BJL-H1 five years after mining is estimated at 2,319 m^3/h, compared to the pre-disturbance estimate of 2,324 m^3/h. This result is expected as:

- it is assumed that groundwater flowing through the underground workings is suitable for discharge without treatment;
- the groundwater modelling indicates that the underground workings become flooded in less than 2 years after the cessation of mining; and
- the surface impacts of the mine cover a small area, relative to the size of the watershed.

7.2. Sensitivity Runs

7.2.1. Operations

As well as evaluating average precipitation conditions, BGC conducted a number of sensitivity runs for operations:

- a 100-year dry year (1240 mm) with the preceding year having average runoff;
- a 100-year wet year (2710 mm) with the preceding year having a 5-year return period runoff;
- East Lake diverts into Brucejack Lake during May;
- a 50% increase in April/May snowmelt;
- tailings density of 1.4 t/m^3 (versus 1.6 t/m^3);
- groundwater inflows to the underground mine for the high conductivity and high recharge scenario (Table 5-4);
- groundwater inflows to the underground mine for the low conductivity scenario (Table 5-4); and
- using a multi-year deterministic dataset for precipitation.

For this last scenario, rather than assuming a specified precipitation for a given year (e.g., average or 100-year wet), the precipitation dataset from Unuk River was applied to the WBM (downscaled to achieve an average annual precipitation of 1900 mm). The resulting deterministic dataset is advantageous in that it can account for an observed sequence of wet years or dry years, which cannot be simulated with a probabilistic model.

Hydrologic data are rarely purely stochastic in nature. The data commonly have both a deterministic and random component. The deterministic component comes from regular cyclical behavior in time (e.g. the normal annual cycle or longer decadal cycles affecting storm patterns). For a probability distribution derived from any given dataset to be valid, it must be stationary (i.e. have no discernable trend). That means that the deterministic trend must be removed leaving only the random component varying around the deterministic curve. This is typically accomplished by breaking the time scale up into discrete intervals (months in the case of Brucejack Lake) and assigning a mean that accounts for the deterministic trend along with a stochastically derived standard deviation to account for the stochastic scatter around the mean. The end result is that the long-term cycle of precipitation cannot be modeled with a stochastic analysis, making the deterministic model a valuable tool.

However, users of the deterministic model should be reminded that the projected monthly and annual precipitation amounts over the time scale of the model do not represent a prediction of precipitation in real time, and are intended only to represent the expected range of variation of the water balance model elements. Deviations from the projected values in any given month or year will likely be observed during the course of the project.

Results of the sensitivity analysis are summarized in Table 7-2 for BJL-H1. Values shown are monthly averages over the life-of-mine. Pertinent results are as follows:

- there is ~35% less runoff for a 100-year dry year compared to average runoff conditions;
- there is ~24% more runoff for a 100-year wet year compared to average runoff conditions;
- average flow only increases ~4% if East lake discharges into Brucejack Lake for the month of May;
- increasing the snowmelt in April/May predominantly changes the distribution of streamflow rather than the total;
- average flows at BJL-H1 are estimated to increase between 5 and 10% during operations for a range of precipitation conditions (100-year dry to 100-year wet). This increase is predominantly the result of treating and releasing groundwater inflows;
- changing the density of the tailings slurry has a negligible impact on streamflows;
- average streamflow at BJL-H1 only increases 1.6% for the low K groundwater scenario; and
- average streamflow at BJL-H1 increases 25% for the high K, high recharge groundwater scenario.

Some of the results are also shown graphically:

- Figure 7-5 shows the variation in monthly discharge at BJL-H1 for a number of the undisturbed sensitivity runs: base case (average precipitation), 100-year dry precipitation, 100-year wet precipitation, and a 50% increase in May snowmelt.
- Figure 7-6 shows the impact of different groundwater inflows into the underground workings in Year 6 of operations; while
- Figure 7-7 shows the deterministic results for construction and operations.

Table 7-2. Monthly averages flows at BJL-H1 (m^3/h) over the life-of-mine for various sensitivity runs.

Month	Undisturbed (m^3/h)					Disturbed (m^3/h)								Deterministic	
	Avg[+]	100-yr Dry	100-yr Wet	East Lake[++]	snow melt*	Avg[+]	100-yr Dry	100-yr Wet	p = 1.4 t/m^3	High K Inflow	Low K Inflow	East Lake[++]	snow melt*	Undis'd	Dist'd
1	342	334	372	342	339	496	487	525	496	864	389	496	493	346	500
2	307	300	329	307	304	450	443	472	450	807	346	450	447	310	453
3	248	248	255	248	248	381	381	389	381	727	281	381	381	249	383
4	458	452	478	458	589	600	594	620	600	982	496	600	736	460	603
5	2,329	2,216	2,511	3,507	3,573	2,516	2,401	2,698	2,516	2,934	2,408	3,694	3,778	2,330	2,517
6	6,593	6,117	7,192	6,593	8,184	6,732	6,259	7,331	6,732	7,181	6,618	6,732	8,292	6,575	6,714
7	5,860	2,585	6,267	5,860	5,330	6,016	2,728	6,422	6,016	6,495	5,896	6,016	5,495	5,631	5,785
8	5,690	1,715	6,973	5,690	3,445	5,834	1,854	7,118	5,834	6,325	5,712	5,834	3,581	5,187	5,335
9	3,471	1,979	7,318	3,471	3,183	3,617	2,131	7,463	3,617	4,118	3,491	3,617	3,334	4,084	4,234
10	1,474	1,248	1,745	1,474	1,443	1,619	1,398	1,890	1,619	2,080	1,498	1,619	1,588	1,519	1,663
11	539	480	607	539	531	680	622	748	680	1,100	564	680	672	551	691
12	434	398	473	434	430	582	547	620	582	979	470	582	577	440	588
average	**2,324**	**1,508**	**2,886**	**2,424**	**2,307**	**2,472**	**1,656**	**3,035**	**2,472**	**2,895**	**2,359**	**2,572**	**2,455**	**2,317**	**2,465**
% increase[1]	**-**	**-35**	**24**	**4.2**	**-0.5**										
% increase[2]						**6.4**	**9.8**	**5.2**	**6.4**	**24.7**	**1.5**	**6.1**	**6.4**	**-**	**6.4**

[+] Average annual precipitation.

[++] East Lake diverts into Brucejack Lake during the month of May.

* 50% increase in April/May snowmelt

[1] Average increase in flow relative to undisturbed conditions with average precipitation.

[2] Average increase in flow relative to same category for undisturbed conditions (e.g., 100-yr dry undisturbed is compared to 100-yr dry disturbed, average undisturbed is compared to High K inflow, etc.).

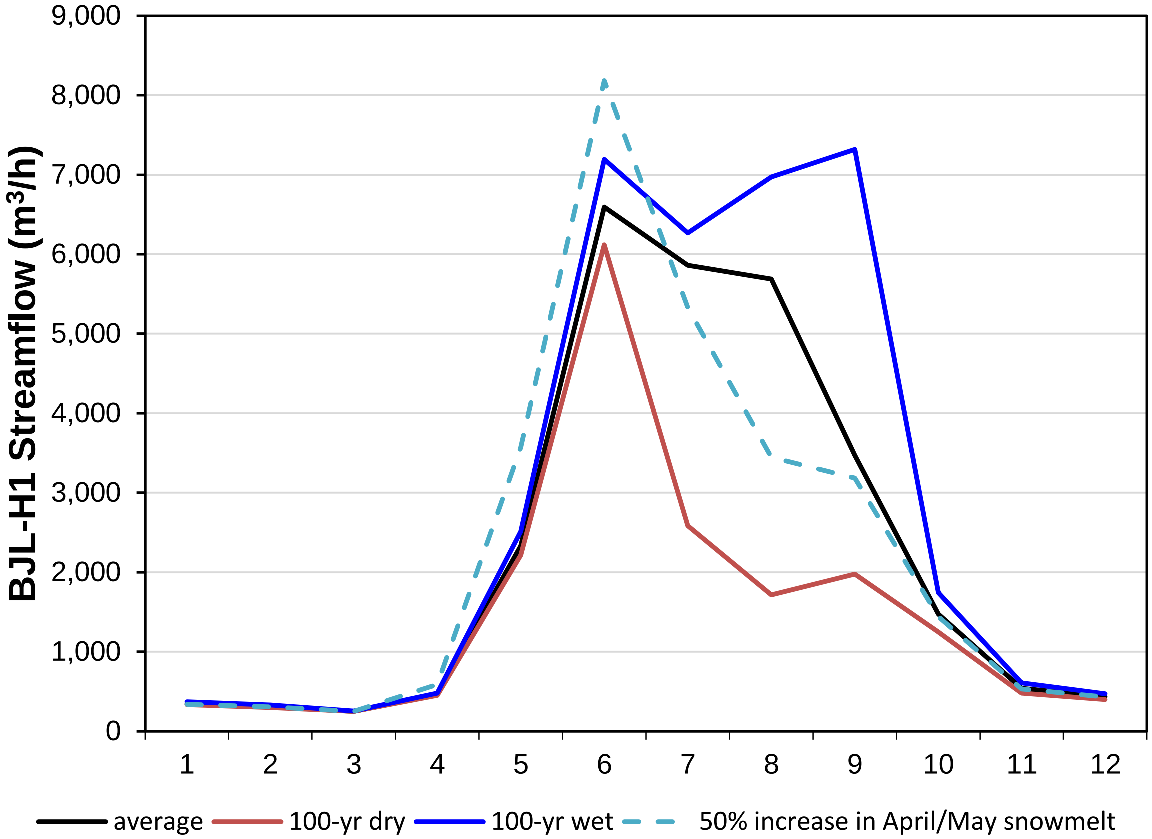


Figure 7-5. Undisturbed runoff at BJL-H1 for a number of precipitation and snowmelt conditions.

