10. Surface Water Hydrology Predictive Study

10.1 INTRODUCTION

Surface water hydrology is a key component of the physical and biological environment because it is linked to other ecosystem components, including surface water quality, fish and fish habitat, and aquatic resources. The proposed Brucejack Gold Mine Project (the Project) could affect surface water hydrology by altering streamflows, channel morphology, and glaciers. Such effects may occur during the Construction, Operation, Closure, and Post-closure phases. The terms "surface water hydrology" and "surface water quantity" are interchangeably used in this Application for an Environmental Assessment Certificate/Environmental Impact Statement.

In this chapter:

- baseline hydrologic conditions within the local and regional study areas are characterized;
- potential effects of the Project on surface water hydrology are identified;
- mitigation measures for such effects are introduced;
- residual effects of the Project on surface water hydrology, after implementation of mitigation measures, are predicted; and
- cumulative effects of the Project and other past, present, and foreseeable future projects on surface water hydrology are assessed.

Detailed data and analyses to support the abovementioned assessment are presented in appendices of this chapter. These include:

- Appendix 10-A, 2012 Surface Water Hydrology Baseline Report — this report estimates key hydrologic indices that characterize the hydrologic regime within the Project area;
- Appendix 10-B, Potential Interactions between the Brucejack Gold Mine Project and Channel Morphology: Preliminary Results — results of a preliminary study to assess the potential effects of the Project on channel morphology are presented in this appendix; and
- Appendix 10-C, Potential Interactions between the Glacier Section of Brucejack Access Road and Knipple Glacier Ablation — this appendix provides estimated effects of the Project on the glaciohydrology of the Knipple Glacier.

Alteration of surface water hydrology could potentially affect receptor VCs that have linkages with surface water hydrology. Effects of the Project on these receptor VCs are assessed in:

- Chapter 13, Assessment of Potential Surface Water Quality Effects;
- Chapter 14, Assessment of Potential Aquatic Resources Effects;
- Chapter 15, Assessment of Potential Fish and Fish Habitat Effects;
- Chapter 16, Assessment of Potential Terrestrial Ecology Effects;
- Chapter 17, Assessment of Potential Wetlands Effects;
- Chapter 23, Assessment of Potential Navigation Effects;

- Chapter 24, Assessment of Potential Commercial and Non-commercial Land Use Effects; and
- Chapter 25, Assessment of Potential Effects to Current Use of Lands and Resources for Traditional Purposes.

10.2 REGULATORY AND POLICY FRAMEWORK

The statutory framework applicable to surface water hydrology for mine developments is listed below and summarized in Table 10.2-1:

- *Canada Water Act* (1985a) provides the framework for joint federal-provincial management of Canada's water resources;
- BC *Water Act* (1996a) is a provincial Act, approvals and licences under which are required to authorize the construction of works for the purposes of diverting, storing, or using water, or causing changes in and about a stream for any purpose;
- *Fisheries Act* (1985b) provides Fisheries and Oceans Canada with the responsibility to ensure sufficient flows for fish by preventing permanent alteration to, or destruction of fish habitat. The proposed Project has the potential to alter the natural flow regime in Sulphurets Creek (Chapter 15, Assessment of Potential Fish and Fish Habitat Effects); and
- *International River Improvements Act* (1985c) was enacted to ensure Canada can meet its obligations under the 1909 *Boundary Waters Treaty*. The intent of the *Boundary Waters Treaty* is to ensure that Canada's water resources in international waters (listed on schedule 5) and in international rivers (subject to the *International River Improvements Act*) are developed and used in the best national interest.

Table 10.2-1. Surface Water Hydrology Legislation, Policy, Standards, and Guidelines

Name	Year	Type	Level of Government	Description
Canada Water Act	1985	Act	National	The Act provides the framework for joint federal-provincial management of Canada's water resources.
Water Act	1996	Act	Provincial	Diverting, storing, or using water, or causing changes in and about a stream for any purpose requires approvals and licenses under that Act.
Fisheries Act	1985	Act	National	The Act holds Fisheries and Oceans Canada responsible for ensuring sufficient flows for fish by preventing permanent alteration to, or destruction of, fish habitat.
International River Improvements Act	1985	Act	National	The Act ensures Canada can meet its obligations under the 1909 *Boundary Waters Treaty*, such that Canada's water resources in international waters and in international rivers are developed and used in the best national interest.
AIR	2014	Guideline	Provincial	The document identifies the information that must be contained within the Application for an EA Certificate.
EIS Guidelines	2013	Guideline	National	The Guidelines identify the information requirements for the preparation of an EIS.

In addition, the following provincial and federal documents specify data collection and assessment methodology requirements for the Project (Table 10.2-1):

- the Application Information Requirements (AIR; BC EAO 2014) document identifies the information that must be contained within the Application. The AIR is formally approved and issued by the British Columbia Environmental Assessment Office (BC EAO); and
- the Environmental Impact Statement Guidelines (the Guidelines) identify the federal information requirements for the preparation of an EIS. The document specifies the nature, scope, and extent of the information required.

The AIR and the Guidelines identify surface water hydrology as a VC.

10.3 BASELINE CHARACTERIZATION

The baseline surface water hydrology conditions of the proposed Project area are described in this section. Surface water hydrology refers to surface water quantity; aspects of the Application/EIS related to surface water quality are presented in Chapter 13, Assessment of Potential Surface Water Quality Effects. Baseline studies have been undertaken in accordance with guidelines from *Water and Air Baseline Monitoring Guidance Document for Mine Proponents and Operators* (BC MOE 2012).

As outlined in the AIR document, results of the information review and field investigations, as described in this section, allows for:

- delineation of drainage basins, at appropriate scales, for all waterbodies that could potentially be exposed to Project effects;
- description of baseline hydrologic conditions and regimes based on streamflow analysis and flow monitoring;
- description of normal and return period baseline statistics for key hydrologic parameters including annual runoff, monthly distribution of runoff, and peak and low flows; and
- description of the influence of glaciers on runoff, relationship to climate, and runoff coefficients.

The sources of the regional and site-specific data, including the time frame and data collection methods where available, are described in the following sections. Any assumptions are documented, and margins of error or degree of uncertainty are reported where appropriate.

10.3.1 Regional Overview

The Project (Figure 10.3-1) lies within the Boundary Ranges of the Coast Mountains in northwestern BC (Holland 1976). The region is characterized by steep, rugged, high elevation topography with substantial glacier coverage that receives relatively high amounts of precipitation. The humid climate and physical characteristics of the region result in dynamic streams and rivers with high annual runoff rates and high average streamflows, making water resource management an important issue for mine plan development as well as operation and closure planning.

The location of key watersheds and the main river systems potentially impacted by the Project are shown in Figure 10.3-2. Details of the watersheds in Figure 10.3-2, including physiographic information and maps, are provided in Appendix 10-A, 2012 Surface Water Hydrology Baseline Report.

The proposed mine site area is situated within the Brucejack Creek watershed (drainage area 11.7 km^2 at hydrometric station BJL-H1), a small headwater sub-basin within the Sulphurets Creek watershed (drainage area 299 km^2). Sulphurets Creek is a tributary of the Unuk River that flows southwest, eventually discharging in to the Pacific Ocean northeast of Ketchikan, Alaska (drainage area 2,577 km^2 at mouth).

Figure 10.3-1

Brucejack Gold Mine Project: Overview

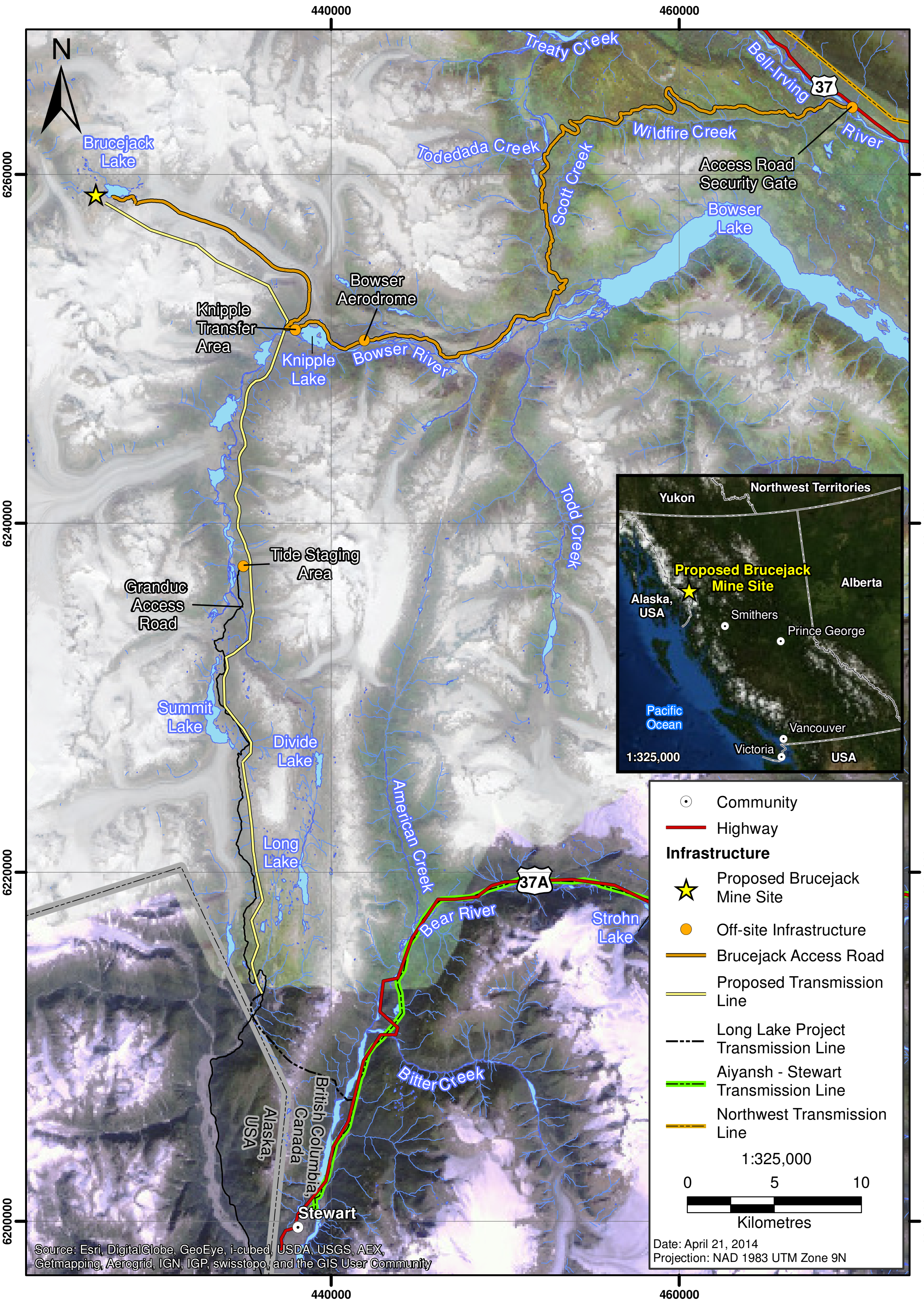
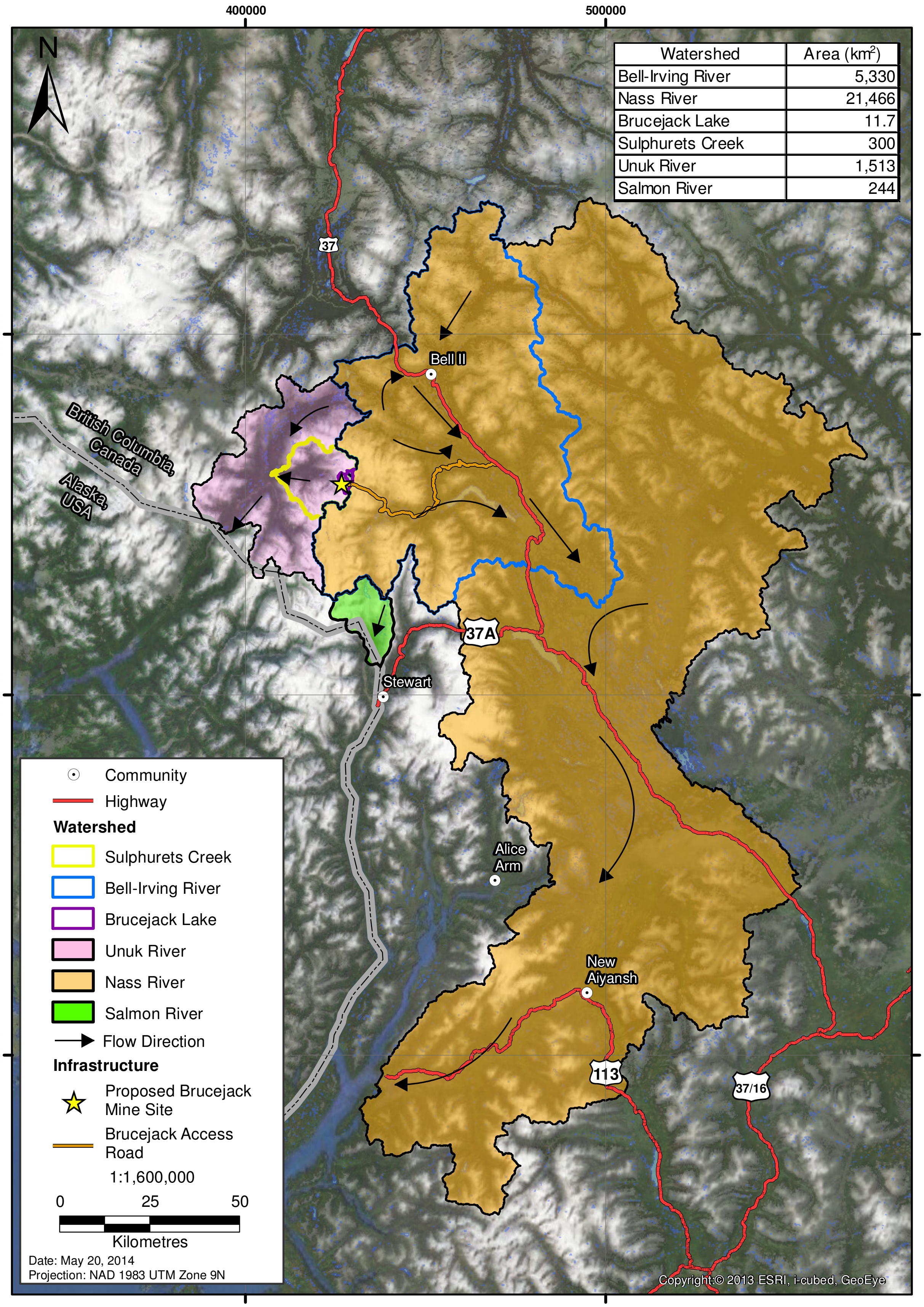


Figure 10.3-2
Regional Hydrological Setting of the Project Area

ERM



Watershed	Area (km²)
Bell-Irving River	5,330
Nass River	21,466
Brucejack Lake	11.7
Sulphurets Creek	300
Unuk River	1,513
Salmon River	244

From its origins northeast of the Project area, the Bell-Irving River flows southwest within the Klappan Range of the Skeena Mountains. The Bell-Irving itself flows within the Nass Basin physiographic region and continues until its confluence with the Nass River. The Nass River flows 380 km from the Coast Mountains southwest to Nass Bay, an inlet of the Pacific Ocean. The Nass watershed (drainage area 21,466 km^2) encompasses the Bell-Irving watershed (drainage area 5,330 km^2), which in turn contains the watersheds of Wildfire Creek (drainage area 66.9 km^2), Scott Creek (drainage area 74.5 km^2), and Todedada Creek (drainage area 61.1 km^2). The 75-km-long Brucejack exploration access road commences at Highway 37 at about 400 m above sea level (masl); follows the drainages of Wildfire, Todedada, and Scott creeks to the Bowser River Valley; and then ascends the Knipple Glacier to the mine site area.

The Salmon River headwater is fed by the Salmon Glacier, and flows 23 km south to tidewater at the head of Portland Canal, Alaska (Mathews and Clague 1993). Drainage area of the Salmon River watershed is 244 km^2.

Watersheds in the Project area may represent glacial, nival, or mixed regimes based on their elevation and glacier coverage. In many northwestern BC watersheds with nival regimes, high flows occur in spring due to snowmelt (freshet) and rain-on-snow events. In such streams, flows steadily decline throughout the summer. However, in watersheds with large glacier coverage, flows are sustained and modulated by glacial melt. In these glacierized watersheds, flows often remain fairly consistent throughout the summer. Large precipitation events are common in the fall for northwestern BC. These major events may result in dramatic short term increases in discharge, and sometimes trigger peak annual flows. However, aside from these short-term increases, flows generally continue to decrease throughout the fall, returning to baseflow levels in the winter.

The Project area lies in a transition zone between the very wet coastal region and the drier interior region of BC. The regional hydroclimate of northwestern BC is dominated by weather systems generated from the Pacific Ocean, and is also strongly influenced by orographic effects caused by the local mountainous topography that produce a high degree of spatial variability in snowfall and precipitation. Local topography also has an influence in controlling temperatures and the rate and timing of snowmelt. In addition, the presence of large glacierized areas can impact snowmelt rates and produce high runoff volume during summer months. Due to the number of competing runoff generation processes and their varying spatial and temporal influences on streamflow hydrographs, the hydrological regime of the region is very dynamic, with a high degree of temporal and spatial variation.

10.3.2 Historical Activities

Several historical and current human activities are within close proximity to the proposed Project area. These activities include mineral exploration and production, hydroelectric power generation, forestry, and road construction and use.

The Granduc Mine was a copper mine located approximately 25 km south of the Project which operated from 1970 to 1978 and 1980 to 1984. The mine included underground workings, a mill site near Summit Lake and an 18.4 km tunnel connecting them. In addition, a 35-km all-weather access road (Granduc Access Road) was built from the communities of Stewart, BC and Hyder, Alaska to the former mill site near Summit Lake. The area of the former mill site is currently used as a staging area for several mineral exploration projects in the region. The terminus of the Granduc Access Road is 25 km south of the proposed Brucejack Mine Site and is currently used by mineral exploration traffic and tourists accessing the Salmon Glacier viewpoint.

The Sulphurets Project was an advanced underground exploration project of Newhawk Gold Mines Ltd. located at the currently proposed Brucejack Mine Site. Underground workings were excavated between 1986 and 1990 as part of an advanced exploration and bulk sampling program. Reclamation efforts following the Newhawk Gold Mines Ltd. advanced exploration work included deposition of waste rock and ore within Brucejack Lake.

The exploration phase of the proposed Brucejack Gold Mine Project commenced in 2011 and has included a drilling program, bulk sample program, construction of an exploration access road from Highway 37 to the west end of Bowser Lake, and rehabilitation of an existing access road from the west end of Bowser Lake to the Brucejack Mine Site.

In 2010, construction began on the Long Lake Hydroelectric Project which is located approximately 42 km south of the Project (CEA Agency 2012). This project includes redevelopment of a 20-m-high rockfill dam located at the head of Long Lake, and a new 10-km-long 138-kV transmission line. The project commenced operation in December 2013.

Historical forestry activities occurred within the immediate Project area between Highway 37 and Bowser Lake, south of the Wildfire Creek and Bell-Irving River confluence. Additional details regarding historic and current human activities near the Project are detailed in Section 6.9.2.

10.3.3 Baseline Studies

The surface water quantity baseline monitoring program was established to characterize the spatial and temporal variation in flows in the baseline study area. Hydrometric stations were established at multiple creeks that could potentially be affected by the proposed mining development. The hydrologic regime is important not only for fish and fish habitat, surface water quality, and aquatics, but is also critical in the development of the engineering design and water management practices of the Project.

Specific objectives of the surface water hydrology monitoring study were to:

- operate and maintain hydrometric stations that contribute to characterization of the hydrologic regime;
- develop and improve the stage-discharge curves at hydrometric monitoring stations;
- calculate flow discharge estimates and generate annual hydrographs for each hydrometric station within the monitored drainage areas; and
- integrate the site specific data with regional analyses to estimate hydrologic indices related to annual runoff, monthly distribution of runoff, as well as peak and low flows.