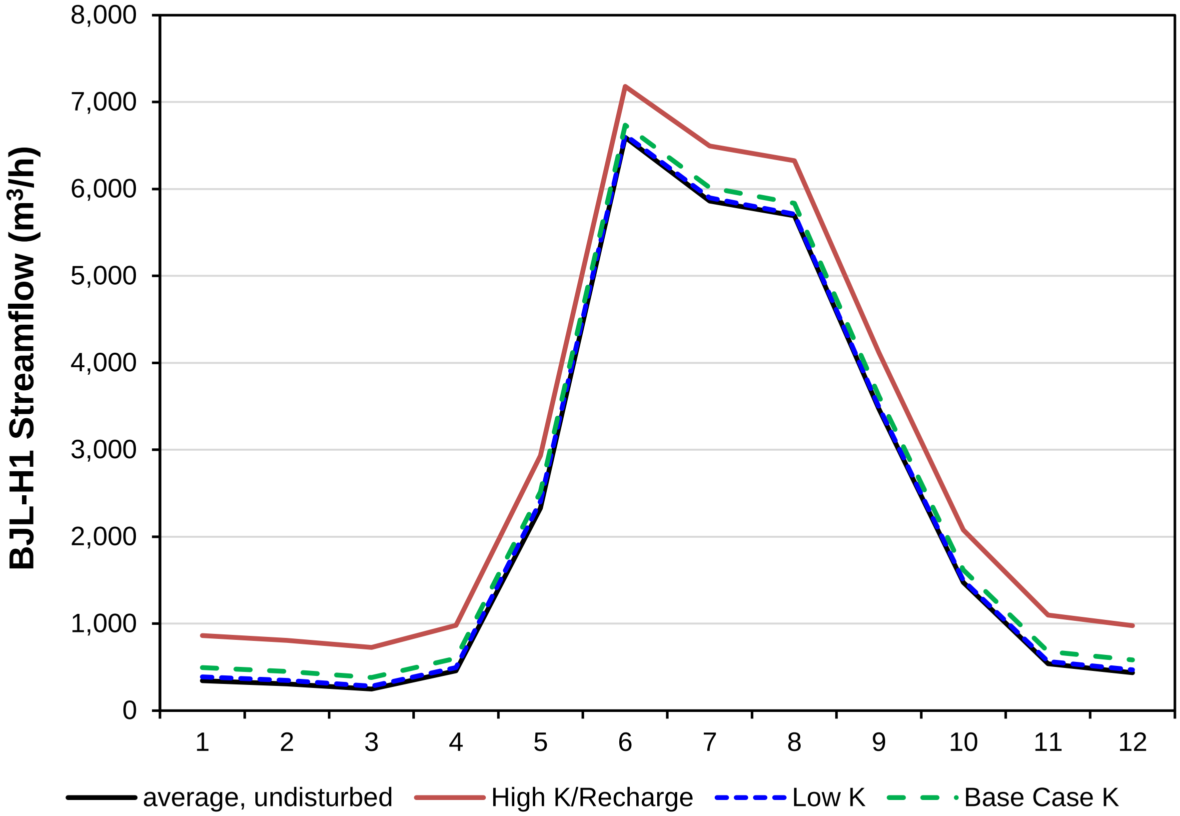


Figure 7-6. Disturbed and undisturbed runoff at BJL-H1 for three groundwater inflow scenarios.

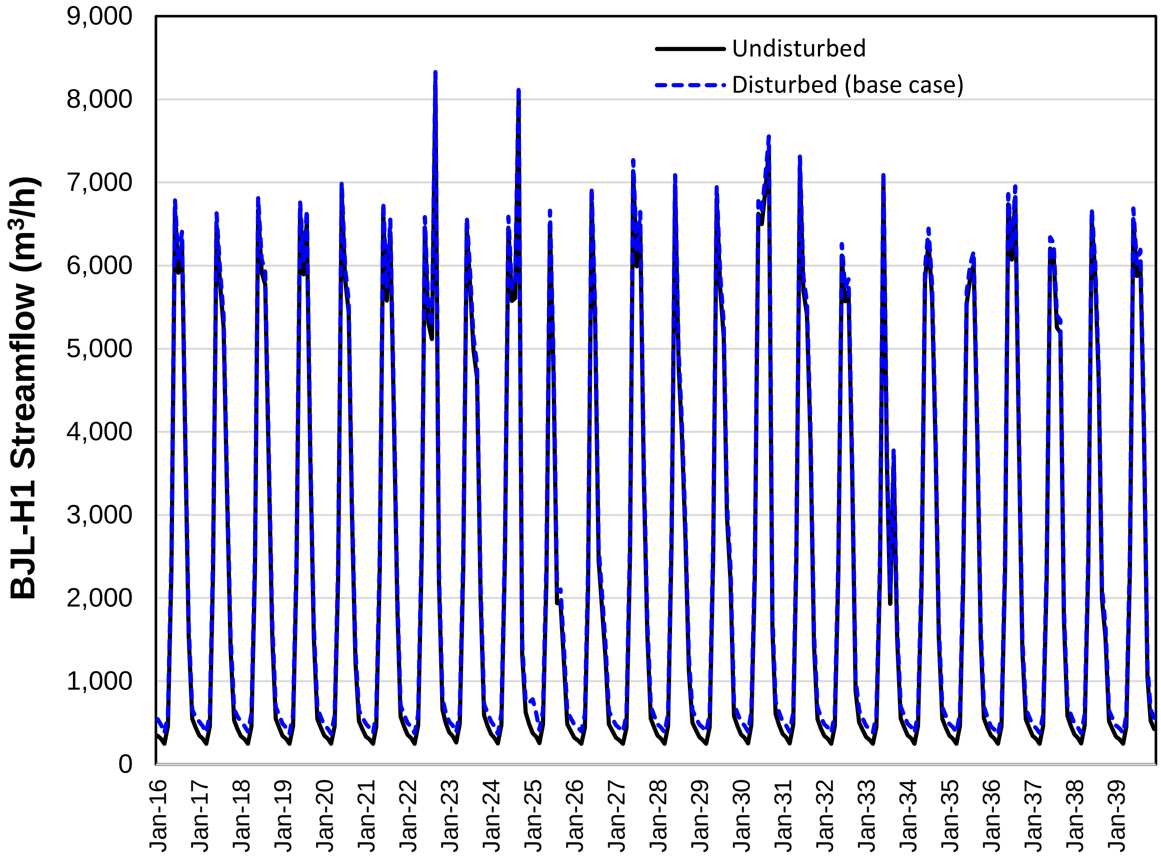


Figure 7-7. Estimated runoff at BJL-H1 using the deterministic precipitation dataset. Runoff is shown for undisturbed and disturbed conditions for the construction and operations period of the mine life.

7.2.2. Closure

A similar number of scenarios were also evaluated for the closure and post-closure periods. As shown in Table 7-3, within five years after the end of mining, streamflows return to almost undisturbed conditions. This result is expected given the small footprint of the proposed mine relative to the size of the watershed.

Table 7-3. Monthly averages flows at BJL-H1 (m^3/h) at Year 5 of closure/post-closure.

Month	Undisturbed (m^3/h)					Closure/Post-Closure (m^3/h)				
	Average Precip	100-yr Dry	100-yr Wet	East Lake+	snowmelt*	Average Precip	100-yr Dry	100-yr Wet	East Lake+	snowmelt*
1	342	334	372	342	339	341	332	370	341	338
2	307	300	329	307	304	306	300	329	306	304
3	248	248	255	248	248	250	250	257	250	250
4	458	452	478	458	455	458	452	478	458	455
5	2,329	2216	2,511	3,507	3,540	2,335	2,221	2,516	3,513	3,551
6	6,593	6117	7,192	6,593	8,824	6,586	6,110	7,184	6,586	8,808
7	5,860	2585	6,267	5,860	5,098	5,851	2,574	6,258	5,851	5,092
8	5,690	1715	6,973	5,690	3,233	5,676	1,700	6,960	5,676	3,217
9	3,471	1979	7,318	3,471	3,164	3,455	1,964	7,302	3,455	3,149
10	1,474	1248	1,745	1,474	1,440	1,461	1,237	1,733	1,461	1,428
11	539	480	607	539	530	530	472	599	530	522
12	434	398	473	434	429	430	394	468	430	425
average	**2,324**	**1,508**	**2,886**	**2,424**	**2,307**	**2,318**	**1,502**	**2,881**	**2,418**	**2,301**

+ East Lake diverts into Brucejack Lake during the month of May.

* 50% increase in May snowmelt

7.2.3. Climate Change

BGC also evaluated the potential effects of climate change on streamflows at BJL-H1. Long-term annual precipitation at the Unuk River Eskay Creek climate station (1950-2099) was estimated based on two global climate models (GCMs):

1. CGCM3.1 (T47) – Canadian Centre for Climate Modelling and Analysis (Canada); and
2. CCSM3 – National Center for Atmospheric Research (USA).

For each GCM, three commonly used greenhouse emission scenarios were considered: A2, B1, and A1B. A2 produces the highest climate forcing by the end of the century; however, before mid-century, none of the three scenarios is consistently the highest. B1 is a low emissions scenario, and thus produces the most conservative climate change prediction. The resulting annual precipitation estimates (for the 1950-2099 period) for each GCM and emission scenario were then adjusted so that the 1990-2009 average annual precipitation was 1900 mm.

Using the A1B1 scenario and averaging the results from the two GCMs, the annual precipitation estimates were input to the calibrated WBM and modelled for undisturbed conditions. Results are shown in Figure 7-8 below. Average streamflow at BJL-H1 is predicted to increase over time, as indicated by the trend line. The estimated average streamflow at BJL-H1 for the 1990-2009 period is 0.65 m^3/s compared to 0.73 m^3/s for the 2080-2099 period, an increase of 12%. This analysis is overly simplistic in that it doesn't account for potential increases in temperature and wind speed, both of which could result in increased evaporative losses and therefore offset the projected increase in precipitation.

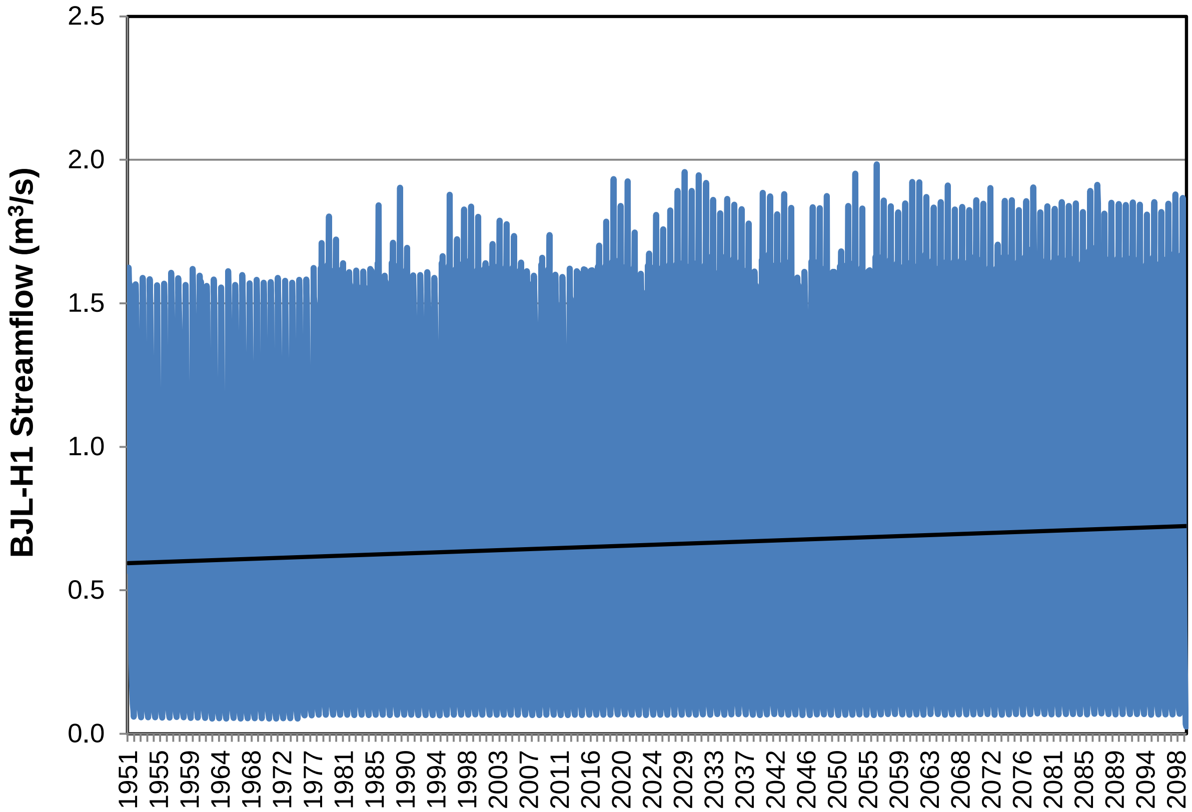


Figure 7-8. Estimated runoff at BJL-H1 using the climate change precipitation dataset for the period 1950-2099. Results reflect the A1B1 emission scenario averaged over two GCMs. A linear trend line, shown in black, is superimposed on the results.

8.0 RECOMMENDATIONS

Recommended actions moving forward include:

- Existing climate and hydrometric stations should continue to be monitored and maintained with an appropriate level of quality control. The data from the climate and hydrometric stations near Brucejack Lake should be reviewed during detailed engineering design to confirm assumptions being used for precipitation and runoff.
- There is currently uncertainty with the watershed area reporting to BJL-H1. If the watershed area was only 8.5 km^2, the implication is that average precipitation at site is on the order of 2560 mm, rather than the current estimate of 1900 mm to 2040 mm. This difference in precipitation would not invalidate the WBM results summarized herein, as the model is calibrated to streamflow, not precipitation. However, confidence in the site precipitation estimates is important for evaluating peak flows and runoff volumes for drainage ditches and collection ponds. Therefore, it is recommended that a site visit be conducted in June 2014 to evaluate runoff patterns at the east end of Brucejack Lake. The purpose of the site visit would be to try and confirm the watershed area reporting to BJL-H1.

9.0 CLOSURE

We trust the above satisfies your requirements at this time. Should you have any questions or comments, please do not hesitate to contact us.

Yours sincerely,

BGC ENGINEERING INC.
per:

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Reviewed by Trevor Crozier, M.Eng., P.Eng.

HW/TC/bb

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APPENDIX A
WATER BALANCE CALIBRATION

A. WATER BALANCE MODEL CALIBRATION

This appendix provides a description of the Vandewiele *et al.* (1992) model and its application to the Brucejack Lake project site.

A1. Monthly Water Balance Models

There are a large number of watershed models presently available for predicting streamflow from climatic inputs and land surface characteristics as evidenced by 72 models reviewed in Singh and Woolhiser (2002). These models are principally constructed on a daily or hourly basis, but can be used on an annual, monthly, or weekly basis. The degree of model complexity varies widely, but most have well in excess of 3 to 5 model parameters and many have more than 10 to 20 parameters. Most of these models are theoretical in that they are physically based (white-box models).

While these physically based models can provide a high resolution of streamflow forecasting, they are data intensive and complicated. Many of these models took years to develop and calibration can take on the order of weeks (Limbrunner *et al.*, 2002). All of the models listed above are far too complex to be incorporated into a model that must be both transparent and relatively easy to use.

In contrast, monthly water balance models are typically used to simulate and forecast monthly runoffs in a watershed. The inter-relation between rainfall, snowmelt, evapotranspiration and runoff on a monthly scale appears to be very close because of the mutual effects and continuous feedback of water movements in the soil-plant-atmosphere continuum (Xiong and Guo, 1999). Hence, if most of the rainfall and snowmelt can be converted into streamflow or water vapour within a month, then it is no longer necessary to distinguish between the runoff generating and routing processes. Monthly water balance models should therefore take a simpler form and use a smaller number of parameters than daily hydrologic models (Xiong and Guo, 1999).

Despite increased computing power and increasingly sophisticated physically-based models, there is an increasing use (and development) of monthly water balance models to address a range of hydrological problems (Xu and Singh, 1998). These monthly models range in complexity but most have 2 to 5 parameters that require calibration. Monthly hydrologic models can be classified as conceptual (grey-box models) where the equations consider the physical processes in a highly simplified manner. A black-box model is one that is purely empirical.

Monthly water balance models were first developed in the 1940s by Thornthwaite (1947) and later revised by Thornthwaite and Mather (1955, 1957). The Thornthwaite model uses two parameters: the soil moisture capacity and the fraction of surplus water that remains in the soil (which is a function of the depth and texture of the soil, basin morphometry, and the nature of the groundwater system). Palmer's (1965) P-model was developed shortly after for agricultural purposes. The model divides the soil into two layers, where moisture cannot be removed from (or recharged to) the lower layer until all the available moisture has been removed from (replenished in) the upper layer. In 1981 Thomas proposed a four-parameter *"abcd"* model, which has been widely applied. Alley (1984) provides a comprehensive review of all three models and introduces variants of the Thornthwaite models. Alley (1984) concluded that prediction errors are relatively similar among the models, but simulated variables, such as soil moisture storage, differ substantially between models.

More recent parsimonious models have been developed by Vandewiele *et al.* (1992), Maklouf and Michel (1994), and Xiong and Guo (1999). The Vandewiele *et al.* (1992) model has been successfully applied in a variety of climatic settings, including northern latitudes (Xu *et al.*, 1996). BGC has utilized this model (weekly and monthly time-step) with good success at a number of mine sites for predicting runoff from undisturbed ground. Based on BGC's experience, the Vandewiele *et al.* (1992) model (with the modifications of Xu *et al.*, 1996) was considered to be suitable for modeling purposes at the Brucejack Project. Details of the model are provided below.

A2. Vandewielete Model Structure

In the Vandewiele *et al.* (1992) monthly model, monthly precipitation P_t and potential evapotranspiration E_t are the inputs; whereas monthly runoff Q_t is the output (t is time in months). The storage or soil moisture content (S) at the end of month t summarizes the hydrologic memory of the watershed, and the water balance is written as:

$$S_t = S_{t-1} + P_t - R_t - Q_t \qquad \text{(Eq. A-1)}$$

where R_t is actual evapotranspiration. All quantities are expressed in millimeters depth. Actual evapotranspiration is computed from monthly potential evapotranspiration (PET) and from the water available W_t for evapotranspiration during month t:

$$W_t = P_t + S_{t-1} \qquad \text{(Eq. A-2)}$$

where S_{t-1} is the soil storage at the beginning of month t. Two possible evapotranspiration equations are defined by Vandewiele *et al.* (1992):

$$R_t = \min\left[E_t\left(1 - a_1^{\frac{W_t}{E_t}}\right), W_t\right] \qquad \text{(Eq. A-3)}$$

$$R_t = \min\left[W_t\left(1 - a_1^{E_t}\right), E_t\right] \qquad \text{(Eq. A-4)}$$

where a_1 is a positive parameter, which is characteristic of the watershed being studied. This parameter is constrained by $0 \le a_1 \le 1$. The equations are structured such that actual evapotranspiration increases with PET and available water (W_t).

Stream discharge Q_t is divided into slow runoff Q_s and fast runoff Q_f. These terms are roughly analogous to baseflow/groundwater flow (slow runoff), and surface runoff and interflow in the unsaturated zone (fast runoff). The runoff components are computed as follows:

$$Q_s = a_2 \left(S_{t-1}\right)^{b_1} \qquad \text{(Eq. A-5)}$$

$$Q_f = a_3 \left(S_{t-1}\right)^{b_2} \left[P_t - E_t \left(1 - \exp\left(\frac{-P_t}{E_t} \right) \right) \right] \qquad \text{(Eq. A-6)}$$

where a_2, a_3, b_1 and b_2 are positive valued parameters. Slow runoff depends on the storage in the catchment in the previous month as shallow groundwater contribution to streamflow is typically on the order of weeks from initial infiltration. The equation for fast runoff is structured such that the greater the storage (S_{t-1}) → the wetter the catchment → the greater the source of fast runoff → the greater the part of the active rainfall running off rapidly.

The model parameter couples (a_2, b_1) and (a_3, b_2) are highly correlated, and therefore the values of b_1 and b_2 are restricted to ½, 1 or 2. While there are a number of possible model variants (two choices for evaporation, and multiple choices for b_1 and b_2), the model is easy to set-up and calibrate. The model can also be easily set-up on a weekly basis, if required.

The model can easily be set-up to accommodate a snowpack and snowmelt. The snowpack water balance is described by the following equation:

$$S_k = S_{k-1} + Snow_k - E_k - M_k \qquad \text{(Eq. A-7)}$$

where S_k = snowpack storage for month k, $Snow_k$ = snowfall, E_k = sublimation, and M_k = snowmelt. Sublimation at Brucejack Lake is calculated as per Section 4.3. The fast component of runoff quickly drops off to zero as the snowpack starts to develop and all of the creek flow is then supplied by groundwater. Figure A-1 is a schematic that shows the contribution of snowmelt and rainfall to creek flows.

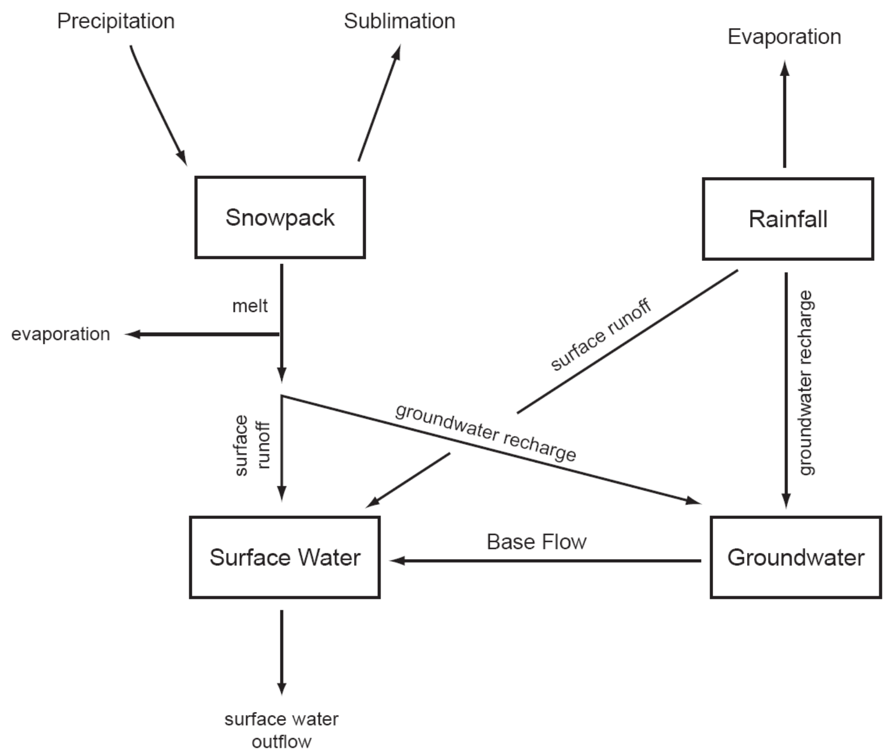


Figure A-1. Water Balance Schematic for Undisturbed Ground

A3. Brucejack Lake Water Balance Model

The Vandewiele *et al.* (1992) model was applied to the project site on a monthly basis using local precipitation data and streamflow data collected by Rescan at BJL-H1. The Brucejack Lake meteorology station (425,836 E, 6,258,812N, 1,360 masl) was installed by Rescan in September 2009 (Rescan, 2013a). The station consists of a standard 10-m meteorological tower with instrumentation to measure wind speed, wind direction, air temperature, barometric pressure, relative humidity, solar radiation and precipitation. The Brucejack Lake hydrometric station (BJL-H1) was initially installed in the fall of 2007 to support an adjacent mining project (Rescan, 2013a). The BJL-H1 station (425,773 E, 6,259,026 N) is located adjacent to the Brucejack Lake meteorology station. Climate and streamflow data collected from 2010 to 2012 were used for the model calibration.