10.3.3.1 Data Sources

The 2009 to 2012 hydrometric program was initiated to collect baseline hydrologic data for specific streams, rivers, and lakes within the study area. Automated hydrometric stations recorded water levels during open water periods to monitor surface water flows in order to characterize the hydrological variation in these water bodies. The monitoring program began in 2009 with two hydrometric stations, one of which had been in operation since 2007 for a neighbouring project. From 2009 to 2012, new automated hydrometric stations were established, and some stations were retired as the Project evolved. A total of nine stations were established in the Bell-Irving drainage basins, and a total of six stations were used in the Sulphurets and Unuk drainages (Table 10.3-1 and Figure 10.3-3).

Figure 10.3-3

Surface Water Quantity Station Locations 2008 to 2012, Brucejack Gold Mine Project

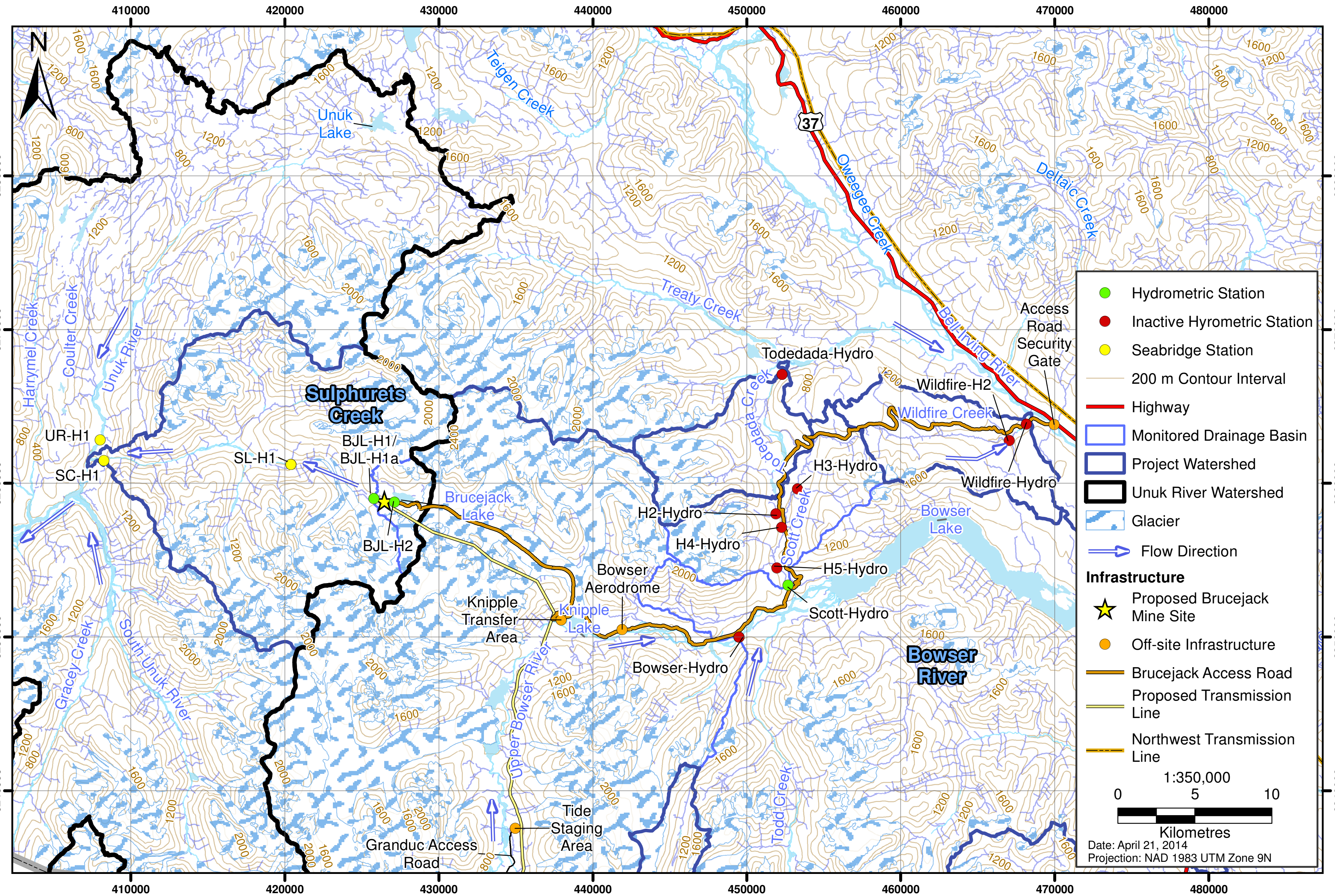


Table 10.3-1. Hydrometric Monitoring Stations in the Brucejack Gold Mine Project Study Area

Hydrometric Monitoring Station	Location	UTM Zone 9U NAD 83 Easting (m)	UTM Zone 9U NAD 83 Northing (m)	Drainage Area (km^2)	Hydrologic Regime Characterized in Appendix 10-A[a]	Period of Operation	Continuous Monitoring Type
Unuk-Sulphurets Drainages							
BJL-H1	Brucejack Creek (downstream of Brucejack Lake)	425,773	6,259,026	11.7[b], 17.0[c]	Yes	August 24, 2007 to July 24, 2012	Stream water level
BJL-H1a	50 m downstream of BJL-H1	425,739	6,259,085	11.7[b], 17.0[c]	Yes	July 24, 2012 to present	Stream water level
BJL-H2	Southern shore of Brucejack Lake	427,107	6,258,788	n/a[d]	n/a[d]	July 21, 2011 to October 16, 2013	Lake water level
SL-H1[e]	Sulphurets Lake at outlet	420,398	6,261,229	84.2	Yes	September 2007 to present	Stream water level
SC-H1[e]	Sulphurets Creek near mouth	408,256	6,261,490	298.6	Yes	January 1, 2010 to November 30, 2011; May 4, 2012 to present	Stream water level
UR-H1[e]	Unuk River upstream of the confluence with Sulphurets Creek	408,007	6,262,837	400.1	Yes	April 28, 2010 to present	Stream water level
Bell-Irving Drainages							
Bowser-Hydro	Upstream of Scott Creek	449,486	6,250,000	757.0	No	July 7, 2010 to October 25, 2010; May 12, 2011 to November 25, 2011	Stream water level
Todedada-Hydro	1 km above the confluence with Treaty Creek	452,290	6,267,089	61.1	Yes	June 21, 2011 to May 22, 2013	Stream water level
Wildfire-Hydro	1 km above the confluence with Bell-Irving River	468,149	6,263,853	66.9	Yes	May 14, 2011 to May 22, 2013	Stream water level
Wildfire-H2	Southern tributary of Wildfire Creek	467,039	6,262,797	19.4	No	May 1, 2012 to November 22, 2012	Stream water level
Scott-Hydro	Near confluence with Bowser River	452,681	6,253,384	74.7	Yes	November 11, 2009 to March 24, 2013	Stream water level
H2-Hydro	Scott Creek north of H4-Hydro	452,260	6,257,144	36.5	No	July 5, 2010 to May 8, 2011	Stream water level
H3-Hydro	Eastern tributary of Scott Creek	453,299	6,259,644	7.6	No	July 8, 2010 to October 21, 2010	Stream water level
H4-Hydro	Western tributary of Scott Creek	451,891	6,258,033	16.5	No	July 4, 2010 to October 24, 2010	Stream water level
H5-Hydro	Western tributary of Scott Creek	451,945	6,254,500	6.8	No	July 6, 2010 to October 23, 2010	Stream water level

[a] Hydrologic regime was characterized for hydrometric stations that were active in 2012.
[b] Based on KPL (2011), excluding the East Lake watershed.
[c] Based on KPL (2011), including the East Lake watershed.
[d] Lake station.
[e] Stations operated by Seabridge Gold.
n/a = No drainage area associated with hydrometric station.

Initial monitoring of surface water flows at the outlet of Brucejack Lake, i.e., Brucejack Creek (BJL-H1), began in August 2007 to support a neighbouring mining development by Seabridge Gold Inc. In 2010, a data sharing agreement between Pretium Resources Inc. and Seabridge Gold Inc. enabled information acquired from the BJL-H1 hydrometric station, as well as three other hydrometric stations within the Unuk-Sulphurets watersheds (SL-H1, SC-H1, and UR-H1), to be used to support the Project.

In July 2012, station BJL-H1 was relocated 50 m downstream where a better hydraulic control for hydrometric monitoring was available. The new location was named BJL-H1a; however, there is no difference between streamflows of the two locations. Therefore, BJL-H1 and BJL-H1a have been interchangeably used in this Application/EIS to name the hydrometric station on Brucejack Creek.

A typical hydrologic or water balance modelling requires an understanding of the interrelationship between the aforementioned streamflow data and information regarding the drainage area of the catchments that generate such streamflows. However, the drainage area of Brucejack Creek cannot be evaluated with certainty. East Lake, located upstream and approximately 500 m east of Brucejack Lake generally fills during late fall, winter, and spring after ice blocks the glacial tunnel that drains the lake eastward under Knipple Glacier. If the East Lake water elevation exceeds the crest elevation of the outflow channel toward Brucejack Lake, flows begin to enter Brucejack Lake. During the summer melt season, warmer water creates a new glacial tunnel into Knipple Glacier and East Lake drains rapidly. From the high water mark created by fine sediment deposits and well-formed beach, it was thought that East Lake remained full and therefore contributed to Brucejack Lake for significantly longer periods in the past (Newhawk 1989). With the retreat and thinning of Knipple Glacier, it is expected that the glacial tunnel either opens earlier in the season (i.e., before East Lake fills and overflows into Brucejack Lake) or remains open throughout the year. It is expected that East Lake contributes to Brucejack Lake less frequently than what has been previously reported by Newhawk Gold Mines Ltd. (1989). The likelihood of East Lake draining into Brucejack Lake will decrease in the future. Observation of water levels in East Lake showed that East Lake was completely drained through Knipple Glacier in June 2013 before it was filled with the freshet runoff and did not contribute any flow to Brucejack Lake.

In this report, the East Lake watershed is excluded from the Brucejack Creek watershed in default analysis scenarios. Given this assumption, the BC Freshwater Atlas (GeoBC 2013) delineation provides a drainage area of 13.9 km^2 for the Brucejack Creek watershed at the BJL-H1 hydrometric station site (Table 10.3-2). A preliminary assessment of a hydroelectric facility at the outlet of Brucejack Lake, KPL (2011) suggested a watershed delineation for Brucejack Creek with a drainage area of 11.7 km^2. The 11.7 km^2 watershed area is supported by hydrologic indices recorded at the Brucejack Lake outlet and hydrometric indices inferred using regional hydrometric datasets (Appendix 10-A, 2012 Surface Water Hydrology Baseline Report). Therefore the default drainage area for Brucejack Creek is assumed to be 11.7 km^2 in this report.

Excluding the East Lake watershed from the Brucejack Creek watershed represents a conservative scenario for most hydrologic indices, and is supported by both the glacier retreat hypothesis and the regional analysis results. However, in the case of estimating peak flows based on regional analysis, a conservative scenario that included contribution of the East Lake watershed to the Brucejack Creek watershed was also studied. In such a scenario, the drainage area of Brucejack Creek watershed includes the East Lake watershed (Table 10.3-2).

Table 10.3-2. Drainage Area Scenarios for Brucejack Creek Watershed at Hydrometric Station BJL-H1

Delineation Source	Drainage Area (km^2)	
	Without East Lake	With East Lake
BC Freshwater Atlas (GeoBC 2013)	13.9	17.2
KPL (2011)	11.7	17.0

The hydrometric monitoring network evolved through the period of study as the scope of the Project changed. Hydrometric stations within the Project area that were active in 2012 and were used for effects assessment include:

- the outflow of Brucejack Lake (Brucejack Creek at BJL-H1) that characterizes the local hydrologic regime at the Brucejack Mine Site;
- three stations on Scott Creek (Scott-Hydro), Todedada Creek (Todedada-Hydro), and Wildfire Creek (Wildfire-Hydro) watersheds that may be impacted by the access road;
- a water level station in Brucejack Lake (BJL-H2); and
- three hydrometric stations from a neighbouring project in the Sulphurets-Unuk watersheds (SL-H1, SC-H1, and UR-H1).

These stations are shown in Figure 10.3-3, and their physiographic characteristics are summarized in Table 10.3-3.

Table 10.3-3. Physiographic Characteristics of Watersheds within the Project Area

Drainage	Watershed	Hydrometric Station	Area (km^2)	Minimum Elevation (m)	Maximum Elevation (m)	Median Elevation (m)	Glacier Coverage (%)	Tributary to
Unuk	Unuk River[a]	UR-H1	400	221	2,265	1,130	14.5	n/a
	Sulphurets Creek	SC-H1	299	217	2,559	1,479	37.7	Unuk River
	Sulphurets Lake	SL-H1	84	572	2,559	1,610	48.7	Sulphurets Creek
	Brucejack Creek	BJL-H1/ BJL-H1a	12[b], 17[c]	1,345	2,383	1,537[b],	29.5[b]	Sulphurets Creek
Bell-Irving	Scott Creek	Scott-Hydro	75	401	2,361	1,180	21.3	Bowser River
	Todedada Creek	Todedada-Hydro	61	574	2,235	1,179	24.8	Treaty Creek
	Wildfire Creek	Wildfire-Hydro	67	464	1,865	950	1.9	Bell-Irving River

[a] *Upstream of confluence with Sulphurets Creek.*
[b] *Based on the Knight Piésold watershed area calculation, excluding the East Lake contribution (KPL 2011).*
[c] *Based on the Knight Piésold watershed area calculation, including the East Lake contribution (KPL 2011).*

Historical streamflow data from 12 hydrometric monitoring stations operated by the Water Survey of Canada (WSC) and US Geological Survey (USGS) within the region (Figure 10.3-4 and Table 10.3-4) were used to conduct a regional hydrologic analysis and supplement the site-specific data collected at hydrometric stations.

Figure 10.3-4

BC Hydrologic Zones: Regional Hydrometric Stations

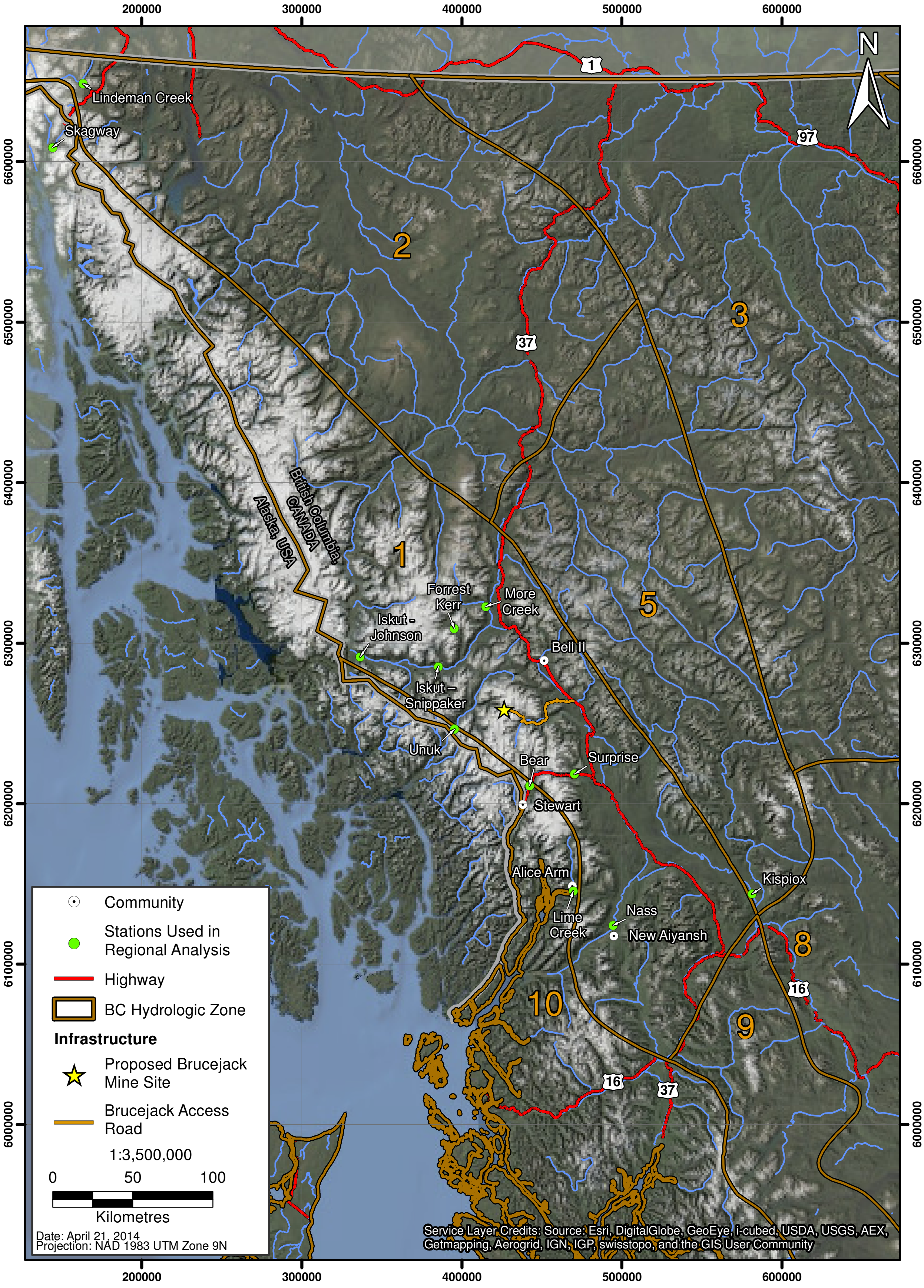


Table 10.3-4. Summary of Regional Hydrometric Stations

Station Name	Station ID	Monitoring Organization	Watershed Area (km^2)	Median Elevation (m)	Years of Available Data
Hydrometric Stations					
Bear River above Bitter Creek	08DC006	WSC	350	1,290	1967 - 1999
Forrest Kerr Creek above 460 m Contour	08CG006	WSC	311	1,360	1972 - 1994
Iskut River below Johnson River	08CG001	WSC	9,500	1,260	1959 - 2010
Iskut above Snippaker Creek	08CG004	WSC	7,230	1,310	1966 - 1995
Kispiox River near Hazelton	08EB004	WSC	1,880	749	1963 - 2011
Lime Creek near the Mouth	08DB010	WSC	40	821	1976 - 1996
Lindeman Creek near Bennett	09AA010	WSC	240	1,100	1950 - 1993
More Creek near the Mouth	08CG005	WSC	844	1,360	1972 - 1995
Nass River above Shumal Creek	08DB001	WSC	18,400	1,050	1929 - 2011
Skagway River at Skagway	15056100	USGS	376	1,180	1963 - 1986
Surprise Creek near the Mouth	08DA005	WSC	218	1,280	1967 - 2010
Unuk River near Stewart	08DD001	WSC	1,480	1,180	1960 - 1996

10.3.3.2 Methods

Baseline studies focused on two groups of watersheds: a) the Unuk-Sulphurets watersheds located on the western side of the Project area are associated with the Brucejack Mine Site; and b) the Bell-Irving subwatersheds are on the eastern side of the Project area and are associated with the access road and transmission corridor.

Given the collected site-specific hydrologic data at the associated hydrometric stations, stage-discharge rating curves were developed for each station in the network. At hydrometric stations where stage-discharge relationships shifted due to changes in channel geometry caused by aggradation, scouring or channel migration, new rating curves were generated. Using the developed rating curves, the continuously recorded water levels were converted into continuous flow discharge hydrographs. Hydrologic indicators were then calculated from discharge hydrographs.

The regional hydrologic analysis was carried out to undertake a hydrological assessment for watersheds within the Project area. Such an assessment included an estimate of expected normal and return period values for a number of key hydrological indices that consider a wide range of hydrologic conditions over an extended time period (Table 10.3-4). The analysis was based on hydrologic data at 12 regional hydrometric stations. The available regional hydrologic data sets were analyzed and used to estimate annual runoff, monthly distribution of annual runoff, and annual peak and low flows. Hydrologic indices were assessed for a range of return periods, and the estimates were adjusted, wherever applicable, based on site-specific observations.

10.3.4 Characterization of Surface Water Hydrology Baseline Condition

Details of estimating hydrologic indices based on the hydrometric monitoring program and the regional analysis are provided in Appendix 10-A, 2012 Surface Water Hydrology Baseline Report. A summary of these indices including annual runoff values, monthly distribution of flow, peak flows, and low flows are discussed below and presented in Tables 10.3-5 through 10.3-9.

Table 10.3-5 highlights the range of annual runoff and mean annual discharge (MAD) among the measured stations; this is an indication of the wide variety of stream sizes that were monitored.

Table 10.3-5. Estimated Annual Runoff (mm) and Mean Annual Discharge (m^3/s) in the Project Area

Watershed	Drainage Area (km^2)	Estimated Based on Baseline Monitoring Program (2008-2012)							Estimated Based on Regional Analysis (Long-term Data)	
		Annual Runoff (mm)						Mean Annual Discharge (m^3/s)	Annual Runoff (mm)	Mean Annual Discharge (m^3/s)
		2008	2009	2010	2011	2012	Average			
BJL-H1/BJL-H1a	11.7[a]	2,008		1,725	1,702	1,582	1,754	0.65	1,695	0.63
	17.0[b]	1,382		1,187	1,171	1,088	1,207	0.65	1,836	0.99
SL-H1	84.2	1,886	2,508	2,297	2,977		2,417	6.4	2,866	7.6
SC-H1	298.6	2,272	2,450	2,302	2,480		2,376	22.5	2,420	22.9
UR-H1	400.0	2,011	2,216	1,870	2,316		2,103	26.7	2,080	26.4
Scott-Hydro	74.5			1,568	1,321	1,501	1,463	3.5	1,645	3.9
Todedada-Hydro	61.1					2,588	2,588	5.0	2,216	4.3
Wildfire-Hydro	66.9					1,188	1,188	2.5	1,222	2.6

[a] *Based on KPL (2011) delineation excluding East Lake.*
[b] *Based on KPL (2011) delineation including East Lake.*

Table 10.3-6. Estimates of Monthly Runoff Distribution for Watersheds within the Project Area

Station Name	Percentage of Annual Runoff Occurring in Each Month (%)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
BJL-H1, UR-H1, Scott-Hydro, and Todedada-Hydro[a]	1.3	1.1	1.2	3.0	11.0	19.8	20.9	16.3	11.2	8.8	3.7	1.8
SL-H1 and SC-H1[b]	0.8	0.6	0.7	1.5	6.1	14.9	23.9	23.7	14.6	9.0	2.9	1.2
Wildfire-Hydro[c]	1.5	1.4	1.6	3.7	19.0	25.3	15.0	8.3	10.7	8.1	3.4	2.0

[a] *Based on long-term average from regional stations.*
[b] *Based on average of WSC Stations Forrest Kerr Creek and Bear River.*
[c] *Based on average from the stations within the Teigen-Treaty Watersheds (Rescan 2013).*

Table 10.3-7. Estimates of Peak Flows (m^3/s) at the Project Stations Based on Regional Quantile Regression Technique

Watershed	Drainage Area (km^2)		Estimated Peak Flow based on Regional Analysis (m^3/s)						
			Q_2	Q_5	Q_{10}	Q_{20}	Q_{50}	Q_{100}	Q_{200}
		k_t*	1.55	3.08	4.21	5.28	6.64	7.64	8.57
		x*	0.80	0.75	0.73	0.73	0.72	0.72	0.72
BJL-H1	11.7[a]		11	20	26	31	39	44	50
	17.0[b]		15	26	34	41	51	58	65
SL-H1	84.2		53	86	109	131	161	183	205
SC-H1	298.6		146	223	276	329	399	453	508
UR-H1	400.0		184	277	343	407	492	559	626
Scott-Hydro	74.5		48	78	100	120	147	168	188
Todedada-Hydro	61.1		41	68	86	104	128	145	163
Wildfire-Hydro	66.9		44	72	92	111	136	155	174

** Equation 10.3-1*
[a] Drainage area without East Lake Watershed.
[b] Drainage area with East Lake Watershed.

Table 10.3-8. Estimated Annual Low Flow Indices for the Watersheds in the Project Area

Watershed	Drainage Area (km^2)		Estimated Annual 7-Day Low Flow based on Regional Analysis (m^3/s)			
			Q_2	Q_5	Q_{10}	Q_{20}
		k_t*	0.0036	0.0020	0.0015	0.0012
		x*	1.028	1.074	1.094	1.106
BJL-H1	11.7		0.05	0.03	0.02	0.02
SL-H1	84.2		0.34	0.23	0.19	0.16
SC-H1	298.6		1.26	0.91	0.77	0.65
UR-H1	400.0		1.71	1.25	1.05	0.90
Scott-Hydro	74.5		0.30	0.20	0.17	0.14
Todedada-Hydro	61.1		0.25	0.17	0.13	0.11
Wildfire-Hydro	66.9		0.27	0.18	0.15	0.13

** Equation 10.3-1*

Within the Project area, the glacial coverage percentage in a watershed affects the magnitude of annual runoff. More runoff is supplied in watersheds that can contribute glacial melt throughout the summer (highly glacierized watersheds), while in snowmelt-fed watersheds, the water supply is largely exhausted after snowmelt. Other factors also control the amount of runoff within the Project area; for example, the type and amount of precipitation. The visual analysis of the annual hydrographs within the Unuk-Sulphurets watersheds (Stations BJL-H1, SL-H1, SC-H1, and UR-H1) shows the contribution of glacial melt to the runoff (Figure 7.5-2 in Appendix 10-A). That is, a glacial or mixed regime was observed in these watersheds where the cumulative runoff continued to rise until September, presumably when falling air temperatures caused a cessation of glacial melt. Although the contribution of glacial melt to the runoff was evident, such a contribution was not quantified.

Table 10.3-9. Estimated June to September Low Flow Indices for the Watersheds in the Project Area

Watershed	Drainage Area (km^2)		Estimated June to September 7-Day Low Flow based on Regional Analysis (m^3/s)			
			Q_2	Q_5	Q_{10}	Q_{20}
		k_t*	0.024[a] / 0.015[b]	0.014[a] / 0.009[b]	0.011[a] / 0.007[b]	0.009[a] / 0.006[b]
		x*	1.060	1.101	1.117	1.128
BJL-H1	11.7		0.33	0.21	0.17	0.14
SL-H1	84.2		2.69	1.84	1.53	1.31
SC-H1	298.6		10.31	7.43	6.27	5.48
UR-H1	400.0		14.06	10.25	8.70	7.62
Scott-Hydro	74.5		2.37	1.61	1.33	1.14
Todedada-Hydro	61.1		1.92	1.30	1.07	0.92
Wildfire-Hydro	66.9		1.32	0.88	0.73	0.64

** Equation 10.3-1*
[a] For Stations BJL-H1/H1a, SL-H1, SC-H1, UR-H1, Scott-Hydro, and Todedada-Hydro.
[b] For Station Wildfire-Hydro.

Unlike runoff, MAD is not normalized to watershed size, and is controlled more by drainage area. During the record period, the lowest MAD was recorded at Station BJL-H1/BJL-H1a (drainage area 11.7 km^2) while the highest MAD was recorded at Station UR-H1 (drainage area 400 km^2).

Monthly flow distribution is an index of the seasonal variation in flows across the region. The methodology used for determining the monthly flow distribution combined a regional analysis, using WSC hydrometric stations, with results from the baseline hydrology program.

At a majority of the regional stations, the regional data indicates that flow is concentrated in the open water season (May to October) with less than 20% of the annual flow occurring from November to April (Table 8.3-1 in Appendix 10-A, 2012 Surface Water Hydrology Baseline Report). During the open water season the distribution of flow depends on the timing of freshet and also the balance between the volumes of water released during the freshet with water resulting from fall rains or glacier melt. Smaller watersheds containing a large percentage of glaciers (for example, Forrest Kerr Creek and Bear Creek) show a higher proportion of flow occurring during July and August compared to the larger watersheds with lower glacier percentage. Such a pattern was also seen in the Project area, especially for stations within the Sulphurets Creek watershed, and reflects the contribution of glacial meltwater in late summer. That is, local differences are visible in the pattern of monthly runoff distributions within the hydrological region.

Table 10.3-6 summarizes monthly runoff distribution values within the Project area. The values for BJL-H1/BJL-H1a, UR-H1, Scott-Hydro, and Todedada-Hydro are based on regional average data. Estimates for SL-H1 and SC-H1 are based on the average of data from Forrest Kerr Creek and Bear River. Values for Wildfire-Hydro are based on average from the stations in neighbouring North Treaty Creek and Teigen Creek (Rescan 2013). For each watershed, the percent value of the annual flow that occurs in each month can be multiplied by the mean annual runoff totals to provide estimates of monthly runoff totals and average monthly flows.

A flood frequency analysis was conducted to predict peak flows associated with different return periods. The return period refers to the probability of occurrence of the flood event. For example, a 1-in-100 year return period (Q_{100}) event is the magnitude of flow that has a 1% chance of being equalled or exceeded in a given year. TThe mean annual flood is generally defined as the Q_2 (i.e., it has a 50% probability of being equalled or exceeded in a given year).

There are no standard methodolgies for flood frequency analysis in BC, although guidance is offered in Coulson (1991). For the analysis discussed here a regional analysis was conducted using the quantile regression technique. A number of previous studies have developed simple regression equations relating peak flows to watershed area in BC (for example, BC Forest Service 1996; Coulson and Obedkoff 1998; Church 1997; Obedkoff 2001; Eaton, Church, and Ham 2002).

The equation generally takes the form:

$$Q_t = k_t A^x \qquad \text{(Equation 10.3-1)}$$

where
Q_t is the flow (m^3/s) with return period t;
k_t is an empirical scaling coefficient for an event with return period t;
A is the watershed area (km^2), and
x is a scaling coefficient usually assumed to be between 0.6 and 1.0.

A flood frequency analysis on regional WSC stations was conducted and the instantaneous discharge data were used to estimate flows of varying return intervals. A regression analysis was then completed using these results for all WSC regional stations to estimate a relationship between Q_t and watershed area, for all return periods between 2 and 200 years (see Appendix 10-A, 2012 Surface Water Hydrology Baseline Report, for additional details). The results of this analysis produced different k_t and x values for each return period, which were then applied to the Project stations. The results of this are shown in Table 10.3-7.

Low flow magnitudes provide an estimate of the normal baseflow conditions of a stream and are important to the sustained health of a stream's aquatic community. Baseflows mostly originate from the saturate zone or shallow groundwater storage. Discharge from the groundwater storage exfiltrates into the stream through the channel banks and/or bed. Thus low flows characterize the link between surface water quantity and the shallow groundwater storage.

A study was undertaken to determine the commonly used indicator of low flows, the 7-day low flow. The 7-day low flow is the minimum average seven day flow that occurs consecutively over a specified period, such as a month, season, or year. A more severe low flow event associated with a 10-year return period (7-day Q_{10}) was also estimated. The 7-day Q_{10} flow is defined as the minimum average seven day flow that has a recurrence interval of 10 years on average between occurences. The 7-day Q_2, Q_5, Q_{10}, and Q_{20} were provided as recommended in the *Water and Air Baseline Monitoring Guidance Document for Mine Proponents and Operators* (BC MOE 2012). The approach was similar to that of peak flows. That is, frequency analysis was carried out for WSC stations with long-term records, and a regression analysis was perfomed to identify the relation between low flows and watershed area (i.e., similar to Equation 10.3-1). The results are summarized in Table 10.3-8.

For streams at higher elevations in the Project area, the annual low flow will consistently occur duing the winter, when most water is stored as either ice or snow. However, important aspects of a stream's health, such as presence of certain aquatic species, or activities that could impact the quantity or quality of water in a stream may be restricted to the open water season. Therefore, it is also useful to identify the low flow that occurs during this period. Estimated average 7-day low flow and the 7-day Q_2, Q_5, Q_{10}, and Q_{20} low flow that occurs from June to September are provided in Table 10.3-9.

10.3.5 Climate Change

Anticipated climate change in the Project area is discussed in detail in Chapter 32, Effects of the Environment on the Project, and in Chapter 12, Assessment of Potential Climate Effects. This section summarizes the expected climate change projections pertinent to surface water hydrology.

Global climate is warming, and will continue to warm in the future (APEGBC 2010; AMS 2012; BCWWA 2013a; IPCC 2013). Heavy precipitation events have become more intense and frequent, and will continue to do so, although confidence in the signature and amount of change is lower than confidence for change in air temperature (AMS 2012). Uncertainty increases when considering local effects and the effects of climate change on the environment, such as vegetation, glaciers, streamflow, and wildfires.

Several cyclical climatic patterns influence the climate of the Project area, including the Pacific Decadal Oscillation (PDO) and El Niño Southern Oscillation (ENSO; see Section 32.2.1.2). The effects of global warming on these patterns are poorly understood. However, in a review of global climate model (GCM) results from the Intergovernmental Panel on Climate Change's *Fourth Assessment Report: Climate Change 2007* (IPCC 2007), it was found that the negative phase of the PDO increased in frequency, especially after 2050. ENSO is expected to experience an "El Niño-like" mean state change, but no change in amplitude (Lapp et al. 2012).

Climate change for the Project area was assessed in Chapter 32, Effects of the Environment on the Project, using the computer program ClimateWNA (Wang et al. 2006; Wang et al. 2012). ClimateWNA aggregates and downscales GCM outputs for various greenhouse gas (GHG) emissions scenarios and time periods. Downscaling was performed for the location and elevation of Brucejack Lake.

To address uncertainty in future climate, it is recommended that a range of predictions be considered (BCWWA 2013b). In this analysis, GCM output used the A2, A1b, and B1 GHG scenarios, to present a range of possible climatic conditions based on assumptions of future population, economics, and technology. The A2 scenario assumes exponentially increasing atmospheric CO_2 levels continuing to the end of the twenty-first century, reaching 800 parts per million (ppm) by 2100. In the A1b scenario, concentrations stabilize at 720 ppm by the end of the century. The B1 scenario assumes that GHG emissions will plateau between 400 and 500 ppm by mid-century. In 2013, the average $C0_2$ concentration at Mauna Loa in Hawaii was 396.5 ppm. Details of the assumptions in Intergovernmental Panel on Climate Change emission scenarios are available in Nakićenović et al. (2000).

GCM data were extracted for the decades of the 2020s, 2050s, and 2080s. All GCM data available from ClimateWNA for the A2, A1b, and B1 scenarios were extracted (6 to 7 GCMs per scenario). Results for each scenario and decade are presented as averages, and high and low extremes (Figure 10.3-5). Historical climate conditions are represented by presenting two "climatic normals:" 1961 to 1990 and 1981 to 2010.

Monthly average air temperature and precipitation were also extracted and plotted for the A2 scenario and climatic normals (Figure 10.3-6; data shown are averages from all available GCMs). Changes are generally less for the A1b and B1 scenarios.

10.3.5.1 Air Temperature

Northern BC is expected to warm more than southern BC as a result of climate change (PCIC 2011). ClimateWNA estimates that the average annual air temperature at Brucejack Lake was -2.2^{o}C from 1961 to 1990, and -0.6^{o}C from 1981 to 2010 (Figure 10.3-5, graph "A").

Figure 10.3-5

Global Climate Model Predictions for Brucejack Lake: Annual Averages and Inter-GCM Variability

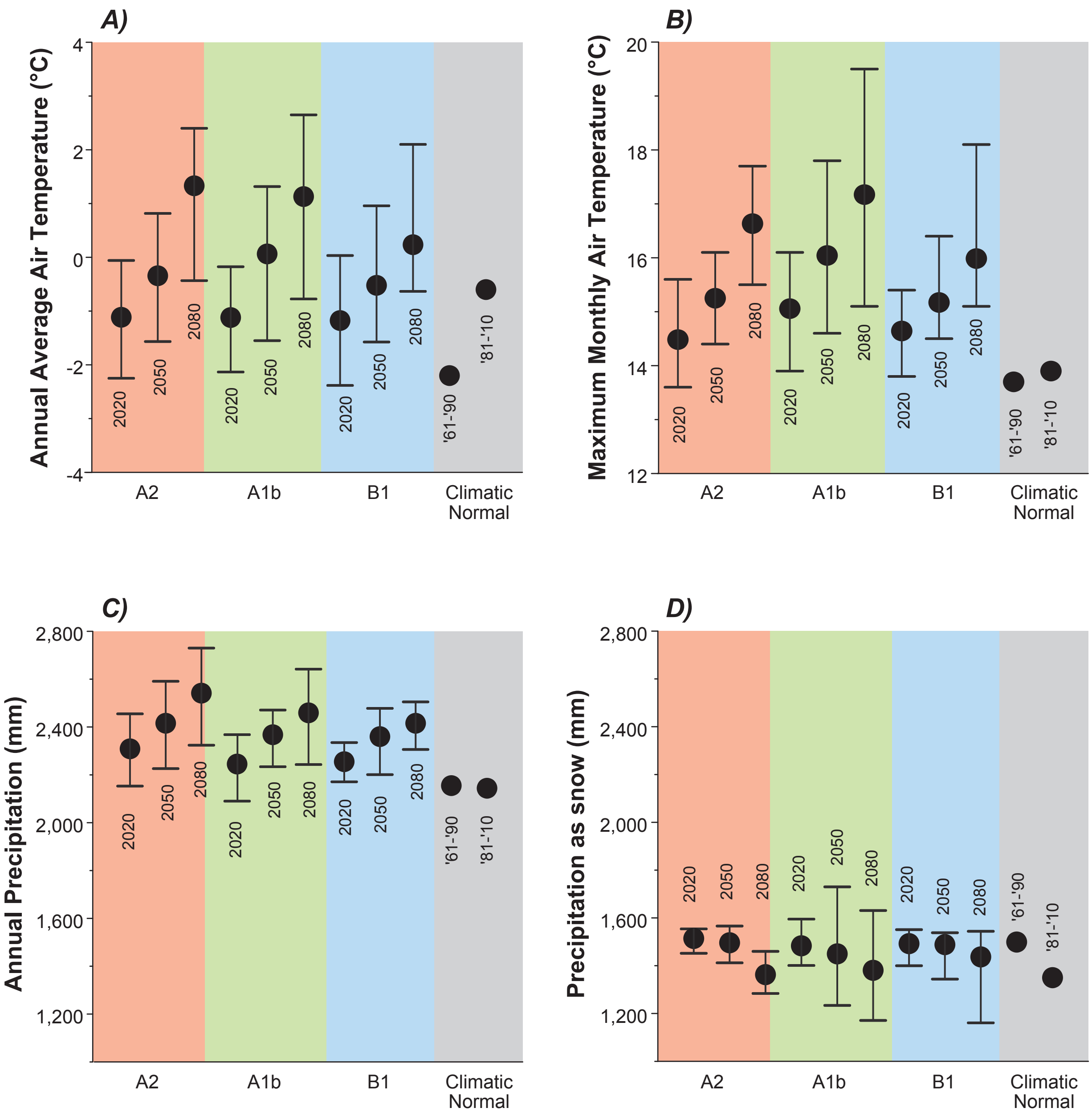
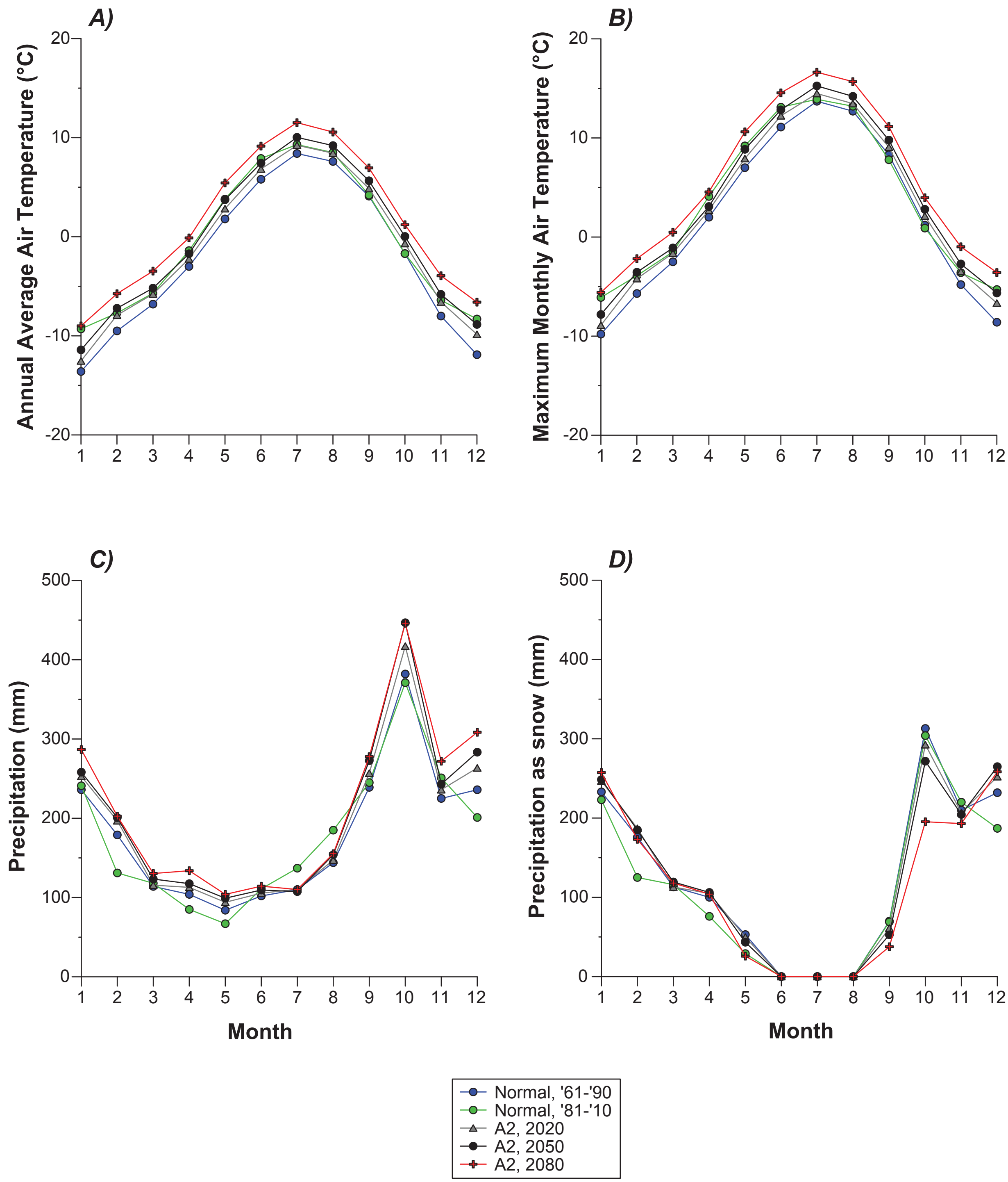