Table A-1 summarizes the data used for the model. Figure A-2 shows the observed Brucejack Lake (BJL-H1) streamflow and precipitation for the calibration period.

Table A-1. Summary of Local Climate Station Data used for Model Calibration

Variable	Units	Frequency	Station
Air Temperature	ºC	Monthly Average	Brucejack Lake Meteorological Station
Precipitation	mm	Monthly Total	Brucejack Lake Meteorological Station
Rainfall	mm	Monthly Total	Brucejack Lake Meteorological Station
Runoff	mm	Monthly Average	Brucejack Lake Hydrometric Station (BJL-H1)
Potential evapotranspiration	mm	Monthly Total	Estimated using wind speed, wind direction, air temperature, relative humidity, solar radiation and barometric pressure data collected from the Brucejack Lake Meteorological Station

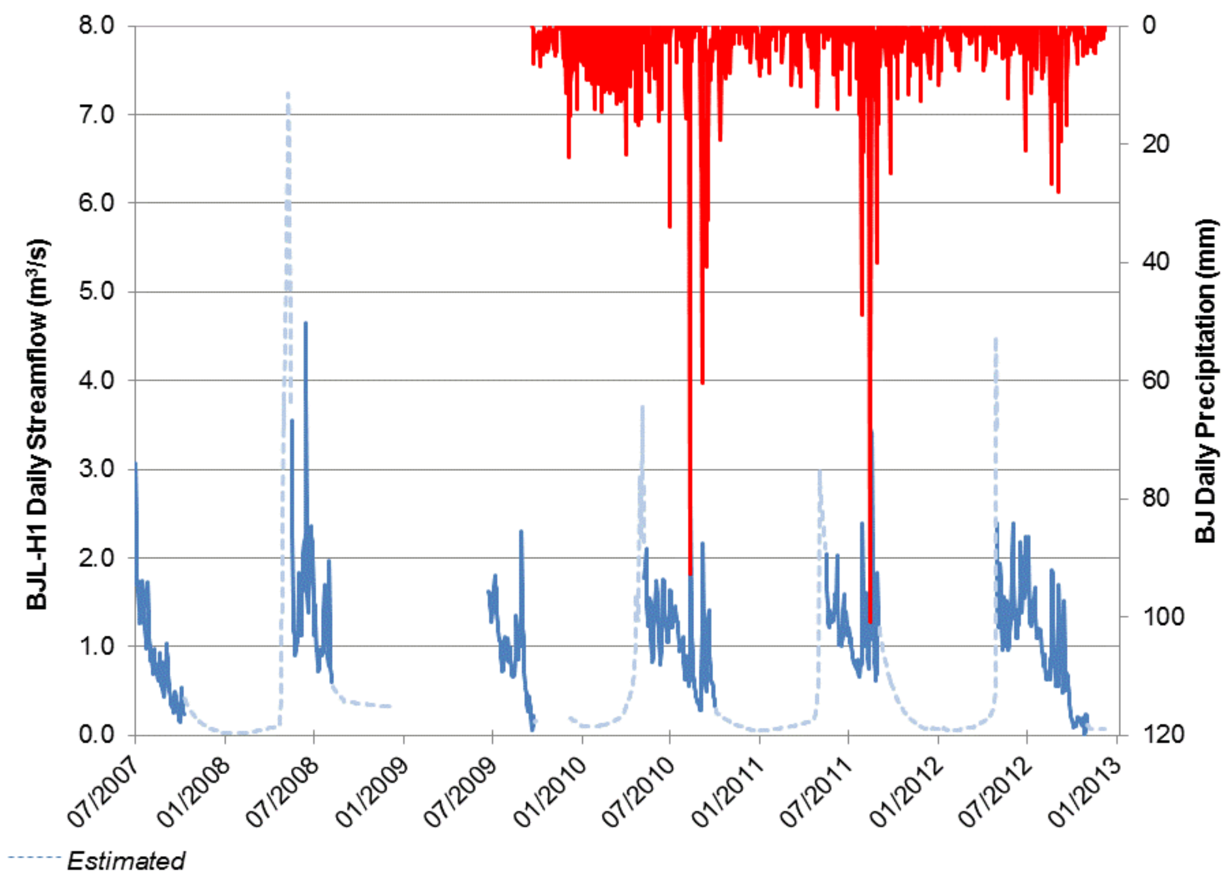


Figure A-2. Brucejack Streamflow (2007-2013) and Precipitation (2009-2013)

The evapotranspiration and runoff equations that provided the best fit to the data are:

$$R_t = \min\left[E_t\left(1 - a_1^{\frac{W_t}{E_t}}\right), W_t\right] \quad \text{(Eq. A-8)}$$

$$Q_t = a_2\left(S_{t-1}\right)^2 + a_3 S_{t-1}\left[P_t - E_t\left(1 - \exp\left(\frac{-P_t}{E_t}\right)\right)\right] \quad \text{(Eq. A-9)}$$

where $b_1 = 2$ and $b_2 = 1$, and $a_1 = 0.75$, $a_2 = 0.0005$, and $a_3 = 0.002$. The calibration process involved systematically adjusting the model parameters until a good fit was achieved between the predicted and observed stream flows. The modeled and observed data show an excellent fit for most of the months (Figure A-3).

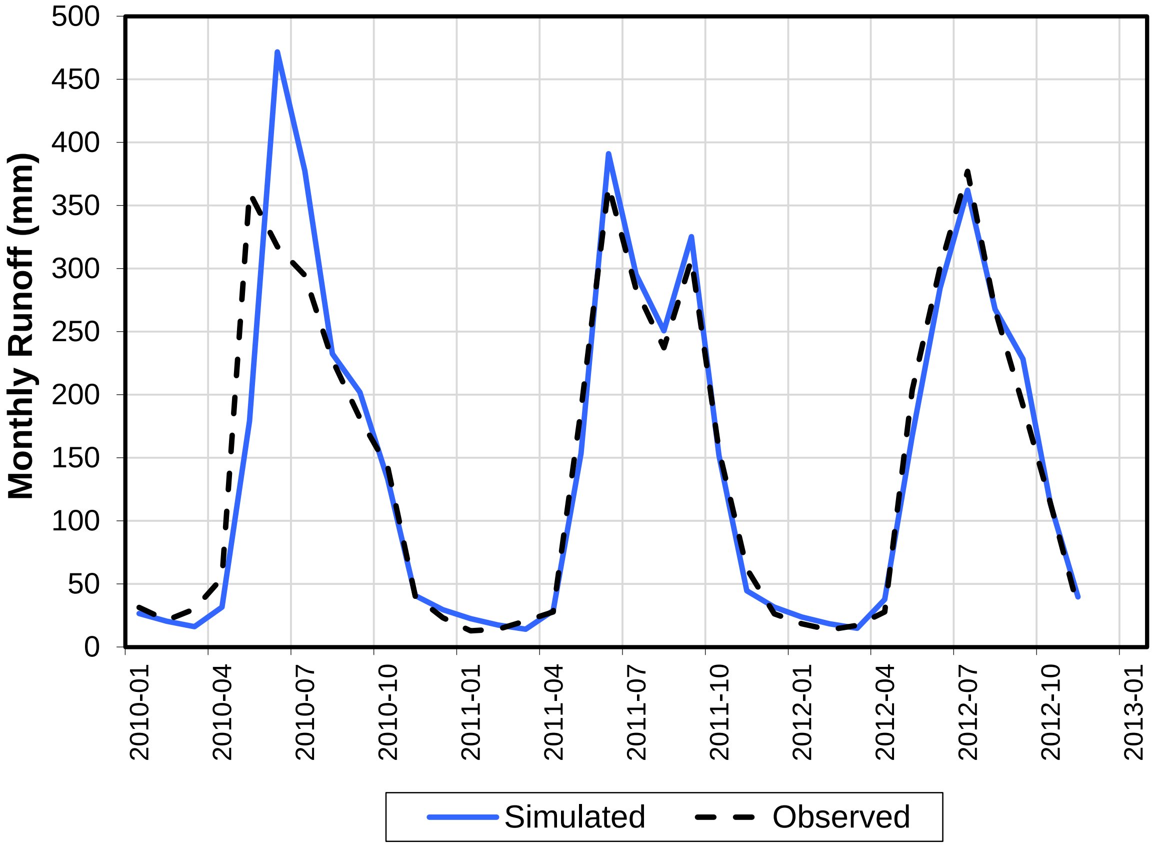


Figure A-3. Simulated and Observed Monthly Runoff for BJL-H1 (2010-2012)

The excellent fit is in part artificial, as the available dataset has limitations. The calibration process involved the following adjustments and assumptions:

- During the snowmelt period of April through August, the amount of snowmelt in each month was adjusted to provide the best fit to observed streamflow data, although a generally consistent trend was observed between months.
- It is assumed that the observed streamflows at BJL-H1 represent all of the runoff from the upstream watershed. In some environments, significant quantities of baseflow can bypass a hydrometric station either as groundwater discharge through an alluvial aquifer or deep groundwater flows that discharge to the valley bottom well downstream of the monitoring station. However, groundwater modelling by BGC indicates that such a situation does not exist at BJL-H1.
- Initial storage at the start of the calibration (January 2010) was adjusted within reasonable bounds to provide a good fit to the observed winter streamflow data.

The most significant adjustment was to winter precipitation. The annual total observed undisturbed runoff from the BJL-H1 station for the period of 2010 to 2012 ranges from 1,595 mm to a maximum of 1,725 mm. In comparison, the observed minimum and maximum annual precipitation for the same period at the Brucejack climate station are 1,129 mm and 1,968 mm suggesting that the climate station is potentially underestimating precipitation rates, very strong orographic effects prevail, or there is a significant contribution of runoff from glacial melt (see Section 4.2).

Table A-2 provides annual averages of the simulated and observed runoff as compared to observed precipitation for the 2010 to 2012 period. Because the observed precipitation was less than the observed runoff, the winter precipitation for 2011 and 2012 needed to be scaled up to provide a realistic calibration. During the calibration process, it was found that the fit dramatically improved by scaling up the 2011 snowpack by 180 mm (25%) and the 2012 snowpack by 370 mm (50%). While the winter precipitation adjustment is large, measuring snowfall at climate stations is notoriously difficult and considerable spatial variation was also observed during snow course surveys. It is also likely that some glacier melt occurred in 2011 and 2012.