Figure 10.3-6

Global Climate Model Predictions for Brucejack Lake: Monthly Averages for the A2 GCM Scenario and Climatic Normals



Both the A2 and A1b scenarios predict similar magnitudes of warming for all time periods (about 1°C by 2050, and 3°C by 2080 relative to 2020). Between-GCM variability is large (up to about 2.9°C), but all models predict warming. The least warming is predicted for the B1 scenario, where GHG concentrations stop increasing by mid-century. Climatic normal maximum monthly air temperatures ranged from 13 to 14°C in the past depending on the normal period (Figure 10.3-6, graph "B"). By 2080, GCM predictions indicated maximum monthly air temperatures of about 16 to 17°C.

10.3.5.2 Precipitation

Precipitation is expected to increase more in the northern than the southern part of the province, especially in winter, spring, and fall (PCIC 2011).

Climatic normal annual total precipitation for Brucejack Lake is very similar for both past normal periods (2,155 mm for 1961 to 1990, and 2,144 mm for 1981 to 2010; Figure 10.3-5, graph "C"). However, an increase in precipitation is predicted for 2020, 2050, and 2080 relative to modern climatic normals (Figure 10.3-5, graph "C"). The greatest increases are expected for the A2 scenario in 2080.

The fraction of precipitation falling as snow is expected to decline in all emissions scenarios and for all time periods (Figure 10.3-5, graph "D"). Decreases in snowpack are greatest for the A2 and A1b scenarios (100 to 150 mm), and relatively small for the B1 scenario (about 20 mm) on average. Since annual total precipitation increases, and the fraction falling as snow decreases, the percentage of precipitation falling as rain will increase.

10.3.5.3 Streamflow

An increase in annual average air temperatures will alter streamflow patterns (Walker and Sydneysmith 2007). The freshet date will shift earlier in the season, and flow will extend for longer in winter. Annual runoff could both increase and decrease, depending on elevation, vegetation, physiography, and the magnitude of climate change. An increase in runoff would occur if runoff from snowfall, rainfall, or glacial melt increases, and if these increases are greater than increases in evapotranspiration. A decrease in runoff would occur if evapotranspiration increases exceed increases in precipitation, or if glacial melt declines due to glacial recession.

Reduced snowfall in winter could lead to a smaller freshet. In the melt period, less glacial coverage by snow would reduce the insulating effect of snow, reduce the albedo of glacial ice, and increase absorption of latent and sensible heat into ice, all of which would increase glacial melt.

Hydrologic modelling is a technique to integrate these hydroclimatic and watershed processes. GCM data for future climate change scenarios are fed into a calibrated and validated hydrologic model, which predicts changes to discharge. The direction and magnitude of hydrologic changes in modelled BC catchments are varied due to differing characteristics of the catchments. Coastal snowmelt-fed rivers will likely see increased winter discharge (PCIC 2011; Schnorbus, Werner, and Bennett 2012). Some glacierized watersheds are predicted to have decreased streamflow from climate change (Stahl et al. 2008). Hydrologic modelling in the nearby KSM Project area predicted increasing discharge in rivers, until at least 2080 (Rescan 2013). Given the proximity and physiographic similarities to the Brucejack Creek watershed, a similar result would be expected in the Project area—namely increased summer discharge, and annual runoff.

It has been noted that until at least 2050, the emissions scenario used has no impact on hydrologic projections in BC watersheds (PCIC 2011). Differences will likely be manifested after 2050.

10.3.5.4 Extreme Events

Extreme events are also likely to increase in frequency and magnitude in the future (Walker and Sydneysmith 2007). Climatic extremes are most likely to be manifested as periods of extreme heat, precipitation, and flooding in the Project area. Storms may increase in frequency and duration due to increases in instability in oceanic and atmospheric circulation arising from stronger temperature differentials projected with climate change. Storm tracks may also change depending on oceanic circulation. In small drainage basins for which information of future local conditions is not sufficient to provide reliable projection, APEGBC (2012) suggests adjusting expected flood magnitude by 20%.

10.3.5.5 Glacial Recession and Thinning

The Brucejack Creek watershed is currently 29.5% glacierized. Glacial recession will likely only slightly reduce this amount in the Project lifespan, given the high elevation of the mine site, and the relatively short Project lifespan. In addition, the glaciers in the Brucejack Creek watershed are part of an icefield, and do not consist of outlet glaciers that would be more prone to rapid recession. However, glacial recession is expected to continue impacting the hydraulic connectivity between Brucejack Lake and East Lake. Brucejack Lake being recharged annually by East Lake will likely occur less frequently in the future, considering the current trend in climate change (see Section 10.3.3.1).

10.4 ESTABLISHING THE SCOPE OF THE ASSESSMENT FOR SURFACE WATER HYDROLOGY

This section includes a description of the scoping process used to identify surface water hydrology as a potentially affected intermediate component that is a pathway to other receptor VCs, and to select assessment boundaries. The scoping process for the assessment of surface water hydrology consisted of the following three steps:

- *Step 1*: scoping process to select intermediate components, sub-components, and indicators based on a consideration of the Project's potential to interact and/or affect with surface water hydrology;
- *Step 2*: consideration of feedback on the results of the scoping process; and
- *Step 3*: defining assessment boundaries for surface water hydrology.

10.4.1 Selecting Intermediate Components

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

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

Surface water hydrology was identified as a key component of the bio-physical environment because it is linked to other ecosystem components, including surface water quality, fish and fish habitat, aquatic resources, terrestrial ecosystems, wetlands, navigation, and land use (Figure 10.4-1).

Subject areas are classified as either an intermediate component or receptor VC and are further refined into sub-components and indicators as described in Section 6.4-1. Surface water hydrology was identified as an intermediate component as a result of the scoping process, and refined to three sub-components (Table 10.4-1). The assessment of changes in the condition of the surface water hydrology and its associated sub-components is evaluated using “indicators” which are relevant, practical, measurable, responsive, accurate, and predictable metrics to measure the condition and trend of surface water hydrology. Sub-components and indicators of surface water hydrology are introduced here and summarized in Table 10.4-1:

- *Streamflows*: Based on the natural flow regime paradigm (Poff et al. 1997; Poff et al. 2010), flow indices are vital elements of aquatic environmental health. Annual runoff, monthly distribution of runoff, peak flow, and low flow were used as streamflow indices.
- *Channel morphology*: Channel morphology not only pertains to the long-term hydrology and sediment transport regime within a watershed, but it also reflects the aquatic habitat within the streams. Drainage morphology and stability were considered to be representative indicators of morphology.
- *Glaciers*: Since glaciers contribute to the hydrologic cycle, and are interrelated with streamflows and channel morphology, glaciers were considered as a sub-component of surface water hydrology in this Application/EIS. For effects assessment purposes, glacier ablation is of primary concern, and therefore was selected as an indicator for this sub-component.

Table 10.4-1. Sub-components and Indicators of Surface Water Hydrology as an Intermediate Component

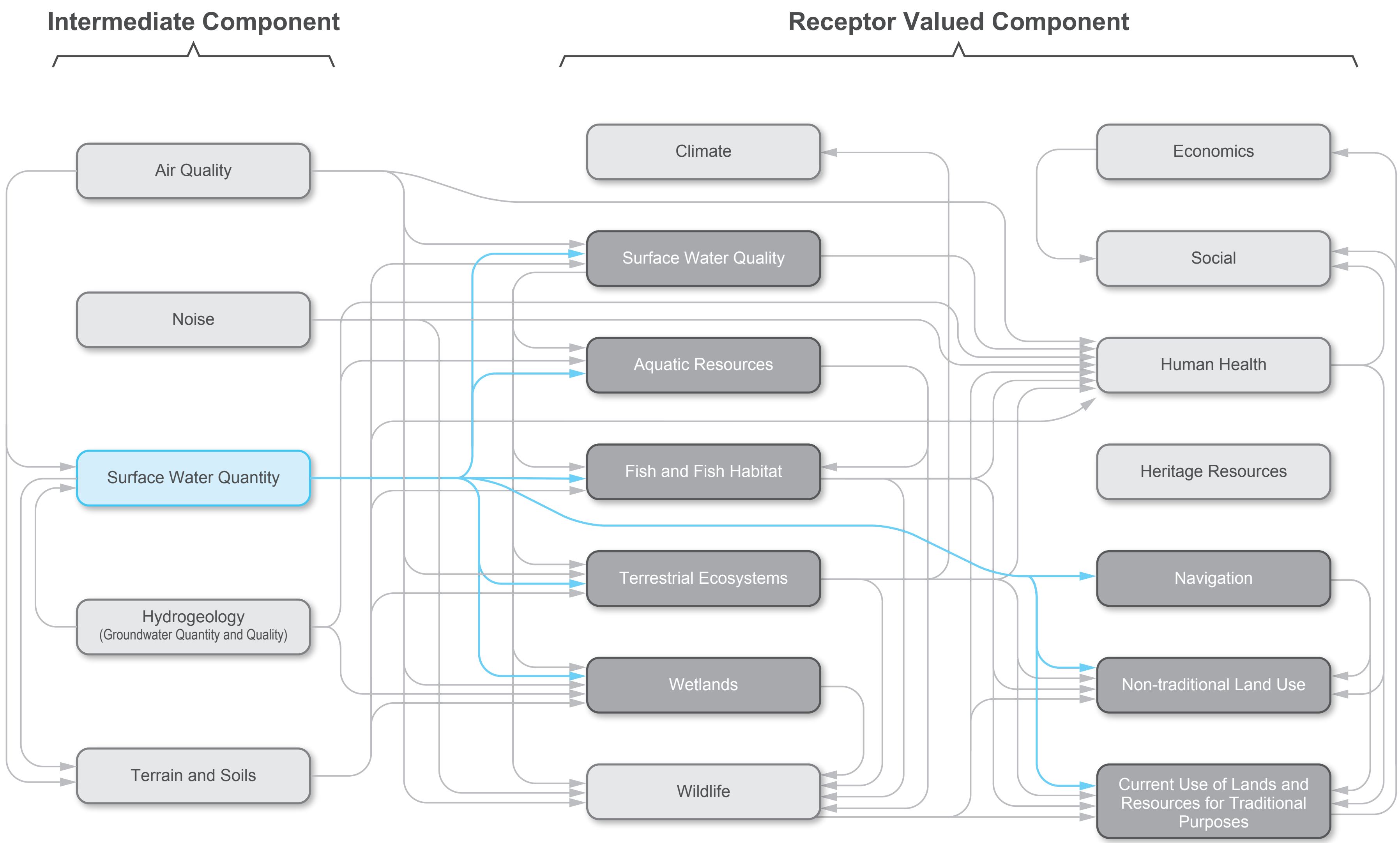
Intermediate Component	Sub-component	Indicator(s)
Surface Water Hydrology	Streamflows	Annual Runoff, Monthly Distribution of Runoff, Peak Flows, and Low Flows
	Channel Morphology	Drainage Morphology and Stability
	Glaciers	Glacier Ablation

A description of potential effects of the Project on surface water hydrology, relevant mitigation measures, and predicted changes to surface water hydrology are provided in Sections 10.4.3 to 10-8. While quantitative assessment was performed on the streamflow, channel geomorphology and glaciers were assessed qualitatively. The determination of significance of changes to receptor VCs are presented in:

- Chapter 13, Assessment of Potential Surface Water Quality Effects;
- Chapter 14, Assessment of Potential Aquatic Resources Effects;
- Chapter 15, Assessment of Potential Fish and Fish Habitat Effects;
- Chapter 16, Assessment of Potential Terrestrial Ecology Effects;
- Chapter 17, Assessment of Potential Wetlands Effects;
- Chapter 23, Assessment of Potential Navigation Effects;
- Chapter 24, Assessment of Potential Commercial and Non-commercial Land Use Effects; and
- Chapter 25, Assessment of Potential Effects to Current Use of Lands and Resources for Traditional Purposes.

Figure 10.4-1

Linkages between Surface Water Hydrology and Receptor Valued Components



10.4.1.1 Potential Interactions between the Project and Surface Water Hydrology

A scoping exercise was conducted during the development of the AIR (Section 6.4.1) to explore potential Project interactions with candidate intermediate components and receptor VCs, and to identify the key potential adverse effects associated with that interaction. The results of the scoping exercise were circulated for review and comment by the EA Working Group, and feedback from that process has been integrated into the Application/EIS.

Table 10.4-2 provides an impact scoping matrix of Project components and physical activities that have a possible or likely interaction with surface water hydrology. A full impact scoping matrix for all candidate intermediate and receptor VCs is provided in Chapter 6, Assessment Methodology (Table 6.4-1).

Interactions between the Project and surface water hydrology were assigned a colour code as follows:

- Likely (black): These include the Project components and activities that:
  - redirect the flow pathways (e.g., surface water diversions);
  - change the natural runoff coefficient of a subcatchment area (e.g., construction of the Brucejack Mine Site buildings);
  - alter the timing of streamflows (e.g., the water treatment plant); and
  - affect channel morphology and/or glaciers (e.g., roads).
- Possible (grey): If no mitigation measure is in place several Project components and activities could potentially affect surface water hydrology. The likelihood, as well as the temporal and spatial scales, of these effects are much less than those of the activities with likely (black) interactions. For example, installation of the transmission line and its associated towers could potentially affect channel morphology if best practice measures are not employed.
- Not expected (white): Interactions coded as not expected, are considered to have no potential for adverse effects on a subject area, and are not considered further.

Table 10.4-2. Interaction of Project Components and Physical Activities with Surface Water Hydrology

Project Components and Physical Activities by Phase	Intermediate Component
Construction Phase	
Activities at existing adit	
Air transport of personnel and goods	
Avalanche control	
Chemical and hazardous material storage, management and handling	
Construction of back-up diesel power plant	
Construction of Bowser Aerodrome	
Construction of detonator storage area	
Construction of electrical tie-in to BC Hydro grid	
Construction of electrical substation at mine site	
Construction of equipment laydown areas	
Construction of helicopter pad	
Construction of incinerators	
Construction of Knipple Transfer Area	

(continued)

Table 10.4-2. Interaction of Project Components and Physical Activities with Surface Water Hydrology (continued)

Project Components and Physical Activities by Phase	Intermediate Component
Construction Phase (cont'd)	
Construction of local site roads	
Construction of mill building (electrical induction furnace, backfill paste plant, warehouse, mill/concentrator)	
Construction of mine portal and ventilation shafts	
Construction of Brucejack Operations Camp	
Construction of ore conveyer	
Construction of tailings pipeline	
Construction and decommissioning of Tide Staging Area construction camp	
Construction of truck shop	
Construction and use of sewage treatment plant and discharge	
Construction and use of surface water diversions	
Construction of water treatment plant	
Development of the underground portal and facilities	
Employment and labour	
Equipment maintenance/machinery and vehicle refuelling/fuel storage and handling	
Explosives storage and handling	
Grading of the mine site area	
Helicopter use	
Installation and use of Project lighting	
Installation of surface and underground crushers	
Installation of transmission line and associated towers	
Machinery and vehicle emissions	
Potable water treatment and use	
Pre-production ore stockpile construction	
Procurement of goods and services	
Quarry construction	
Solid waste management	
Transportation of workers and materials	
Underground water management	
Upgrade and use of exploration access road	
Use of Granduc Access Road	
Operation Phase	
Air transport of personnel and goods and use of aerodrome	
Avalanche control	
Backfill paste plant	
Back-up diesel power plant	
Bowser Aerodrome	

(continued)

Table 10.4-2. Interaction of Project Components and Physical Activities with Surface Water Hydrology (continued)

Project Components and Physical Activities by Phase	Intermediate Component
Operation Phase (cont'd)	
Brucejack Access Road use and maintenance	
Brucejack Operations Camp	
Chemical and hazardous material storage, management, and handling	
Concentrate storage and handling	
Contact water management	
Detonator storage	
Discharge from Brucejack Lake	
Electrical induction furnace	
Electrical substation	
Employment and labour	
Equipment laydown areas	
Equipment maintenance/machine and vehicle refueling/fuel storage and handling	
Explosives storage and handling	
Helicopter pad(s)	
Helicopter use	
Knipple Transfer Area	
Machine and vehicle emissions	
Mill building/concentrators	
Non-contact water management	
Ore conveyer	
Potable water treatment and use	
Pre-production ore storage	
Procurement of goods and services	
Project lighting	
Quarry operation	
Sewage treatment and discharge	
Solid waste management/incinerator	
Subaqueous tailings disposal	
Subaqueous waste rock disposal	
Surface crushers	
Tailings pipeline	
Truck shop	
Waste rock transfer pad	
Transmission line operation and maintenance	
Underground backfill tailing storage	
Underground backfill waste rock storage	

(continued)

Table 10.4-2. Interaction of Project Components and Physical Activities with Surface Water Hydrology (continued)

Project Components and Physical Activities by Phase	Intermediate Component
Operation Phase (cont'd)	
Underground crushers	
Underground: drilling, blasting, excavation	
Underground explosives storage	
Underground mine ventilation	
Underground water management	
Use of mine site haul roads	
Use of portals	
Ventilation shafts	
Warehouse	
Water treatment plant	
Closure Phase	
Air transport of personnel and goods	
Avalanche control	
Chemical and hazardous material storage, management, and handling	
Closure of mine portals	
Closure of quarry	
Closure of subaqueous tailing and waste rock storage (Brucejack Lake)	
Decommissioning of Bowser Aerodrome	
Decommissioning of back-up diesel power plant	
Decommissioning of Brucejack Access Road	
Decommissioning of camps	
Decommissioning of diversion channels	
Decommissioning of equipment laydown	
Decommissioning of fuel storage tanks	
Decommissioning of helicopter pad(s)	
Decommissioning of incinerators	
Decommissioning of local site roads	
Decommissioning of mill building	
Decommissioning of ore conveyer	
Decommissioning of Project lighting	
Decommissioning of sewage treatment plant and discharge	
Decommissioning of surface crushers	
Decommissioning of surface explosives storage	
Decommissioning of tailings pipeline	
Decommissioning of transmission line and ancillary structures	
Decommissioning of underground crushers	

(continued)

Table 10.4-2. Interaction of Project Components and Physical Activities with Surface Water Hydrology (completed)

Project Components and Physical Activities by Phase	Intermediate Component
Closure Phase (cont'd)	
Decommissioning of waste rock transfer pad	
Decommissioning of water treatment plant	
Employment and labour	
Helicopter use	
Machine and vehicle emissions	
Procurement of goods and services	
Removal or treatment of contaminated soils	
Solid waste management	
Transportation of workers and materials (mine site and access roads)	
Post-closure Phase	
Discharge from Brucejack Lake	
Employment and labour	
Environmental monitoring	
Procurement of goods and services	
Subaqueous tailing and waste rock storage	
Underground mine	

Notes:
Black = likely interaction between project components/physical activities and an intermediate component.
Grey = possible interaction between project components/physical activities and an intermediate component.
White = unlikely interaction between project components/physical activities and an intermediate component.