Table A-2. Model Simulated, Synthetic and Observed Annual Runoff from Undisturbed Ground and Observed Precipitation (2010 to 2012)

Year	Undisturbed Runoff (mm)		Observed Precipitation (mm)
	Simulated	Observed	
2010	1,607	1,725	1,968
2011	1,665	1,702	1,672
2012	1,582	1,595	1,129
Average	**1,584**	**1,669**	**1,589**

An overall goodness of fit can be calculated using two equations. The first is the Nash-Sutcliffe efficiency criterion (Nash and Sutcliffe, 1970):

$$r^2 = \frac{Fo - F}{Fo} * 100(\%) \quad \text{(Eq. A-10)}$$

$$Fo = \sum_i (Q_i - \bar{Q}_c)^2 \quad \text{(Eq. A-11)}$$

$$F = \sum_i (Q_i - \hat{Q}_i)^2 \quad \text{(Eq. A-12)}$$

where F_o is the sum of the squared deviations of the observed runoff Q_i from the mean value Q_c of the observed runoff, and F is the sum of the squared discrepancies of the simulated runoff $\hat{Q}_i$ from the observed runoff. The value of r^2 approaches 100% for a good simulation of the observed runoff. The second equation is the relative error of the volumetric fit between the observed runoff series and the simulated series:

$$RE = \sum (Q_i - \hat{Q}_i) / \sum Q_i * 100\% \quad \text{(Eq. A-13)}$$

The value of RE is expected to be close to zero for a good simulation of the total volume of the observed runoff series. The monthly simulations resulted in an r^2 = 88% and RE = -0.9%. The relatively low RE value is very important as while there are monthly variations between observed and simulated runoff, average monthly runoff volumes are within 12 mm for the calibration period at 1674 mm versus 1686 mm, respectively, as summarized on a monthly basis in Table A-3. During the calibration process, BGC noted that glacier melt of 40 mm in August and 20 mm in September was required to improve the calibration fit in these months, which is a realistic assumption given that about one-quarter of the watershed is glacierized.

Table A-3. Observed versus Modelled Average Monthly Runoff (2010 to 2012)

Month	Observed Runoff (mm)	Modelled Runoff (mm)
January	21	22
February	16	17
March	23	14
April	37	34
May	251	180
June	328	382
July	319	348
August	244	250
September	227	250
October	138	124
November	45	36
December	27	28
Total	**1674**	**1686**

Figure A-4 shows the simulated runoff for the 2010-2012 period, with baseflows superimposed on total flow. Soil moisture storage, as tracked by the Vandewiele *et al.* (1992) is also plotted. The baseflows shown on this figure are consistent with the concurrent groundwater modelling being conducted for the site by BGC (2014).

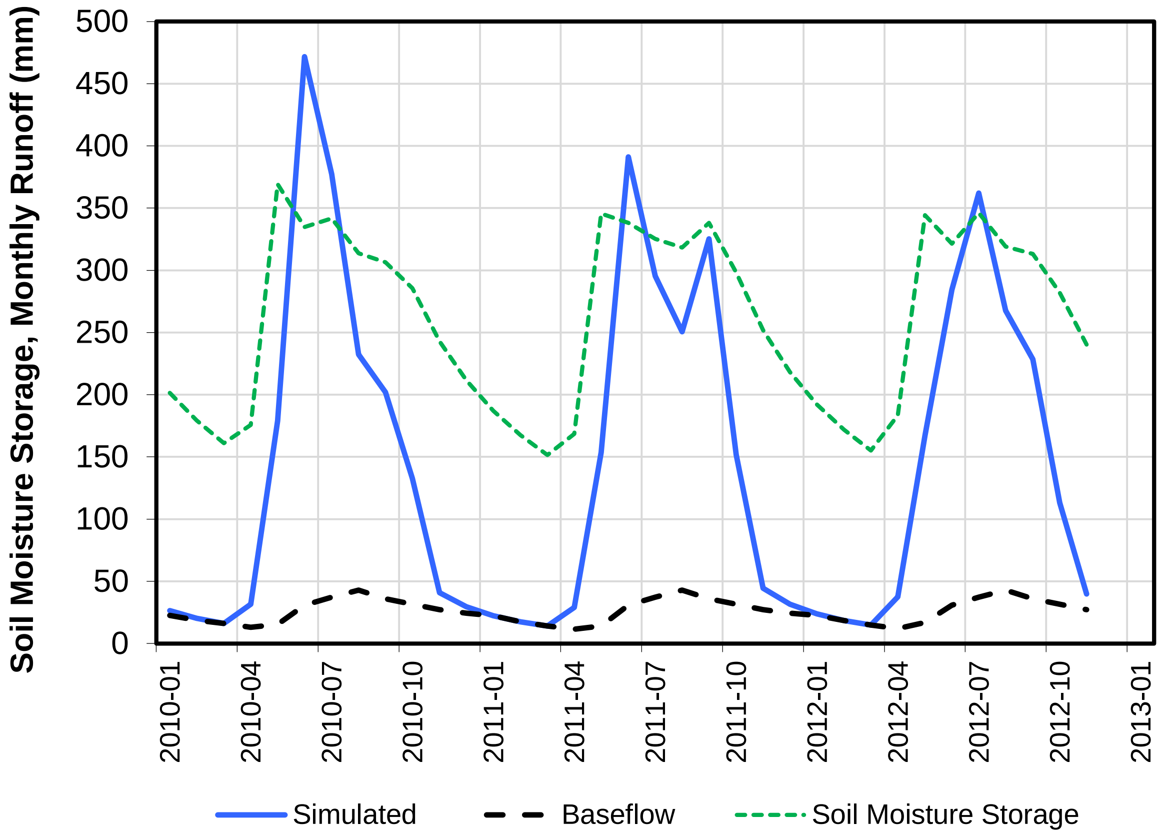


Figure A-4. Simulated Monthly Runoff and Soil Moisture Storage at BJL-H1 (2010-2012)

A3. Model Application

A number of assumptions were made when applying the calibrated Vandewiele *et al.* model to the site-wide WBM.

1. The slow component of the Vandewiele *et al.* model is a reasonable approximation of the modelled baseflows from the groundwater modelling (BGC, 2014). However, to ensure consistency between the two models to the extent possible, the baseflows from the groundwater model were superimposed on the Vandewiele *et al.* model results.
2. Glacier melt of 40 mm in August and 20 mm in September was assumed.
3. When evaluating average annual precipitation or exceptionally dry or wet years, it was assumed that the monthly distribution of precipitation was the same as shown in Table 4-10.
4. The proportion of rainfall and snowfall in a given month and potential snowmelt was as summarized in Table A-4.

Table A-4. Assumed monthly distribution of rainfall, snowfall and snowmelt.

Month	Rainfall portion (%)	Snowfall portion (%)	Potential Snowmelt (mm)
January	0%	100%	0
February	0%	100%	0
March	0%	100%	0
April	0%	100%	50
May	50%	50%	300
June	100%	0%	350
July	100%	0%	350
August	100%	0%	300
September	100%	0%	200
October	35%	65%	0
November	0%	100%	0
December	0%	100%	0

The potential snowmelt depths listed in Table A-4 are average values based on the calibration process and resulted in the best fit to the observed streamflow and rainfall data. A simplified, temperature-based approach was also investigated (Hock, 2003). Snowmelt is also a function of wind speed and radiation, but temperature-based methods can also yield a reasonable approximation of snowmelt. For months with T > 0°C, potential snowmelt, M_{pot}, is calculated as:

$$M_{pot} = k_m \cdot T \cdot n_d \qquad \text{(Eq. A-14)}$$

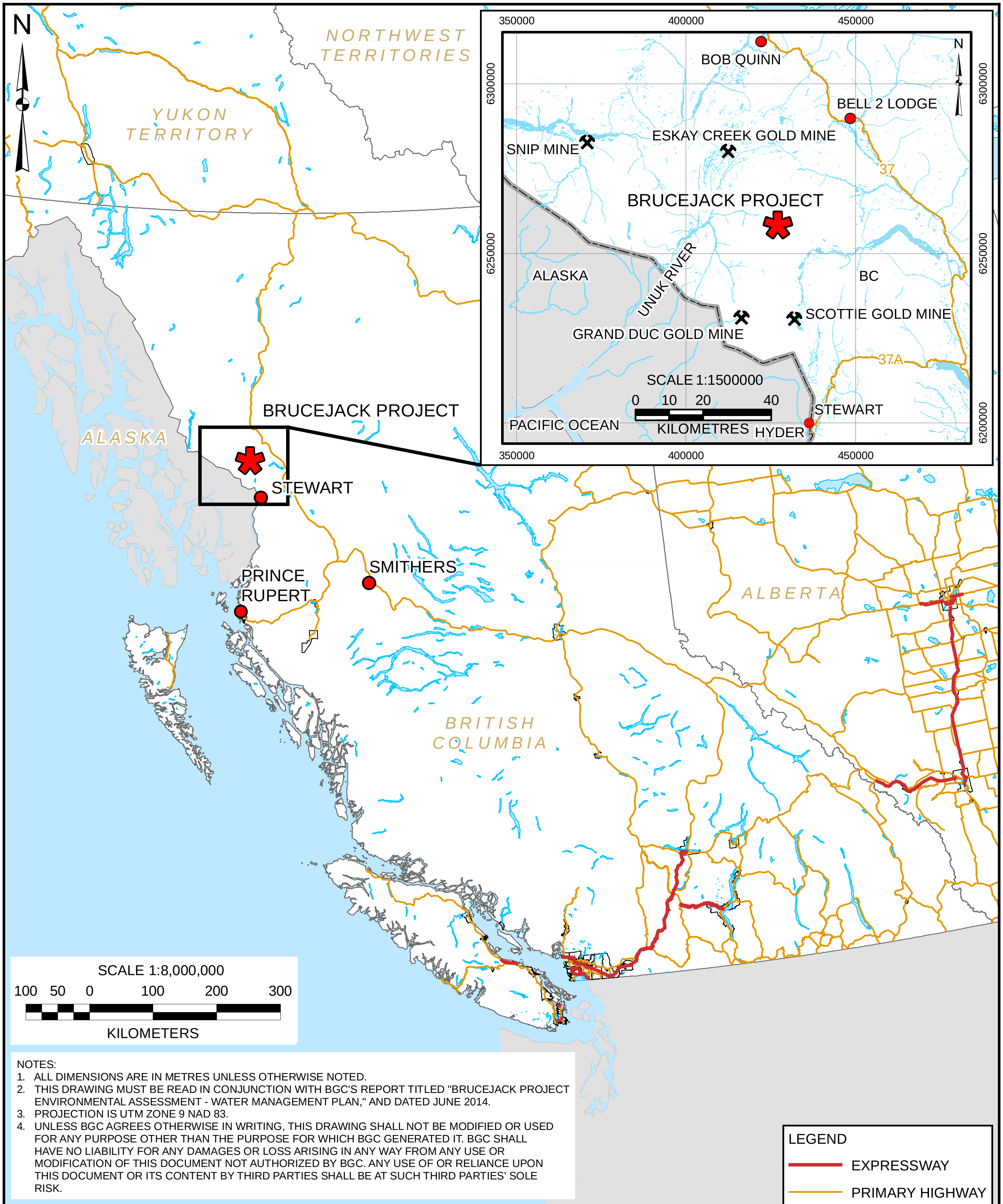
where k_m is a degree-day factor (mm/°C/day), T is the average monthly temperature, and n_d is the number of months in a given month.