10.4.1.2 Consultation Feedback on Intermediate Components

The importance of investigating the hydrological regime and effects of the Project on surface water hydrology were emphasized through the consultation process with aboriginal groups and the provincial and federal governments. Aboriginal people's concerns regarding surface water hydrology include:

- warmer temperatures and increased winter rain in the last 20 years—rivers do not freeze up anymore, making them unsafe to cross (Appendix 25-B, Skii km Lax Ha Traditional Knowledge/ Traditional Use Report);
- more extreme flood events on the rivers (Rescan 2013); and
- general decline in lake levels (Rescan 2013).

As previously mentioned (Section 10.2), several provincial and national regulations are applicable to surface water hydrology for mine developments.

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

All sub-components of surface water hydrology were considered in the assessment. These include streamflows, channel morphology, and glaciers (Table 10.4-3).

No potential sub-component was excluded from further assessment.

Table 10.4-3. Surface Water Hydrology Intermediate Components Included in the Application/EIS

Surface Water Hydrology Sub-component	Identified by*				Rationale for Inclusion
	AG	G	P/S	IM	
Streamflows	x	x		x	Vital elements of aquatic environmental health (natural flow regime paradigm)
Channel Morphology				x	Pertains to the long-term hydrology and sediment transport regime within a watershed; reflects the aquatic habitat within the streams
Glaciers		x			Contribute to the hydrologic cycle, interact with streamflows and channel morphology

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

10.4.2 Assessment Boundaries for Surface Water Hydrology

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

10.4.2.1 Spatial Boundaries

The spatial boundaries of the surface water hydrology effects assessment are presented in Figure 10.4-2. The spatial boundaries include the baseline watershed boundaries and have considered watersheds over a range of spatial scales from local (i.e., immediately downstream of Brucejack Lake) to regional (i.e., Unuk River at the international border). The spatial boundaries have been divided into an LSA and RSA, which are discussed further below.

<u>Local Study Area</u>

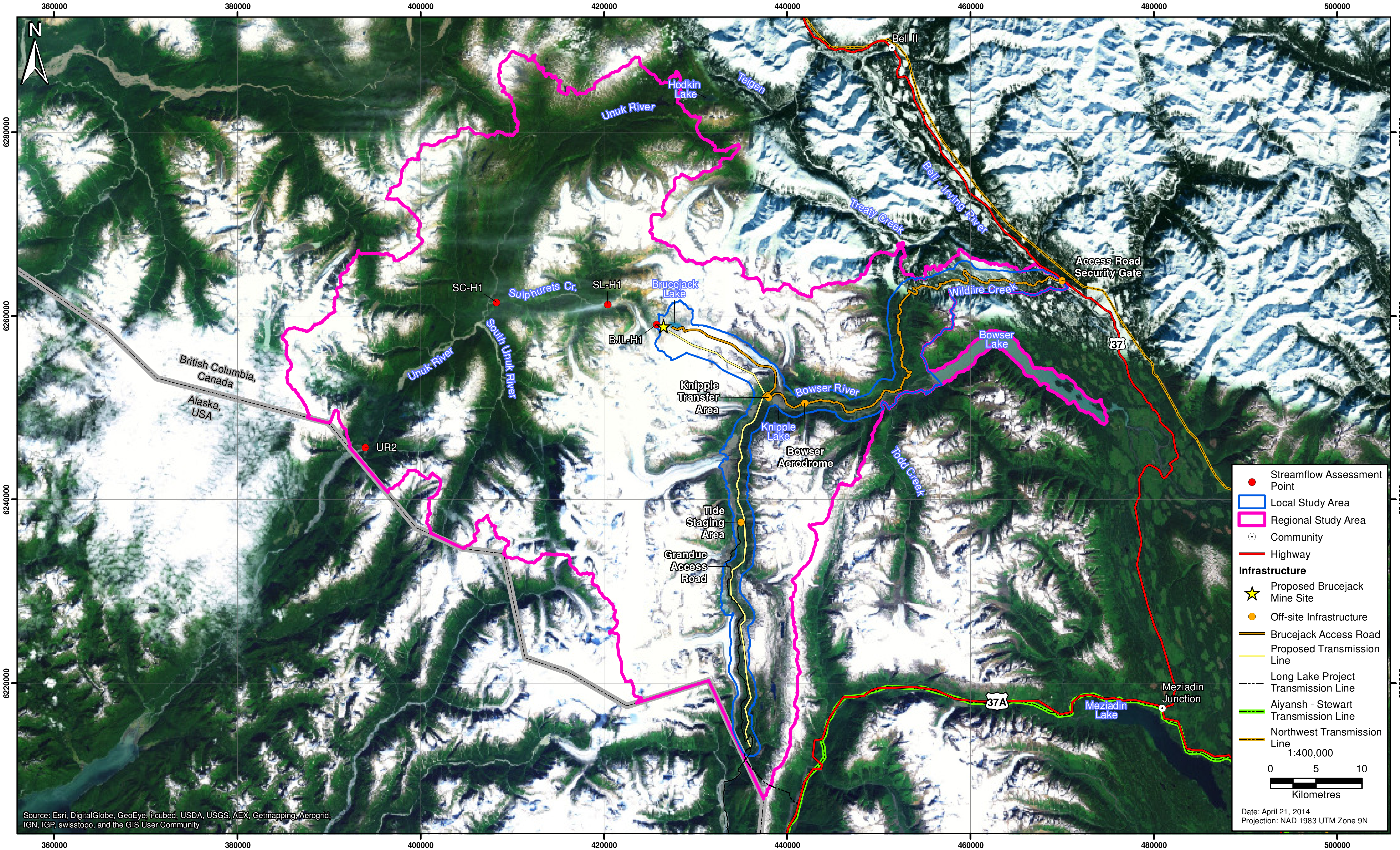
The surface water hydrology LSA (Figure 10.4-2) is based on the proposed Project footprint and activities that could affect surface water quantity. The LSA proposed for surface water hydrology effects includes:

- Brucejack Lake area,
- the access road corridor, and
- the transmission line corridor.

The LSA boundary at Brucejack Lake area follows the boundary of the Brucejack Creek watershed at hydrometric station BJL-H1 (Figure 10.4-2).

The LSA regions for the access road and transmission line corridors were identified as buffer zones around the access road and transmission line. At this stage, the Project-related activities in these areas are not expected to directly interfere with streamflows. Therefore, these LSA regions did not include the entire watershed boundaries of streams within them, and quantitative watershed-based studies were not performed in such areas. Rather, qualitative assessments were performed in these areas.

Figure 10.4-2
Regional and Local Study Areas for Surface Water Hydrology Effects Assessment



Regional Study Area

The surface water hydrology RSA (Figure 10.4-2) encompasses the LSA and includes the following watersheds:

- Unuk River: There is a potential for change to surface water hydrology due to the Project within the Unuk River at the international border.
- Bowser River (downstream of Knipple Lake), Scott Creek, Todedada Creek, and Wildfire Creek: There is a potential for change to surface water hydrology due to the upgrade, maintenance, and use of the Brucejack Access Road through these watersheds.
- Salmon River and Bowser River (upstream of Knipple Lake): These watersheds may potentially be affected by the Brucejack Transmission Line. Similar to the Unuk River watershed, potential effects on Salmon River would have international implications.

Effects related to historical activities are assumed to be included in the baseline studies conducted for this section (Appendix 10-A, 2012 Surface Water Hydrology Baseline Report).

10.4.2.2 Temporal Boundaries

Temporal boundaries for the surface water hydrology assessment are aligned with the four phases of the Project:

- **Construction:** 2 years;
- **Operation:** 22 years;
- **Closure:** 2 years (includes project decommissioning, abandonment and reclamation activities); and
- **Post-closure:** minimum of 3 years (includes ongoing reclamation activities and post-closure monitoring).

The surface water hydrology effects assessment considered monthly changes in water quantity. Baseline water quantity data and Project design information were used to support water balance modelling at a monthly scale during the Construction, Operation, Closure, and Post-closure phases. Regional analysis was used to estimate hydrologic events with return periods beyond observed flows during the baseline monitoring program.

10.4.3 Identifying Key Potential Effects on Surface Water Hydrology

For the purpose of this assessment three potential effects of the Project on surface water hydrology were identified. These effects are:

- streamflow changes—Project components and activities could potentially alter streamflow indicators including annual runoff, monthly distribution of runoff, peak flows, and low flows;
- channel morphology alteration—drainage morphology and stability may be affected due to the Project activities; and
- effects on glaciers—Project activities may have effects on glacier ablation.

Assessment of these three effects provides a comprehensive understanding of the potential impacts on surface water hydrology. Effects of different components and physical activities of the Project on surface water hydrology during the Construction, Operation, Closure and Post-closure phases are identified and ranked in Table 10.4-4. Project components and physical activities are categorized into four major groups including:

- Brucejack Access Road;
- Brucejack Mine Site Water Management Components and Activities;
- Bowser Aerodrome and Knipple Transfer Area; and
- Brucejack Transmission Line.

Table 10.4-4. Ranking Potential Effects on Surface Water Hydrology

Project Components and Physical Activities by Phase	Potential Effects on Surface Water Hydrology		
	Change Streamflow	Alter Channel Morphology	Affect Glaciers
Construction Phase			
Brucejack Access Road	● (yellow)	● (red)	● (red)
Brucejack Mine Site Water Management Components and Activities	● (red)	● (green)	● (yellow)
Bowser Aerodrome and Knipple Transfer Area	● (green)	● (red)	○
Brucejack Transmission Line	● (green)	● (red)	○
Operation Phase			
Brucejack Access Road	● (yellow)	● (red)	● (red)
Brucejack Mine Site Water Management Components and Activities	● (red)	● (green)	● (yellow)
Bowser Aerodrome and Knipple Transfer Area	● (green)	● (red)	○
Transmission Line	● (green)	● (yellow)	○
Closure Phase			
Brucejack Access Road	● (yellow)	● (red)	● (red)
Brucejack Mine Site Water Management Components and Activities	● (red)	● (green)	● (yellow)
Bowser Aerodrome and Knipple Transfer Area	● (green)	● (red)	○
Brucejack Transmission Line	● (green)	● (yellow)	○
Post-closure Phase			
Brucejack Access Road	● (yellow)	● (red)	● (yellow)
Brucejack Mine Site Water Management Components and Activities	● (red)	● (green)	● (yellow)
Bowser Aerodrome and Knipple Transfer Area	● (green)	● (yellow)	○
Brucejack Transmission Line	● (green)	● (yellow)	○

Notes:
○ = *No detectable interaction anticipated.*
● (green) = *Negligible to minor adverse effect expected; implementation of best practices, standard mitigation and management measures; no monitoring required, no further consideration warranted.*
● (yellow) = *Potential moderate adverse effect requiring unique active management/monitoring/mitigation; warrants further consideration.*
● (red) = *Key interaction resulting in potential significant major adverse effect or significant concern; warrants further consideration.*

Project components and physical activities that could potentially cause key effects on surface water hydrology during different phases of the Project (red interactions in Table 10.4-4) are described in this section.

10.4.3.1 Construction

Brucejack Mine Site water management components and activities—including construction, use of surface water diversions, and underground water management—could potentially cause key effects on streamflow. The Project increases the Brucejack Creek flows by pumping groundwater from the underground mine to Brucejack Lake. Surface water diversions could change the flow pathways, and thereby the streamflow volumes. Likewise, underground water management has the potential to affect the streamflow, especially during periods of low flow.

Maintenance and upgrades of the Brucejack Access Road (e.g., maintenance of culverts and bridges) could potentially result in key effects on channel morphology by altering the natural sediment transport regime. Similarly, construction of the Bowser Aerodrome and Brucejack Transmission Line towers within the floodplain of Bowser River and its tributaries could potentially affect the channel morphology.

Knipple Glacier ablation could potentially be affected by increased dust and debris due to operation of the access road.

10.4.3.2 Operation

Streamflows could be affected by several Brucejack Mine Site water management components and activities during Operation. The Project increases the Brucejack Creek flows by pumping groundwater from the underground mine to Brucejack Lake. Key effects could also be caused by diversion of contact and non-contact water. These diversions could change the flow pathway and hence the streamflow volumes. Underground water management has the potential to affect the streamflow, especially the low flows. Different influent and effluent flow rates at the water treatment plant could also affect the streamflows. In addition, if the geometry of the lake outlet is altered (i.e., the lake volume-outflow relation is changed), instantaneous flows (i.e., peak flows) could be changed.

Annual maintenance and use of the Brucejack Access Road (e.g., maintenance of culverts and bridges) could potentially affect the channel morphology by altering the sediment feed into the channels, and by changing the channel hydraulics at the stream crossings. Likewise, the Bowser Aerodrome and Knipple Transfer Area on Bowser River banks could affect the natural sediment transport regime, especially during extreme flood events.

Knipple Glacier ablation could be affected by increased dust and debris due to operation of the Brucejack Access Road.

10.4.3.3 Closure and Reclamation

Closure of the Brucejack Mine Site water management infrastructure could affect the streamflows. During closure and reclamation the Project will decrease the discharge of groundwater from the mine site into Brucejack Lake as operations shift to flooding of the underground mine.

Decommissioning of the Brucejack Access Road, Bowser Aerodrome, and Knipple Transfer Area could affect the channel morphology regime developed during the 22-year life of mine operations. Removal of the roads and associated hydraulic structures could alter sediment transport within the system thus affecting channel morphology. Similarly, decommissioning of the access road may affect the glacier ablation.

10.4.3.4 Post-closure

If the geometry of the lake outlet is altered (i.e., the lake volume-outflow relation is changed) instantaneous flows (i.e., peak flows) could be different from the baseline conditions. Similarly, if the flow pathways are not restored to baseline conditions, streamflows could change permanently.

There is a potential for permanent effects of the decommissioned Brucejack Access Road on channel morphology if the closure and reclamation plan is not implemented in accordance with specified best practices.

10.5 PREDICTIVE STUDY METHODS FOR SURFACE WATER HYDROLOGY

10.5.1 Streamflows

The Project components and physical activities within the mine site area have the potential to affect the streamflows in Brucejack Creek (Table 10.4-4). Therefore, a streamflow assessment point was selected on Brucejack Creek (hydrometric station BJL-H1) within the LSA. In order to quantify the effects on downstream locations, further assessment points were considered within the RSA. These include assessment points in Sulphurets Lake (hydrometric station SL-H1), Sulphurets Creek (hydrometric station SC-H1), and the Unuk River at the international border (water quality sampling point UR2). These assessment points are shown in Figure 10.5-1. The methods used to estimate the effects of the Project on streamflows at different assessment points are described in the following sections.

Due to the inherent data and modelling uncertainty in hydrologic studies, it is reasonable to account for at least a 5% error in streamflow estimates. Therefore, it was assumed that any streamflow change of less than 5%, compared to the baseline flows, could be an artifact of data and/or modelling uncertainty; therefore, it was considered a negligible change.

10.5.1.1 Brucejack Creek

BGC developed a water balance model (WBM) for the Brucejack Creek watershed (i.e., drainage area of Station BJL-H1/BJL-H1a in Figure 10.3-3). Details of the model, including input data, modelling assumptions, calibration, and results are available in Appendix 5-C, Brucejack Project Environmental Assessment — Water Management Plan (BGC 2014). The WBM was set up in MS Excel™ with monthly time-steps, and used data including:

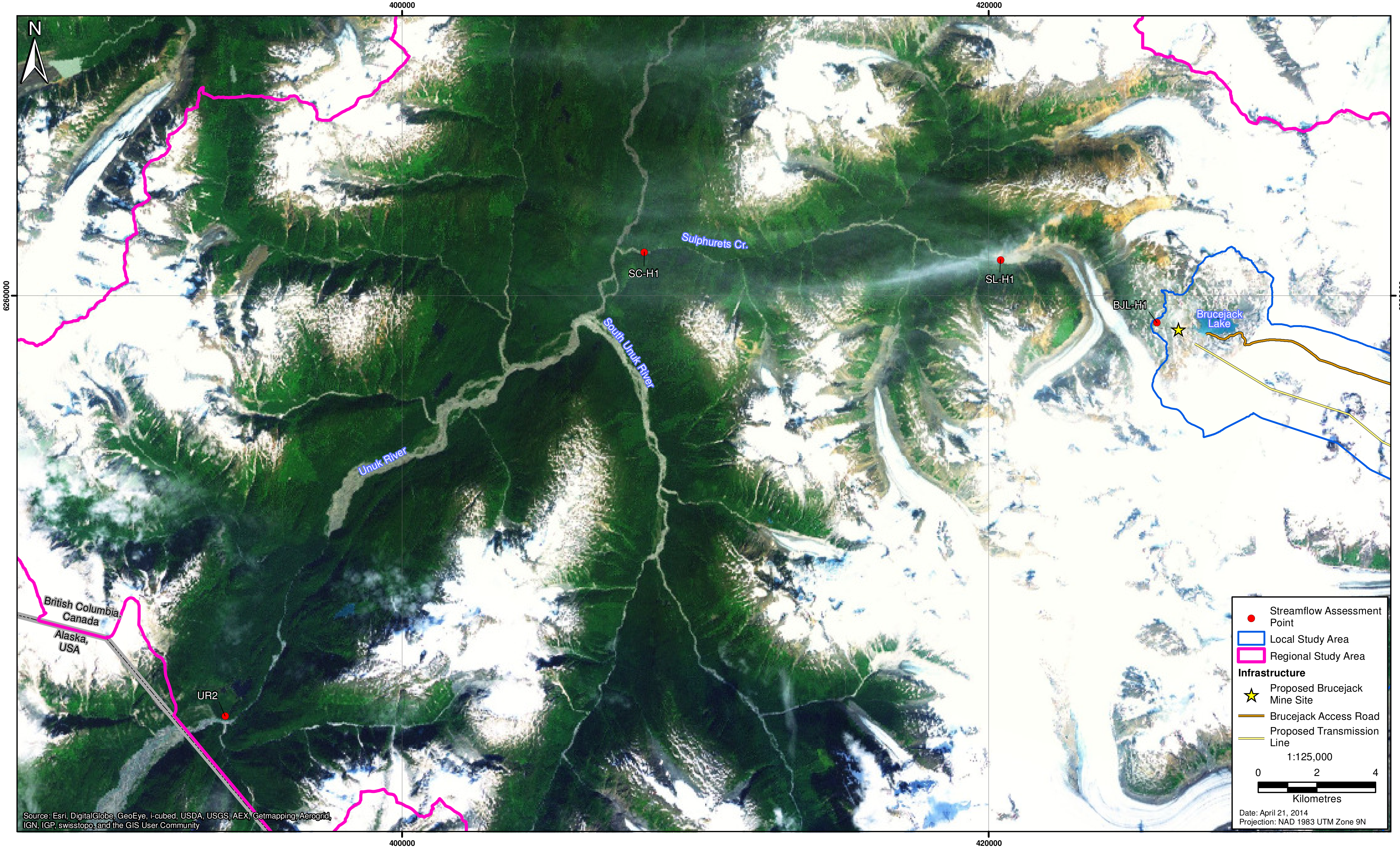
- underground mine design and mill feed rates;
- site-specific and long-term climate dataset, including precipitation, potential evaporation, and temperature;
- precipitation frequency analysis;
- drainage areas and runoff coefficients;
- estimated groundwater flows and seepage rates;
- process plant water balance model (including freshwater make-up requirement); and
- assumed tailings densities and properties.

The WBM evaluated the streamflows at BJL-H1 under nine hydrologic scenarios including:

- ***Base Case***: The average annual precipitation is assumed to occur on the watershed (1,740 mm/year). Further, it is assumed that East Lake does not contribute to Brucejack Lake.
- ***100-Year Dry***: All parameters are similar to the base case except a 100-year-dry annual precipitation condition (1,240 mm/year).
- ***100-Year Wet***: All parameters are similar to the base case except a 100-year-wet annual precipitation conditions (2,710 mm/year).
- ***Low Dry Density:*** All parameters are similar to the base case except a dry density of 1.4 t/m^3 for tailings (instead of 1.6 t/m^3 in the base case scenario).

Figure 10.5-1
Streamflow Assessment Points within the Local and Regional Study Areas

ERM



- ***High Hydraulic Conductivity:*** All parameters are similar to the base case except hydraulic conductivity values are increased by a factor of five.
- ***Low Hydraulic Conductivity:*** All parameters are similar to the base case except hydraulic conductivity values are decreased by a factor of five.
- ***East Lake Contribution:*** All parameters are similar to the base case except runoff from East Lake is assumed to flow into Brucejack Lake during May.
- ***Early Snowmelt:*** All parameters are similar to the base case except the snowmelt pattern is changed in a way that snowmelt before June was increased by 50%.
- ***Variable Flows***: All parameters are similar to the base case except using a variable annual precipitation time series based on a synthetic streamflow dataset.

The model estimated monthly flows at Station BJL-H1 at baseline conditions, as well as flows during the Construction, Operation, Closure, and Post-closure phases of the Project under the nine aforementioned precipitation scenarios. These results were used to estimate the effects of the Project on annual runoff (Section 10.6.1.1), monthly distribution of runoff (Section 10.6.1.2), and low flows (Section 10.6.1.4). In relation to the duration of the Operation phase for the Project, the most recent feasibility study report from June 2014 (Appendix 5-A) describes an 18 year Operation phase, while an earlier feasibility study (Tetra Tech 2013) had identified a 22 year Operation phase. For the purposes of this environmental assessment, an Operation phase of 22 years has been used as this is expected to provide, overall, a more conservative effects assessment associated with greater waste rock and tailings production and longer period of active disturbance prior to reclamation activities.

Streamflows in Brucejack Creek have little fluctuation during March, which represents the lowest monthly flow in a year (Appendix 10-A, 2012 Surface Water Hydrology Baseline Report). Therefore, in this assessment, monthly flows in March were used to represent the low flow indicator of streamflows.

Since the WBM is set up based on monthly water quantity data, it may not reliably estimate the effects of the Project on peak flows. The magnitude and timing of peak flows within a watershed are a function of three parameters. These are the:

- magnitude and timing of storm, as well as snowmelt and glacier melt, events;
- catchment area of the watershed; and
- runoff coefficient within the watershed.

Among these three parameters, the last two are more likely to potentially be affected by the Project. The catchment area and runoff coefficient of the Brucejack Lake watershed will be impacted due to the Project. The runoff coefficient within the disturbed area of the Project will be changed due to surface disturbance. In addition, contact water from such disturbed areas is planned to be collected and stored in a pond. These changes were considered in estimating the effects of the Project on peak flows (Section 10.6.1.3).

10.5.1.2 Sulphurets Creek and Unuk River

In estimating the effects of the Project on streamflows within the Sulphurets Creek and Unuk River, it was assumed that the flow volumes, and thereby the effects of the Project on flow volumes, were proportional to the catchment areas. This assumption is reasonable for annual and monthly flows in watersheds with similar hydrologic characteristics. Measured runoff values in Brucejack Creek, Sulphurets Creek, and Unuk River watersheds (Table 10.3-5) indicate that runoff in the Brucejack watershed is lower than those in Sulphurets Creek and Unuk River watersheds. Therefore, the abovementioned assumption is conservative for estimating effects of the Project on streamflows within the Sulphurets Creek and Unuk River.

Such an assumption is not applicable to peak flows that follow a non-linear relationship with the catchment area (Table 10.3-6). However, the predictive study results in Section 10.6.1.3 show negligible effects on peak flows at BJL-H1. Therefore, effects on peak flows at downstream locations were also deemed negligible.

10.5.1.3 Bowser River, Scott Creek, Todedada Creek, Wildfire Creek, and Salmon River

No Project component or physical activity within these watersheds is expected to alter the streamflows.

10.5.2 Channel Morphology

A preliminary study was performed to assess the potential effects of the Project on channel morphology (Appendix 10-B, Potential Interactions between the Brucejack Gold Mine Project and Channel Morphology: Preliminary Results). The access road begins at Highway 37 at about 400 masl, passes through the drainages of Wildfire Creek, Todedada Creek, Scott Creek, and Bowser River and then ascends the Knipple Glacier to the mine site.

There are a total of 246 culverts and 14 bridges on the access road. Channel morphology of the watersheds at these crossings, as well as their sensitivity to potential effects of the access road operation and maintenance are assessed in Appendix 10-B.

10.5.3 Glaciers

10.5.3.1 Effects of the Access Road on Knipple Glacier

Debris on the glacier surface, due to vehicle traffic or maintenance of the glacier portion of the Brucejack Access Road, may change glacier melt. Potential effects of the Project on the glaciohydrology of the Knipple Glacier are assessed in Appendix 10-C, Potential Interactions between the Glacier Section of Brucejack Access Road and Knipple Glacier Ablation. Glacier melt is controlled by the energy balance at the glacier surface, with a net positive energy flux at the glacier surface resulting in melt. Net positive conditions (resulting in a net loss in water equivalence) in this region dominantly occur during the ablation season, approximately April to September (Rescan 2013), so the impacts during the ablation season were the primary focus of this assessment.

An initial approximation of the impacts of the access road on glaciohydrology was quantified in Appendix 10-C. The total expected summer ablation on the Knipple Glacier was estimated. Summer glacier ablation data from the nearby Mitchell Glacier (Rescan 2013), located approximately 8 km to the northwest of the Knipple Glacier were used as a proxy for the ablation that can be expected on Knipple Glacier. A quadratic equation relating the melt to elevation, derived for the Mitchell Glacier (Rescan 2013), was used as an approximation to assess the summer ablation for the baseline condition and during the life of the Project (Appendix 10-C).

10.5.3.2 Effects of the Fugitive Dust Deposition on Knipple Glacier

Increased glacier melt due to changes in albedo caused by dust on the ice surface is documented in the literature, but mainly mineral or biogenic dust has been studied (Paul, Kääb, and Heberli 2007; Oerlemans, Giesen, and Van Den Broeke 2009). Dust associated with mine operation is referred to as either fugitive dust or non-fugitive dust; only fugitive dusts were considered to be a potential significant source for local dustfall (Chapter 7, Air Quality Predictive Study). Activities such as blasting, bulldozing, grading, and material handling, as well as road dust, are common sources of fugitive dust. Fugitive dusts that are mechanically generated typically tend to have larger particle sizes when compared to non-mechanically generated dust. For example, unpaved industrial road dust contains approximately 3% $PM_{2.5}$ and 28% PM_{10} (following the calculations outlined in *AP-42 - Compilation of Air Pollutant Emission Factors* [US EPA 1995] Section 13.2.2-2), while blasting fugitive dust contains 3% $PM_{2.5}$ and 52% PM_{10} (US EPA 1995; Chapter 11.9-1). Due to the larger particle size, fugitive dust tends to deposit within a short distance with limited vertical movement.

For the Project, primary sources of fugitive dust include unpaved road dust (on gravel roads) and ore processing activities. It was assumed that the segments of the access road built on the glacier do not generate dust as the road would be covered with snow or ice. For the air quality dispersion modelling, the Knipple Glacier segment of the road was conservatively assumed to be shorter than the planned length of this segment. That is, the dust generating segment of the road was increased.

Since most of the Brucejack Mine Site dust sources are either occurring underground or mitigated (e.g., with baghouses), the increase in dustfall levels at the mine site area is not expected to extend to the glaciers. The specific mitigation measures for dust deposition are listed in Chapter 7, Air Quality Predictive Study (Section 7.7) and in the Air Quality Management Plan (Section 29.2).

10.6 PREDICTIVE STUDY RESULTS FOR SURFACE WATER HYDROLOGY

10.6.1 Change in Streamflows

10.6.1.1 Mean Annual Flow

The WBM simulation results (Appendix 5-C, Brucejack Project Environmental Assessment — Water Management Plan) were used to estimate the effects of the Project on mean annual flows. The effects during each phase of the Project under the base case scenario (i.e., average annual precipitation; Figure 10.6-1; Table 10.6-1) are:

- Construction: the mean annual flows are increased by 7%, i.e., no negative effect on mean annual flows is expected;
- Operation: the mean annual flows are increased by 6%, i.e., no negative effect on mean annual flows is expected;
- Closure: the mean annual flows are expected to be decreased by 1%. The estimated change is within the range of data and modelling uncertainty (5%; Section 10.5.1). In addition, the effects will only occur during two years of closure. Therefore, the effect is considered to be negligible; and
- Post-closure: the mean annual flows are estimated to be similar to the baseline flows (i.e., 0.2% decrease in annual flows). That is, changes from the baseline condition are expected to be negligible.

Table 10.6-1 and Figures 10.6-2 to 10.6-9 show that none of the other eight scenarios are expected to result in negative effects on mean annual flows in excess of the range of data and modelling uncertainty (5%; Section 10.5.1). Likewise, the increase in mean annual flows during Construction and Operation is limited to 10% under all scenarios except for the high hydraulic conductivity scenario where the mean annual flows are expected to be increased by up to 20% during Construction, and 25% during Operation.

WBM results (Appendix 5-C, Brucejack Project Environmental Assessment — Water Management Plan) do not include output from the simulated streamflows during the Closure and Post-closure phases of the Project under the low dry density, high hydraulic conductivity, and low hydraulic conductivity scenarios. The Closure and Post-closure streamflows under these scenarios were assumed to be the same as those of the base case scenario.

Figure 10.6-1

Mean Annual Flows in Brucejack Creek (Station BJL-H1) for the Baseline Condition and during Different Phases of the Project under the Base Case Scenario

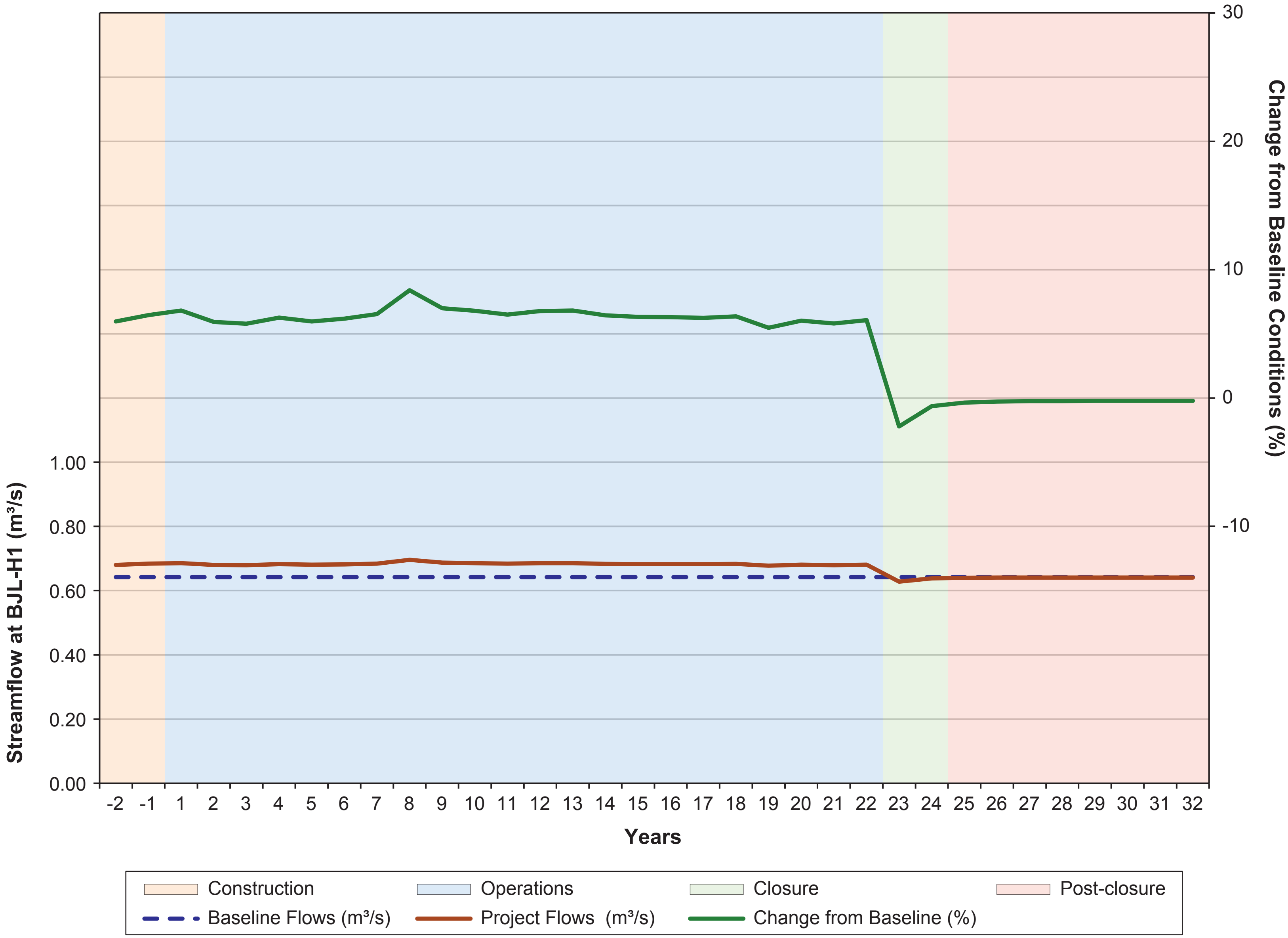


Table 10.6-1. Changes in Annual Flows in Brucejack Creek (BJL-H1) Compared to Baseline Conditions

Assessment Scenario	Construction			Operation			Closure			Post-closure		
	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)
Average Annual Precipitation (Base Case)	0.642	0.686	6.7%	0.642	0.683	6.4%	0.642	0.633	-1.4%	0.642	0.641	-0.2%
100-Year Dry Annual Precipitation	0.418	0.462	10.3%	0.418	0.459	9.8%	0.418	0.408	-2.4%	0.418	0.417	-0.4%
100-Year Wet Annual Precipitation	0.799	0.843	5.4%	0.799	0.840	5.1%	0.799	0.790	-1.1%	0.799	0.798	-0.2%
Average Annual Precipitation with Low Dry Density*	0.642	0.686	6.7%	0.642	0.683	6.4%	0.642	0.633*	-1.4%	0.642	0.641*	-0.2%
Average Annual Precipitation with High Hydraulic Conductivity*	0.642	0.772	20.2%	0.642	0.801	24.7%	0.642	0.633*	-1.4%	0.642	0.641*	-0.2%
Average Annual Precipitation with Low Hydraulic Conductivity*	0.642	0.660	2.7%	0.642	0.652	1.5%	0.642	0.633*	-1.4%	0.642	0.641*	-0.2%
Average Annual Precipitation with East Lake Contribution during Freshet	0.670	0.713	6.5%	0.670	0.711	6.1%	0.670	0.660	-1.4%	0.670	0.668	-0.2%
Average Annual Precipitation with 50% Increase in April-May Snowmelt	0.639	0.682	6.8%	0.639	0.680	6.4%	0.639	0.629	-1.6%	0.639	0.637	-0.2%
Variable Annual Precipitation based on Synthetic Long-term Flows	0.643	0.686	6.7%	0.641	0.682	6.6%	0.666	0.656	-1.5%	0.642	0.647	0.8%

** Closure and Post-closure flows were assumed to be similar to those of the average annual precipitation (base case) scenario.*

Figure 10.6-2

Mean Annual Flows in Brucejack Creek (Station BJL-H1) for the Baseline Condition and during Different Phases of the Project under the 100-Year Dry Precipitation Scenario

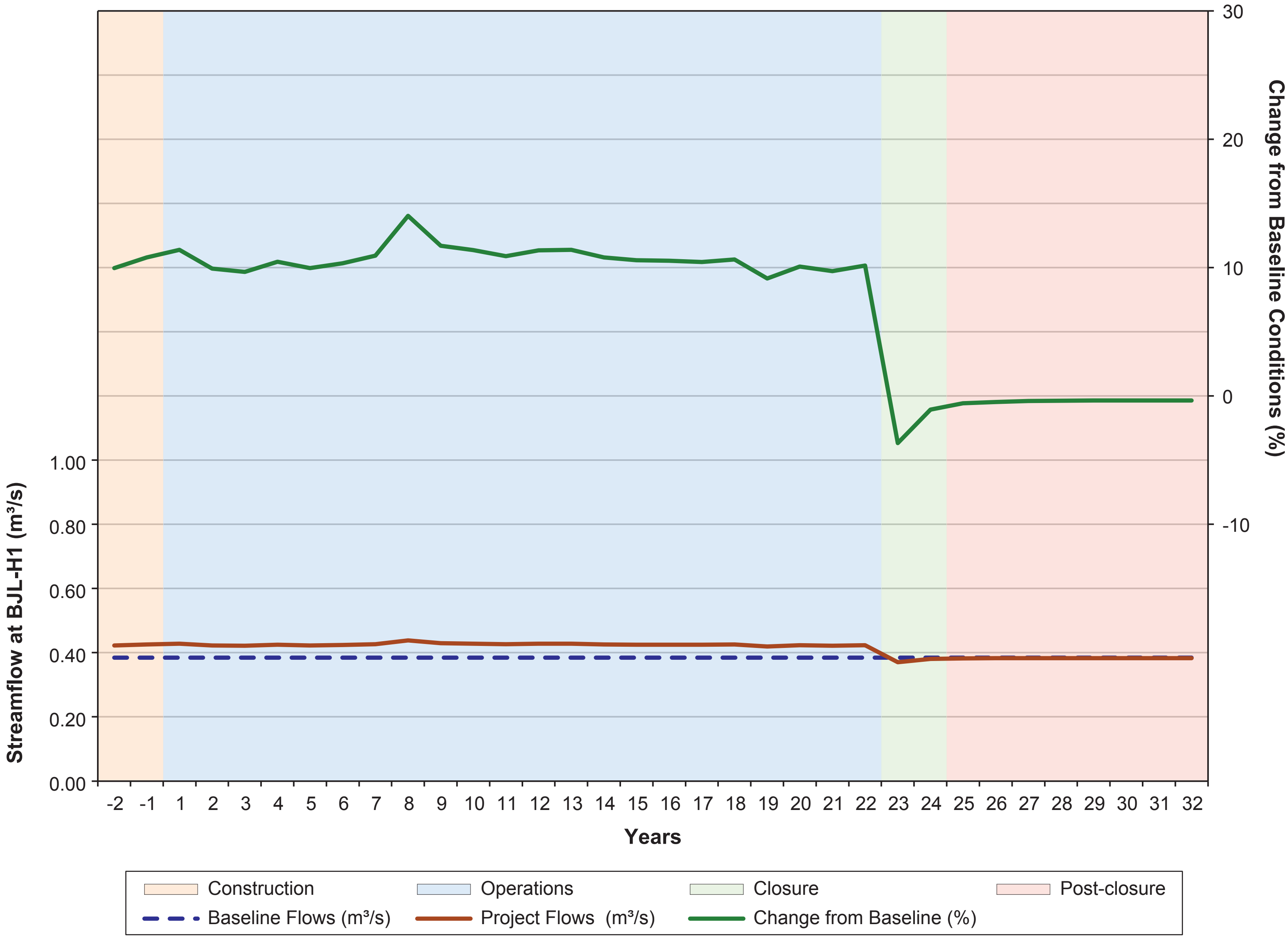


Figure 10.6-3

Mean Annual Flows in Brucejack Creek (Station BJL-H1) for the Baseline Condition and during Different Phases of the Project under the 100-Year Wet Precipitation Scenario