The degree-day factor is a function of land cover and was set to 3.5 mm/°C/day for Brucejack, as per Moore *et al.* (2012). Results are shown in Table A-5 for the period 2010-2012, using temperature data from the Brucejack climate station. The resulting potential snowmelt values are too low to utilize in the WBM, as a significant snowpack would remain at the end of each year. It is further noted that the temperatures used in the calculations are from the Brucejack climate station, which is positioned in the lower watershed. If the monthly temperatures were scaled with elevation, the potential snowmelt depths would be lower than shown.

Table A-5. Potential snowmelt at Brucejack using a temperature-based approach.

Month	Average Temperature (ºC)			Potential Snowmelt (mm)		
	2010	2011	2012	2010	2011	2012
January	-5.7	-8.8	-10.6	0	0	0
February	-3.9	-10.6	-6.2	0	0	0
March	-4.8	-7.1	-7.1	0	0	0
April	-2.2	-4.2	-1.7	0	0	0
May	2.4	2.2	-0.3	43	39	0
June	4.1	4.7	3.5	86	100	74
July	7.1	6.0	7.1	174	148	174
August	8.4	5.6	7.9	235	157	223
September	4.5	3.9	4.9	143	123	155
October	-0.5	-1.2	-2.7	0	0	0
November	-6.6	-7.7	-4.0	0	0	0
December	-8.6	-6.6		0	0	0
Total				**680**	**565**	**626**

DRAWINGS



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TITLE: PROJECT LOCATION

PROJECT No.:	DWG No.:
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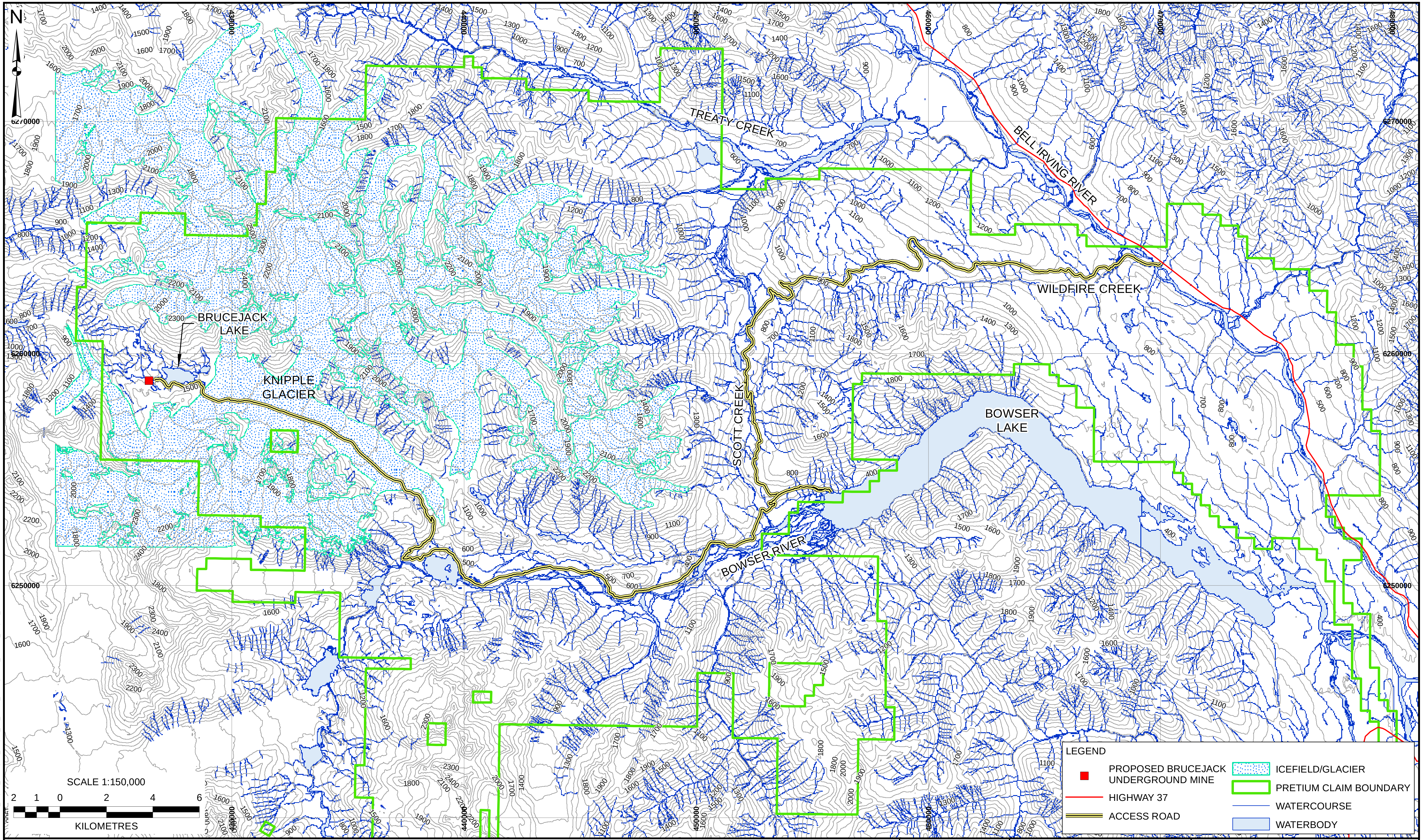

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TITLE: BRUCEJACK LAKE WATERSHED AREAS

PROJECT No.: 1008010

DWG No.: 03

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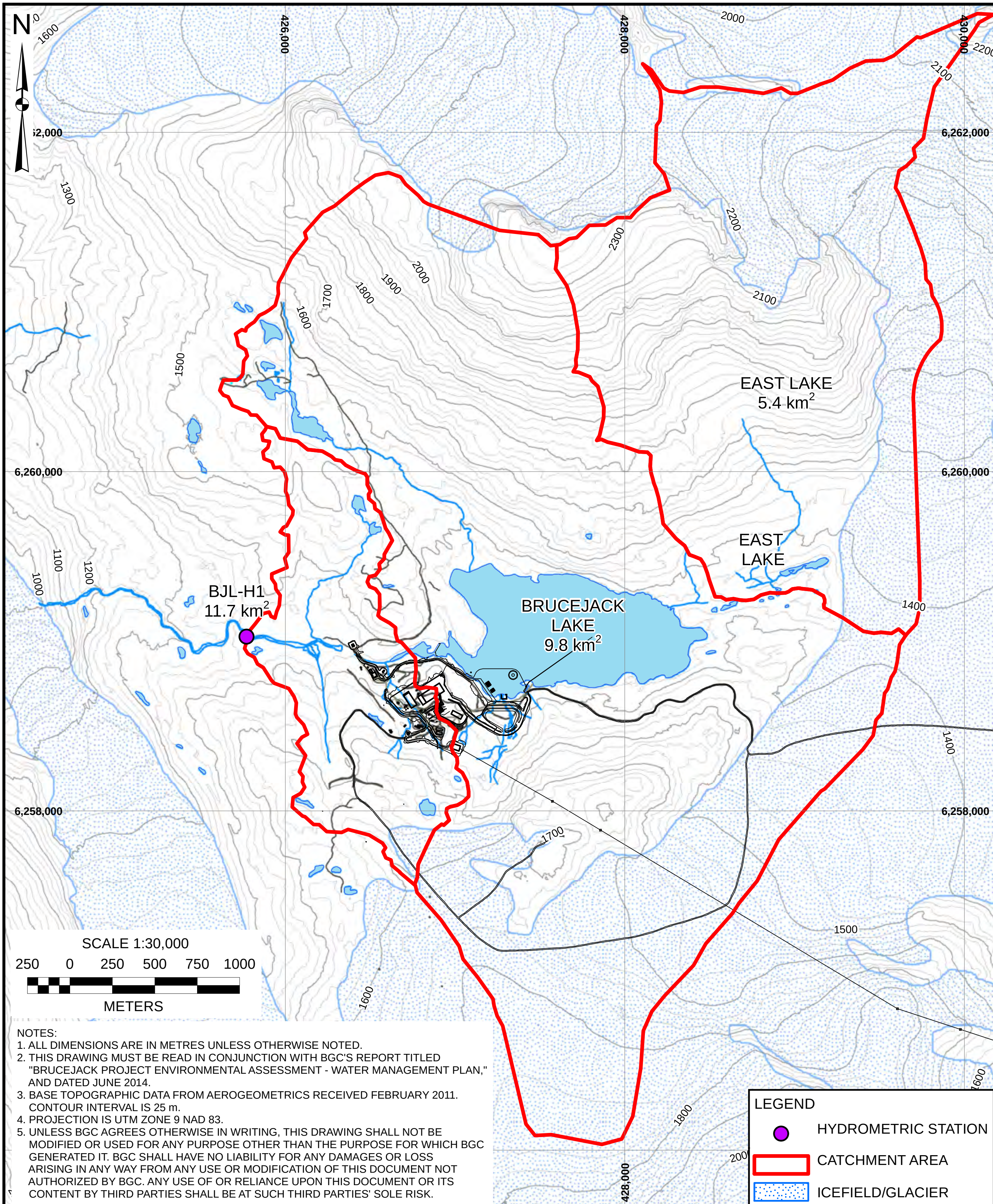

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LEGEND
- HYDROMETRIC STATION
- CATCHMENT AREA
- ICEFIELD/GLACIER

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CONTOUR MAP OF BRUCEJACK WATERSHED