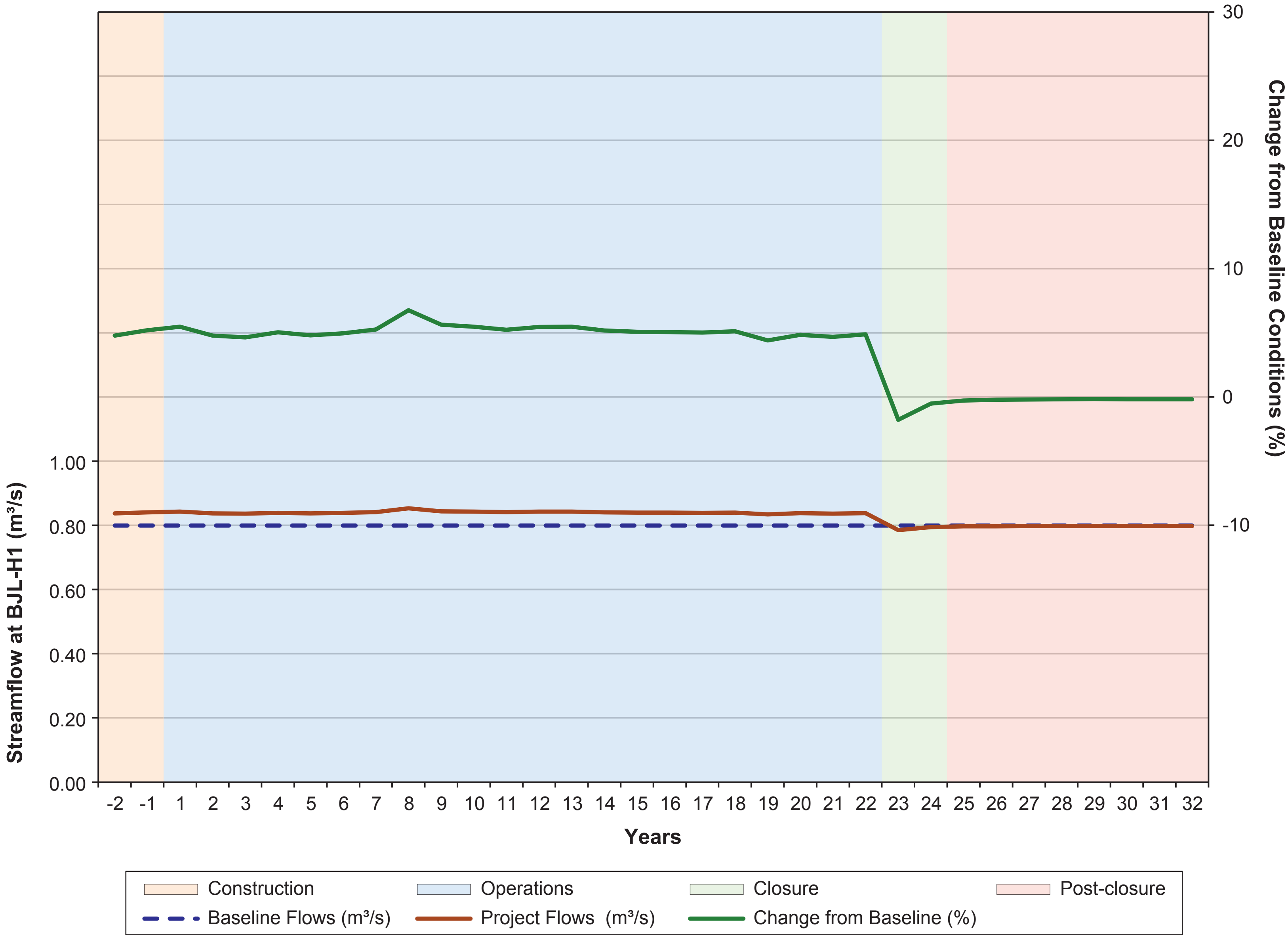


Figure 10.6-4

Mean Annual Flows in Brucejack Creek (Station BJL-H1) for the Baseline Condition and during Different Phases of the Project under the Low Dry Density Scenario

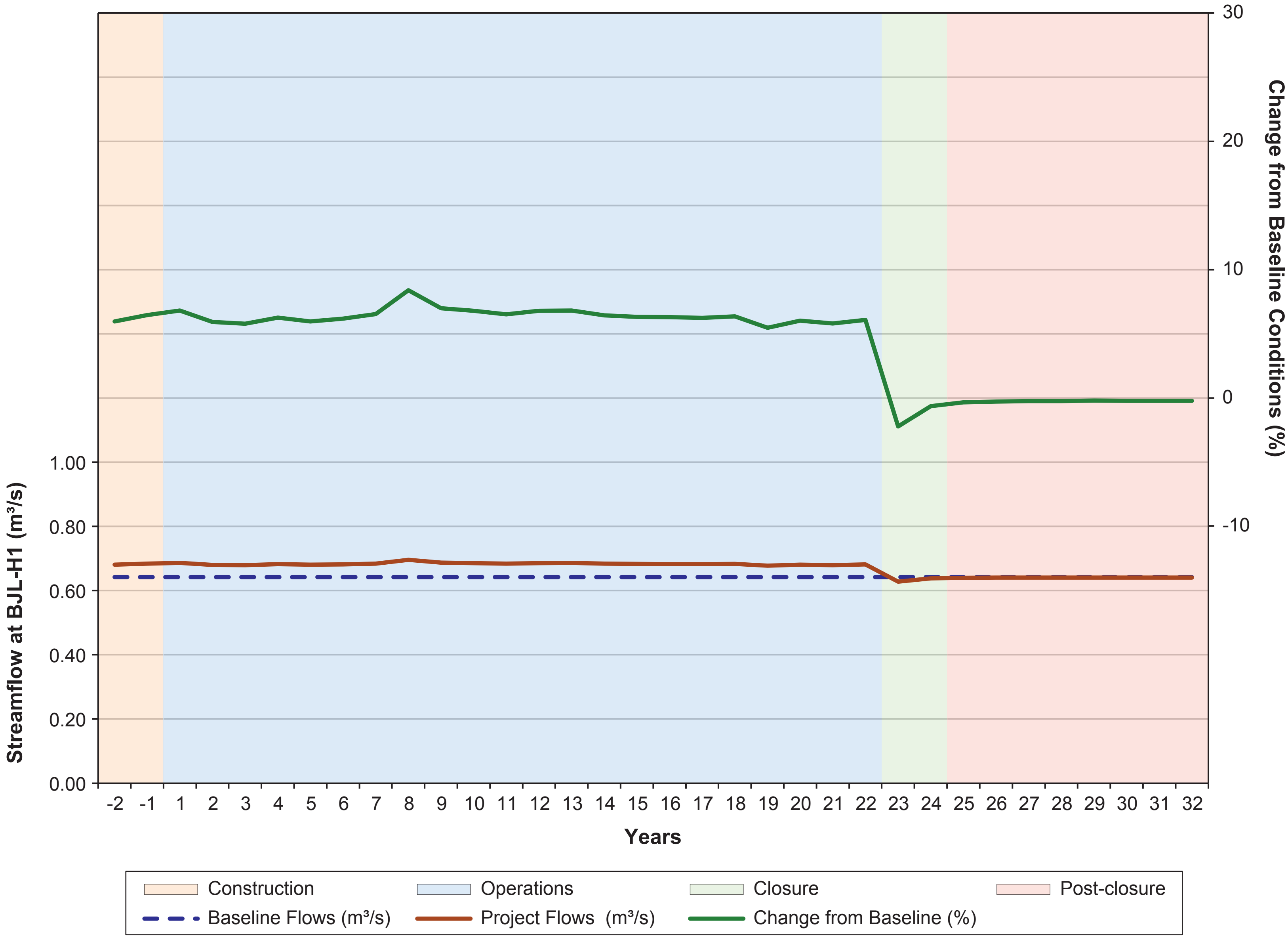


Figure 10.6-5

Mean Annual Flows in Brucejack Creek (Station BJL-H1) for the Baseline Condition and during Different Phases of the Project under the High Hydraulic Conductivity Scenario

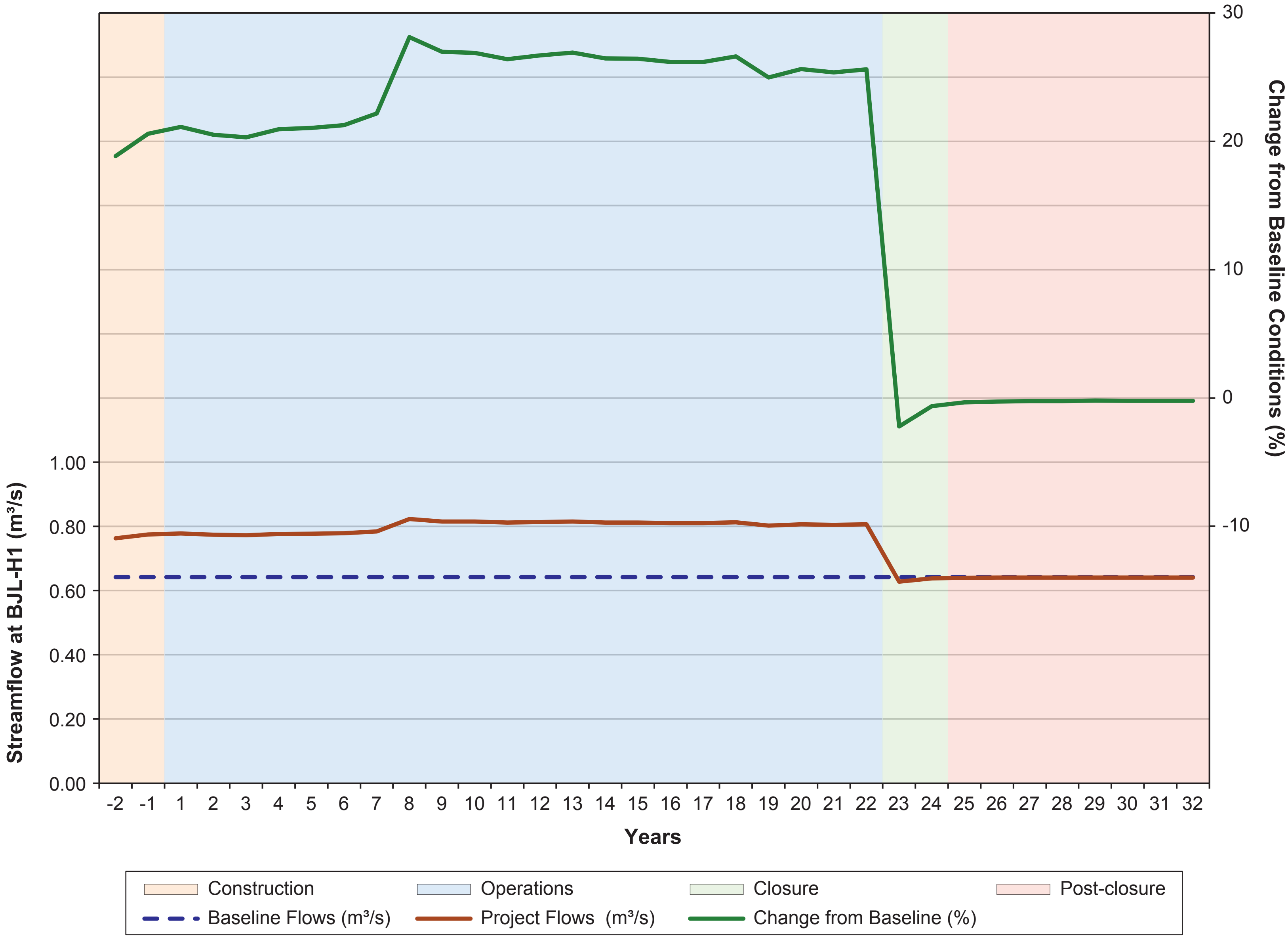


Figure 10.6-6

Mean Annual Flows in Brucejack Creek (Station BJL-H1) for the Baseline Condition and during Different Phases of the Project under the Low Hydraulic Conductivity Scenario

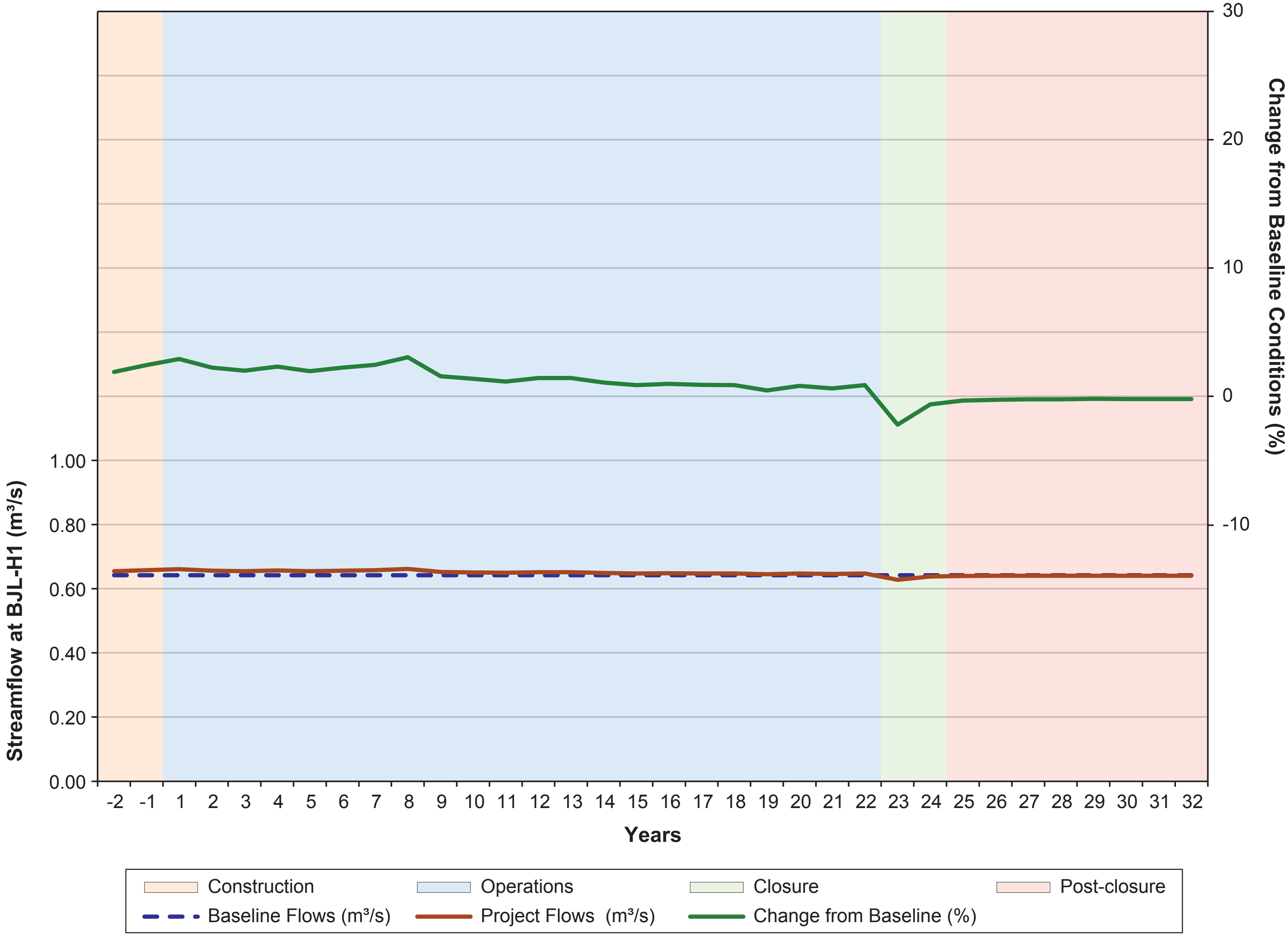


Figure 10.6-7
Mean Annual Flows in Brucejack Creek (Station BJL-H1) for the Baseline Condition and during Different Phases of the Project with East Lake Contribution

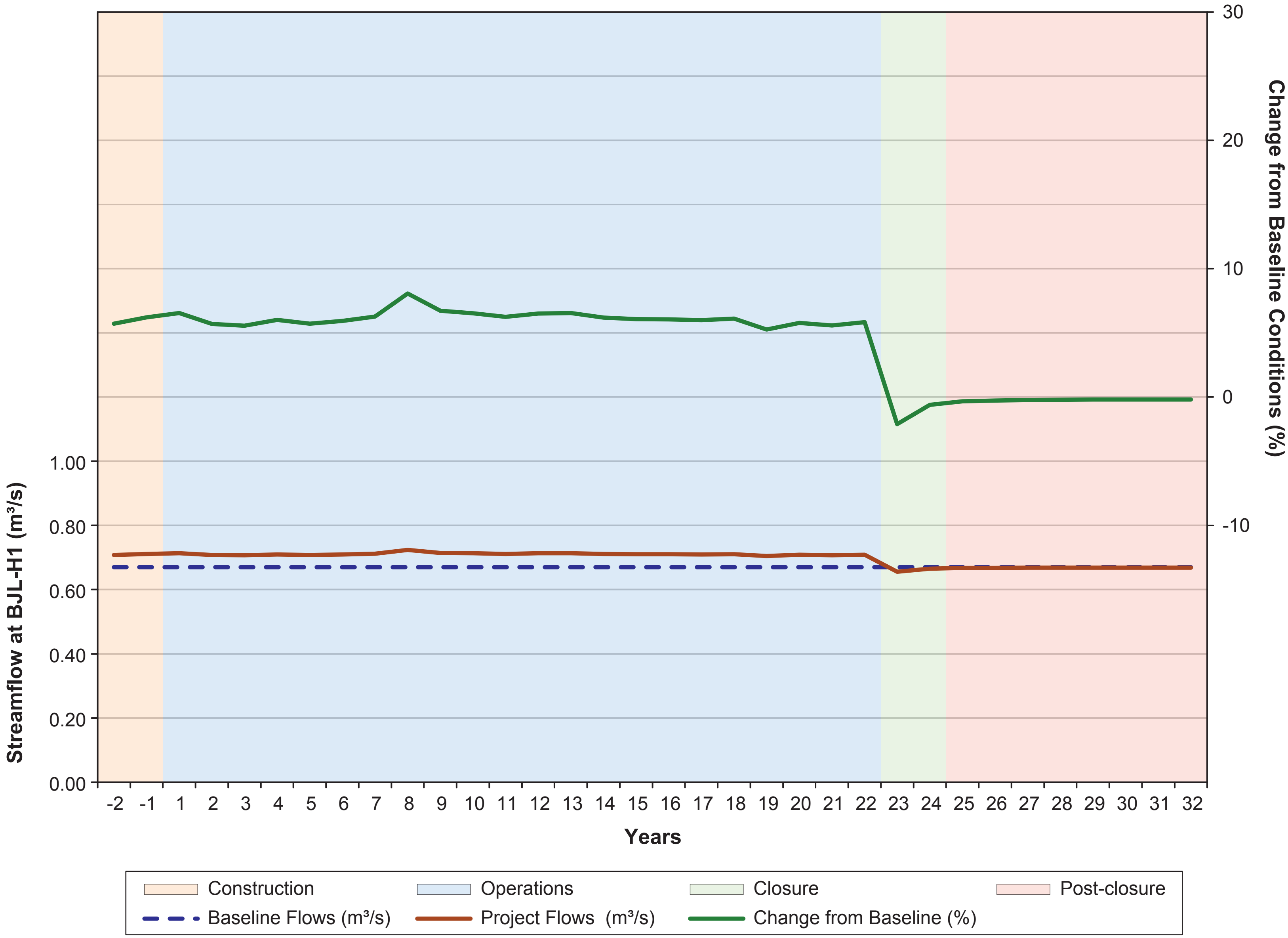


Figure 10.6-8

Mean Annual Flows in Brucejack Creek (Station BJL-H1) for the Baseline Condition and during Different Phases of the Project under the Increased Snowmelt in April-May Scenario