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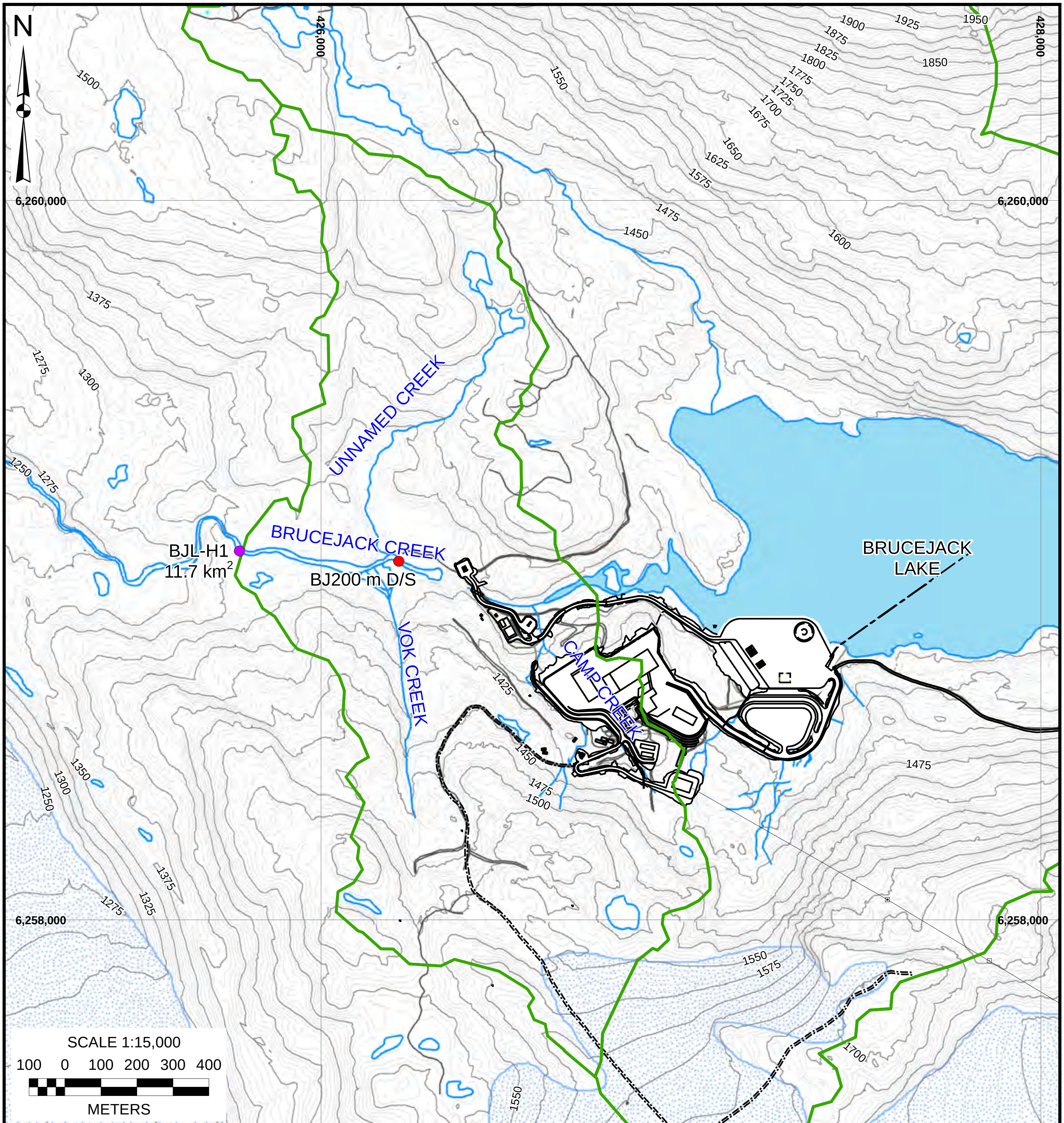

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TITLE: WATERSHED DOWNSTREAM OF BRUCEJACK LAKE

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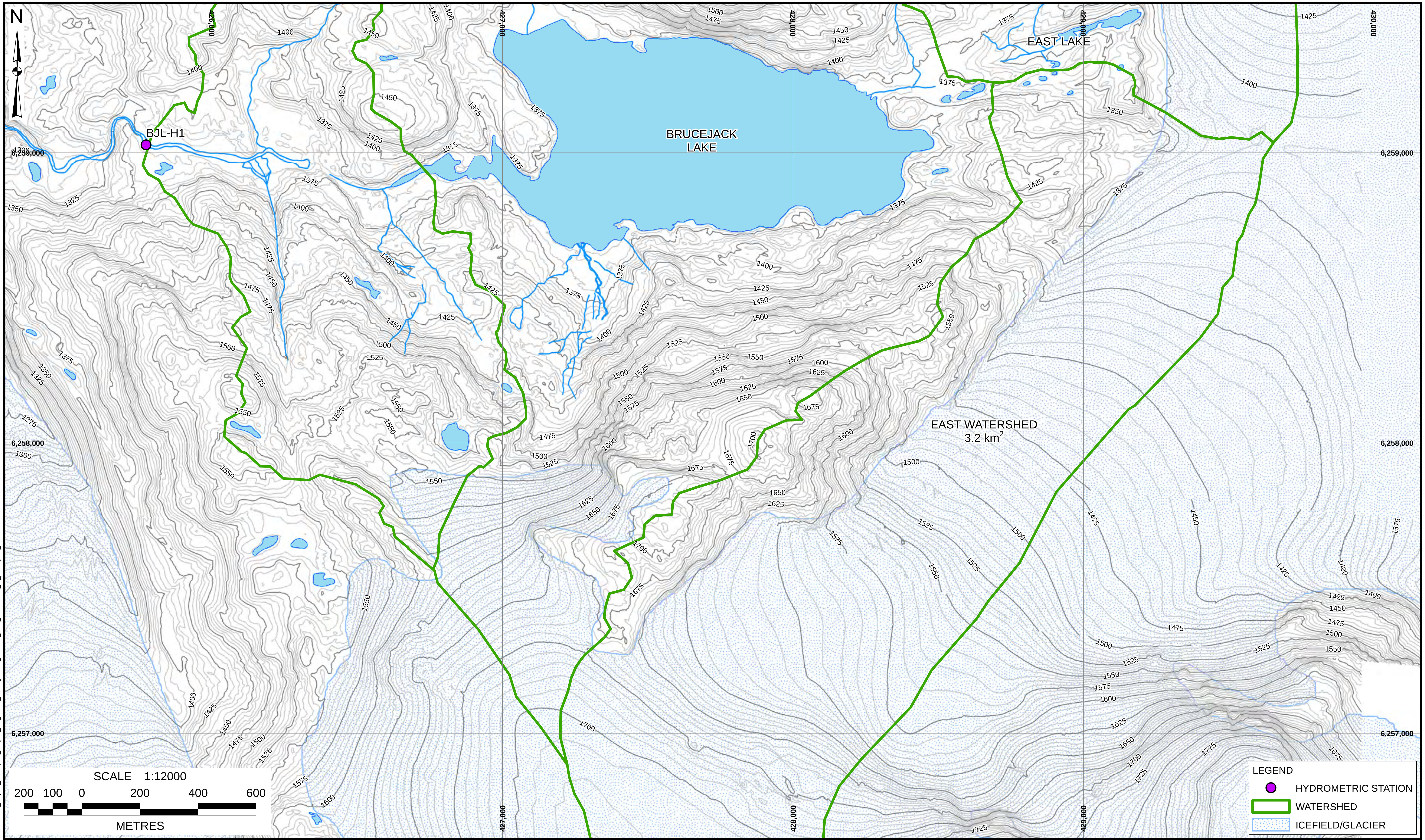

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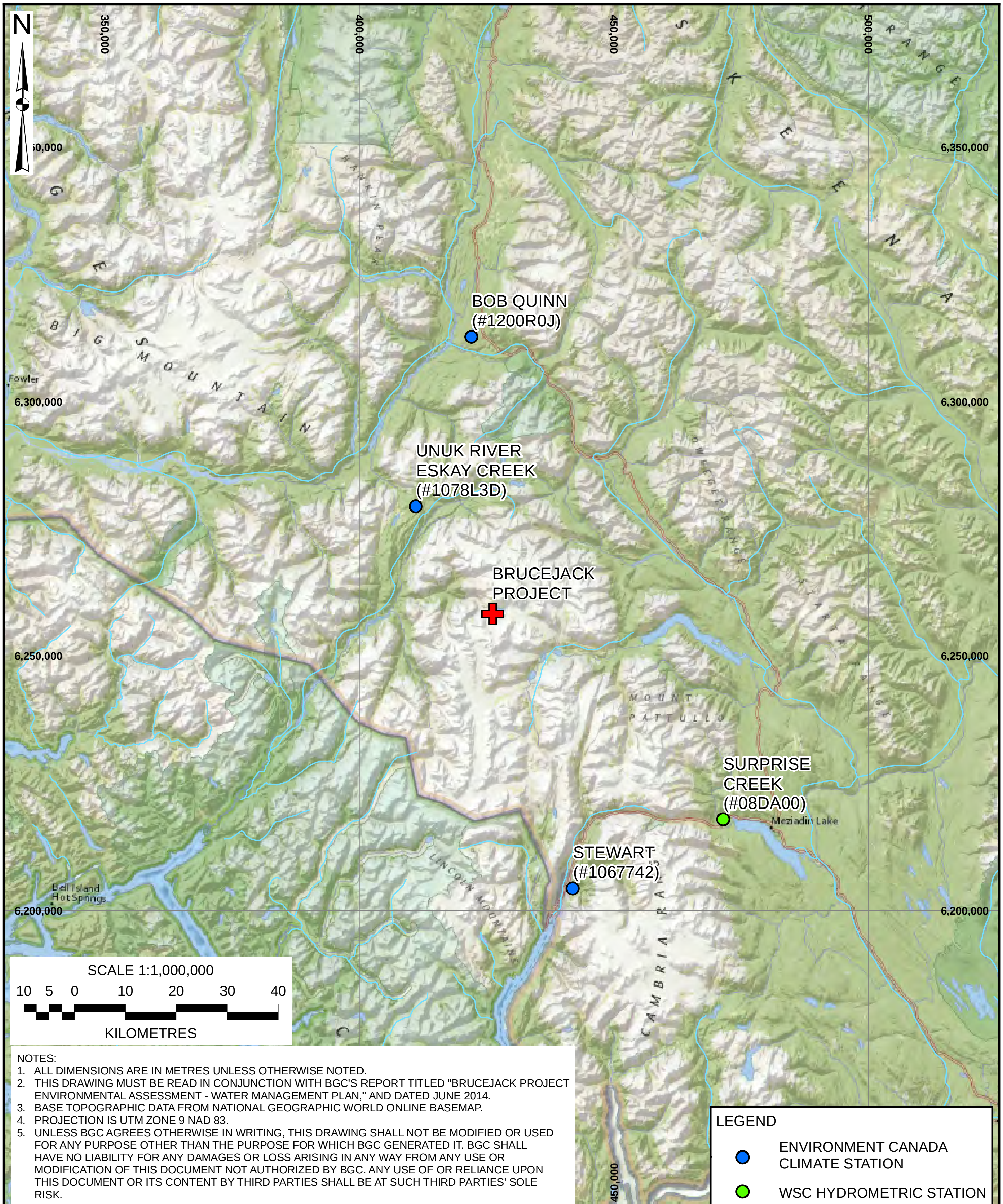

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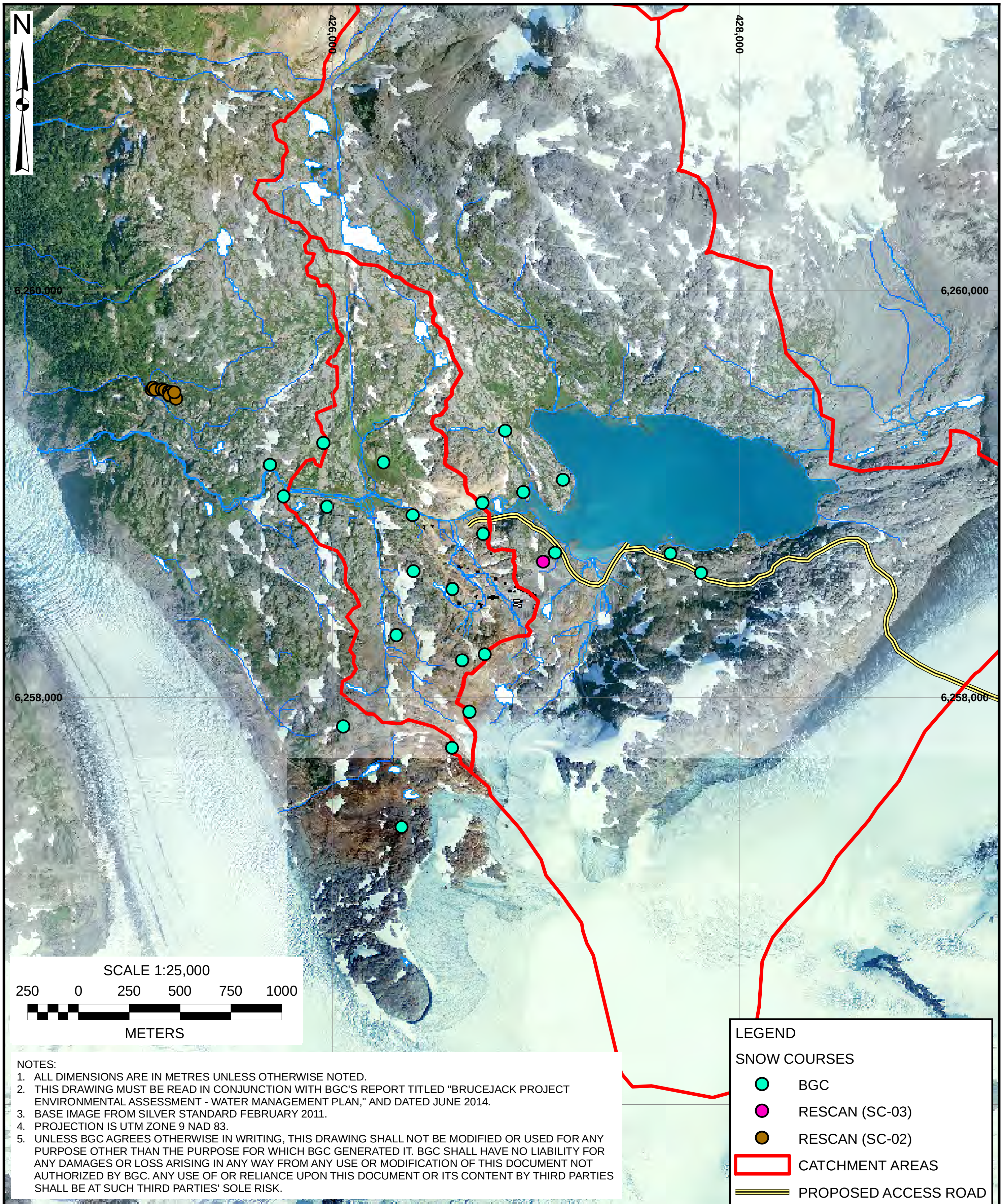

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SNOW COURSES

- BGC
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- RESCAN (SC-02)
- CATCHMENT AREAS
- PROPOSED ACCESS ROAD

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TITLE: BRUCEJACK LAKE SNOW COURSE SURVEY LOCATIONS

PROJECT No.:	DWG No.:
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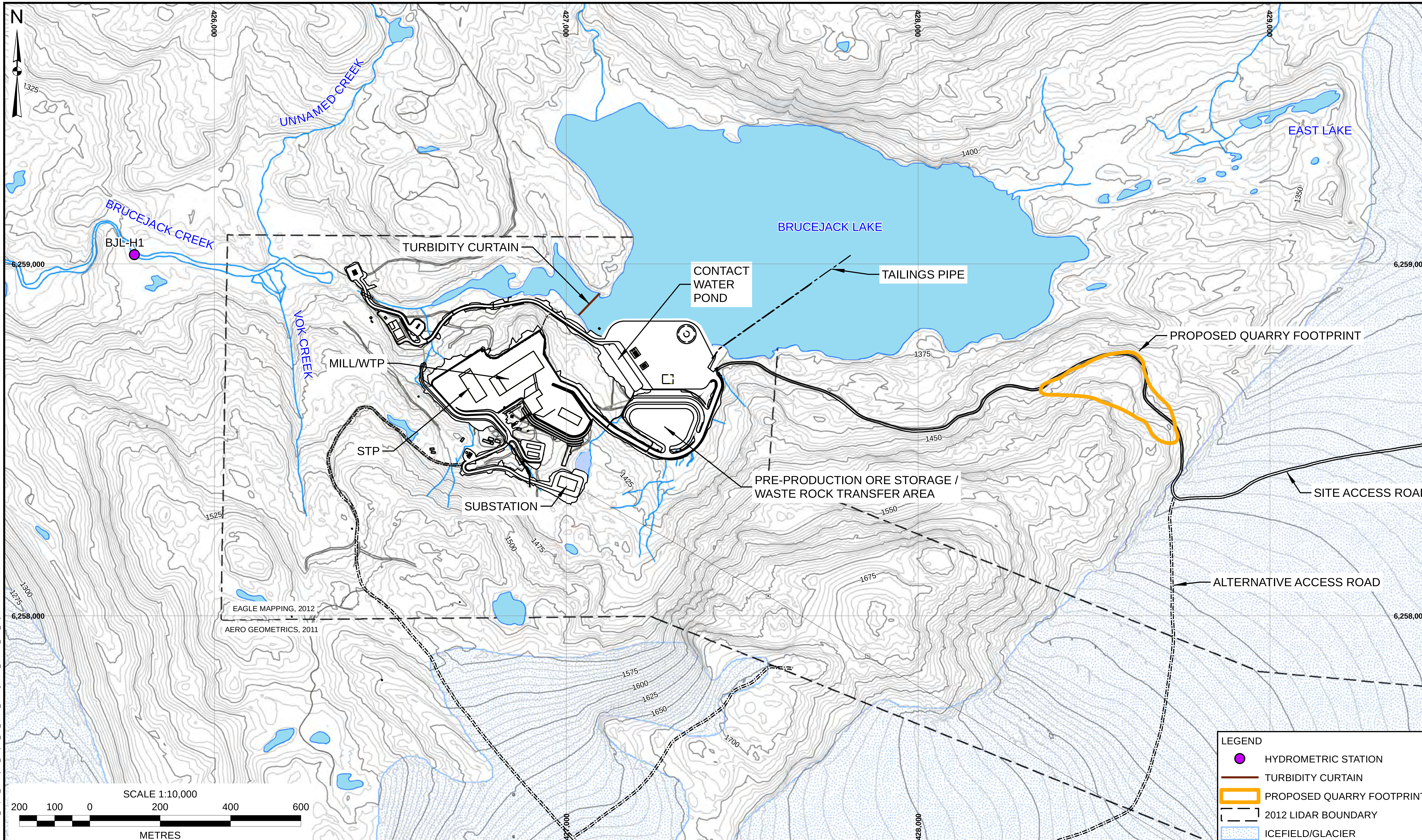

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SITE LAYOUT

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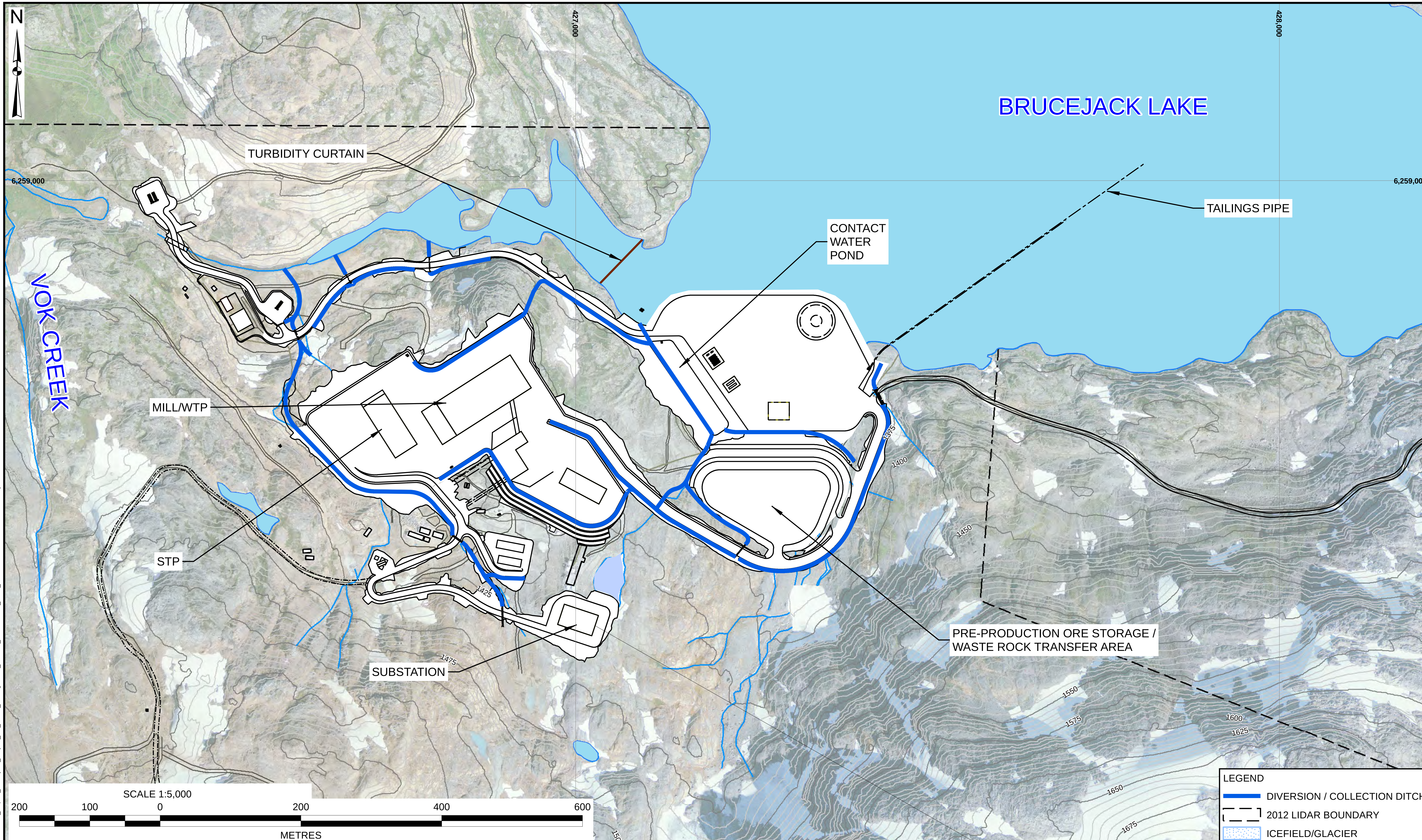

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BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
PRETIVM

PROJECT: BRUCEJACK PROJECT
ENVIRONMENTAL ASSESSMENT -
WATER MANAGEMENT PLAN

TITLE: PROPOSED SITE DRAINAGE

PROJECT No.:	DWG No.:
1008010	10

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