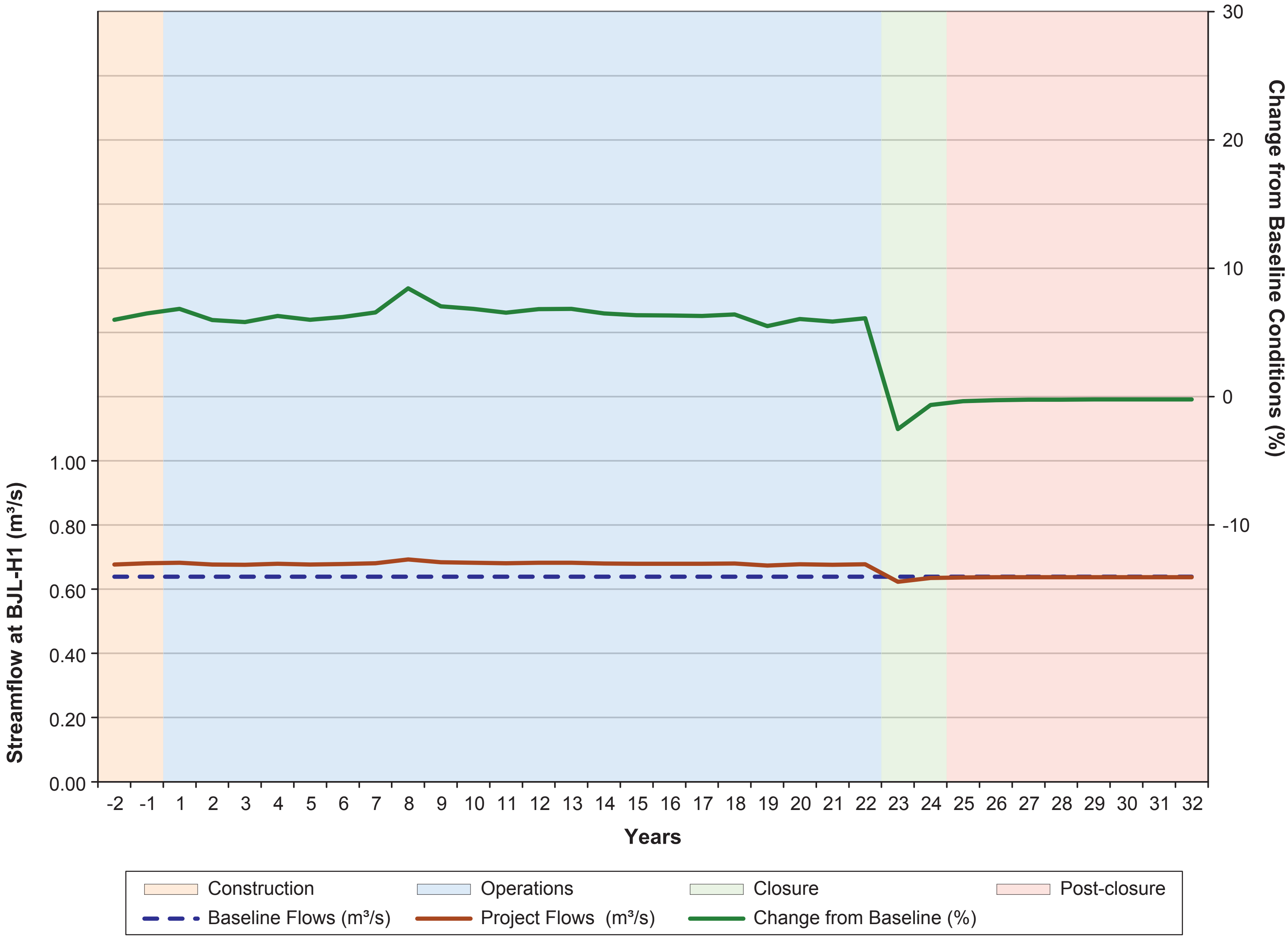
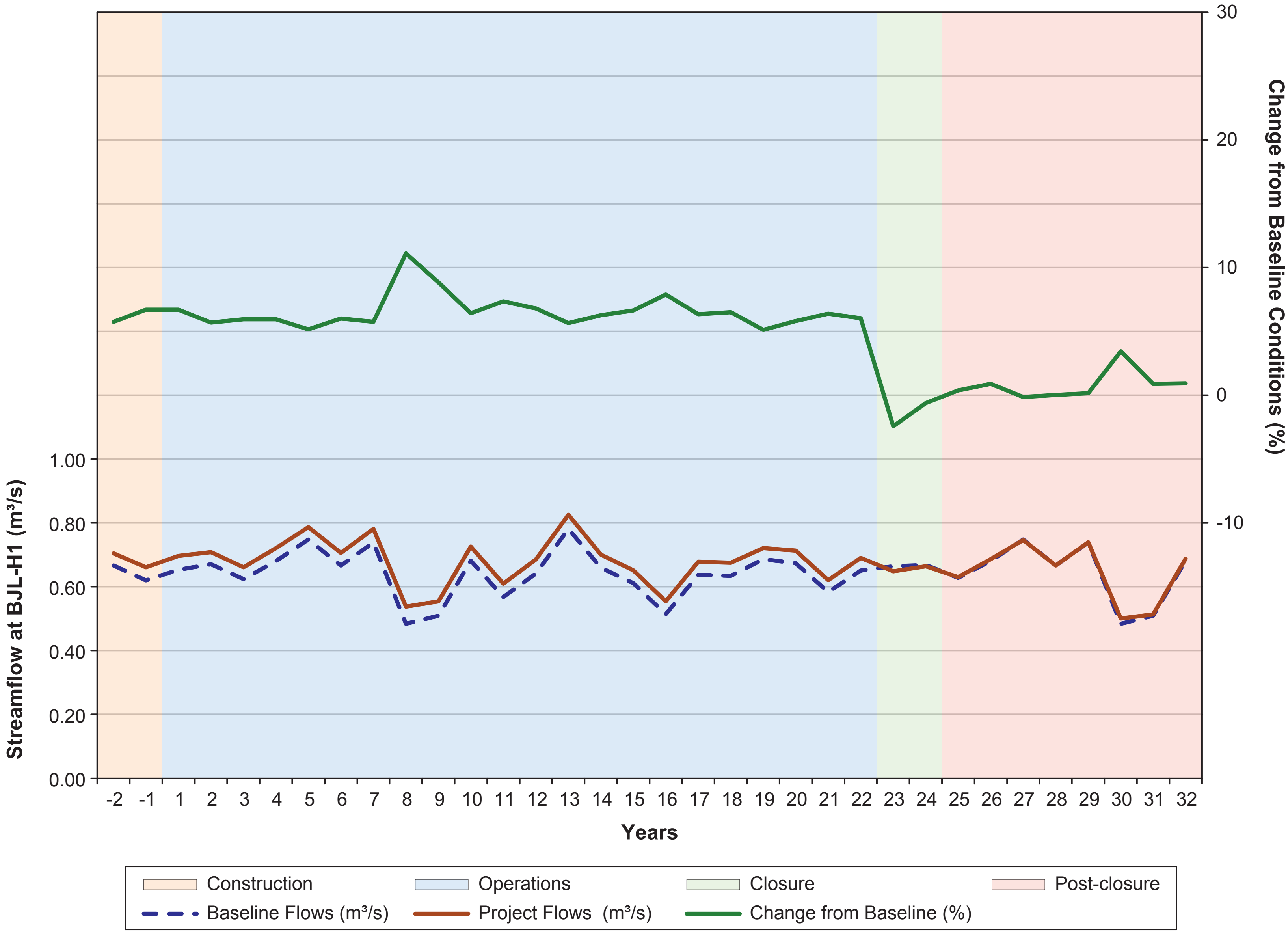


Figure 10.6-9

Mean Annual Flows in Brucejack Creek (Station BJL-H1) for the Baseline Condition and during Different Phases of the Project under the Synthetic Variable Flow Scenario



The drainage areas of SL-H1 (84 km^2), SC-H1 (298 km^2), and UR2 (1,480 km^2) are 7, 25, and 126 times of the BJL-H1 drainage area (11.7 km^2), respectively. That is, during the Construction and Operation phases, the maximum annual flow increase estimated at BJL-H1 (7%) under the base case scenario is estimated to cause a negligible flow increase in downstream watersheds including 0.9% (SL-H1), 0.3% (SC-H1), and less than 0.1% (UR2). These estimated changes are within the data and modelling uncertainty range (5%; Section 10.5.1). During Closure, the 1% annual flow reduction at BJL-H1 will cause a flow reduction of less than 1% in all downstream assessment points (i.e., SL-H1, SC-H1, and UR2). These figures indicate that the changes at these locations are negligible.

10.6.1.2 Monthly Distribution of Runoff

Flows in Brucejack Creek (Station BJL-H1) were simulated for the 9 assessment scenarios (Appendix 5-C, Brucejack Project Environmental Assessment — Water Management Plan). The results are summarized in Tables 10.6-2 to 10.6-5 for different phases of the Project. Monthly distribution of annual flow during different phases of the Project was compared to the monthly distribution of runoff at the baseline condition (Figures 10.6-10 to 10.6-18). As expected, the underground seepage affects the monthly distribution of runoff by flattening the monthly distribution of annual runoff. That is, the contribution of low flow months (i.e., November to April) are increased and those of the high flow months (i.e., June to August) are decreased. However, the changes in contribution of each month in respect to annual runoff did not change more than 3% when compared to the baseline conditions. Therefore, effects of the Project on monthly distribution of annual runoff were considered to be negligible.

10.6.1.3 Peak Flow

The magnitude and timing of peak flows within a watershed are a function of three parameters:

- the magnitude and timing of storm, as well as snowmelt and glacier melt, events;
- the catchment area of the watershed; and
- the runoff coefficient within the watershed.

Among these parameters, the catchment area and runoff coefficient of the Brucejack Creek watershed will be changed by the Project. The runoff coefficient within the disturbed area of the Project will be changed (generally increased) due to surface disturbance activities. In addition, contact water from such disturbed areas is planned to be collected and stored in a pond.

Effects of these two processes on the magnitude and timing of the peak flows is expected to be in two opposite directions. That is, the first process is expected to increase the magnitude of peak flows and decrease the lag time of peak flows, and the second process would decrease the magnitude and increase the lag time. Further, the catchment area of contact waters is 0.15 km^2, which is less than 2% of the BJL-H1 catchment area (11.7 km^2). Therefore, the effects of the Project on peak flows are expected to be negligible.

10.6.1.4 Low Flow

Based on the observation of monthly flows at baseline conditions, as well as the simulated monthly flows under the nine streamflow simulation scenarios, March flows represent the lowest monthly flows annually. Further, significant intra-month variations were not expected, nor were observed, in the baseline flows during March (Appendix 10-A, 2012 Surface Water Hydrology Baseline Report). Therefore, the March monthly flows were used as an estimate for low flows during different phases of the Project in this assessment. The WBM simulation results (Appendix 5-C, Brucejack Project Environmental Assessment — Water Management Plan) were used to estimate the effects of the Project on low flows.

Table 10.6-2. Monthly Flows in Brucejack Creek (BJL-H1) for the Baseline Condition and during Construction

	January			February			March			April			May			June		
Assessment Scenario	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)
Average Annual Precipitation (Base Case)	0.095	0.158	66.5%	0.085	0.138	61.8%	0.069	0.111	61.7%	0.127	0.171	34.3%	0.647	0.702	8.5%	1.831	1.872	2.2%
100-Year Dry Annual Precipitation	0.093	0.156	68.3%	0.083	0.136	63.3%	0.069	0.111	61.7%	0.125	0.169	34.8%	0.615	0.670	8.8%	1.699	1.740	2.4%
100-Year Wet Annual Precipitation	0.103	0.166	61.1%	0.092	0.144	57.4%	0.071	0.113	59.6%	0.133	0.176	32.8%	0.697	0.753	7.9%	1.998	2.037	2.0%
Average Annual Precipitation with Low Dry Density	0.095	0.158	66.5%	0.085	0.138	61.8%	0.069	0.111	61.7%	0.127	0.171	34.3%	0.647	0.702	8.5%	1.831	1.872	2.2%
Average Annual Precipitation with High Hydraulic Conductivity	0.095	0.240	152.8%	0.085	0.209	144.9%	0.069	0.171	148.2%	0.127	0.242	90.4%	0.647	0.785	21.3%	1.831	1.962	7.1%
Average Annual Precipitation with Low Hydraulic Conductivity	0.095	0.125	31.8%	0.085	0.110	28.8%	0.069	0.088	27.9%	0.127	0.147	15.6%	0.647	0.677	4.7%	1.831	1.847	0.8%
Average Annual Precipitation with East Lake Contribution during Freshet	0.095	0.158	66.5%	0.085	0.138	61.8%	0.069	0.111	61.7%	0.127	0.171	34.3%	0.974	1.029	5.6%	1.831	1.872	2.2%
Average Annual Precipitation with 50% Increase in April-May Snowmelt	0.094	0.158	67.2%	0.085	0.137	62.4%	0.069	0.111	61.7%	0.164	0.209	27.4%	0.992	1.052	6.0%	2.273	2.305	1.4%
Variable Annual Precipitation based on Synthetic Long-term Flows	0.095	0.158	66.7%	0.085	0.138	61.9%	0.069	0.111	61.7%	0.127	0.171	34.3%	0.651	0.706	8.4%	1.852	1.893	2.2%

	July			August			September			October			November			December		
Assessment Scenario	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)
Average Annual Precipitation (Base Case)	1.628	1.672	2.7%	1.581	1.621	2.6%	0.964	1.004	4.1%	0.409	0.449	9.6%	0.150	0.187	25.0%	0.121	0.163	35.2%
100-Year Dry Annual Precipitation	0.718	0.759	5.7%	0.476	0.515	8.1%	0.550	0.592	7.6%	0.347	0.387	11.7%	0.133	0.171	28.3%	0.111	0.153	38.6%
100-Year Wet Annual Precipitation	1.741	1.786	2.6%	1.937	1.981	2.3%	2.033	2.076	2.1%	0.485	0.522	7.8%	0.169	0.206	21.9%	0.131	0.174	32.2%
Average Annual Precipitation with Low Dry Density	1.628	1.672	2.7%	1.581	1.621	2.6%	0.964	1.004	4.1%	0.409	0.449	9.6%	0.150	0.187	25.0%	0.121	0.163	35.2%
Average Annual Precipitation with High Hydraulic Conductivity	1.628	1.769	8.7%	1.581	1.720	8.8%	0.964	1.105	14.6%	0.409	0.536	31.0%	0.150	0.262	74.8%	0.121	0.240	98.9%
Average Annual Precipitation with Low Hydraulic Conductivity	1.628	1.646	1.1%	1.581	1.594	0.9%	0.964	0.977	1.4%	0.409	0.423	3.4%	0.150	0.163	8.8%	0.121	0.137	13.7%
Average Annual Precipitation with East Lake Contribution during Freshet	1.628	1.672	2.7%	1.581	1.621	2.6%	0.964	1.004	4.1%	0.409	0.449	9.6%	0.150	0.187	25.0%	0.121	0.163	35.2%
Average Annual Precipitation with 50% Increase in April-May Snowmelt	1.480	1.528	3.2%	0.957	0.995	4.0%	0.884	0.926	4.7%	0.401	0.440	9.8%	0.148	0.185	25.4%	0.119	0.162	35.6%
Variable Annual Precipitation based on Synthetic Long-term Flows	1.643	1.687	2.7%	1.746	1.787	2.3%	1.027	1.067	3.9%	0.429	0.468	9.1%	0.152	0.189	24.6%	0.122	0.164	34.8%

Table 10.6-3. Monthly Flows in Brucejack Creek (BJL-H1) for the Baseline Condition and during Operation

	January			February			March			April			May			June		
Assessment Scenario	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)
Average Annual Precipitation (Base Case)	0.095	0.138	45.1%	0.085	0.125	46.7%	0.069	0.106	53.9%	0.127	0.167	31.1%	0.647	0.699	8.0%	1.831	1.870	2.1%
100-Year Dry Annual Precipitation	0.093	0.136	46.3%	0.083	0.123	47.8%	0.069	0.106	53.9%	0.125	0.165	31.6%	0.615	0.667	8.4%	1.699	1.739	2.3%
100-Year Wet Annual Precipitation	0.103	0.146	41.5%	0.092	0.131	43.5%	0.071	0.108	52.4%	0.133	0.172	29.8%	0.697	0.749	7.5%	1.998	2.036	1.9%
Average Annual Precipitation with Low Dry Density	0.095	0.138	45.1%	0.085	0.125	46.7%	0.069	0.106	53.9%	0.127	0.167	31.1%	0.647	0.699	8.0%	1.831	1.870	2.1%
Average Annual Precipitation with High Hydraulic Conductivity	0.095	0.240	152.2%	0.085	0.224	162.5%	0.069	0.202	192.7%	0.127	0.272	114.2%	0.647	0.815	25.9%	1.831	1.994	8.9%
Average Annual Precipitation with Low Hydraulic Conductivity	0.095	0.108	14.0%	0.085	0.096	13.1%	0.069	0.078	13.5%	0.127	0.138	8.4%	0.647	0.669	3.4%	1.831	1.839	0.4%
Average Annual Precipitation with East Lake Contribution during Freshet	0.095	0.138	45.1%	0.085	0.125	46.7%	0.069	0.106	53.9%	0.127	0.167	31.1%	0.974	1.026	5.3%	1.831	1.870	2.1%
Average Annual Precipitation with 50% Increase in April-May Snowmelt	0.094	0.137	45.5%	0.085	0.124	47.1%	0.069	0.106	53.9%	0.164	0.205	25.0%	0.992	1.049	5.7%	2.273	2.303	1.3%
Variable Annual Precipitation based on Synthetic Long-term Flows	0.096	0.139	44.3%	0.086	0.126	46.1%	0.069	0.106	53.5%	0.128	0.168	31.0%	0.648	0.700	8.0%	1.827	1.865	2.1%

	July			August			September			October			November			December		
Assessment Scenario	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)
Average Annual Precipitation (Base Case)	1.628	1.671	2.7%	1.581	1.621	2.5%	0.964	1.005	4.2%	0.409	0.450	9.9%	0.150	0.189	26.2%	0.121	0.162	34.1%
100-Year Dry Annual Precipitation	0.718	0.758	5.6%	0.476	0.515	8.1%	0.550	0.592	7.7%	0.347	0.388	12.0%	0.133	0.173	29.6%	0.111	0.152	37.4%
100-Year Wet Annual Precipitation	1.741	1.784	2.5%	1.937	1.977	2.1%	2.033	2.073	2.0%	0.485	0.525	8.3%	0.169	0.208	23.2%	0.131	0.173	31.3%
Average Annual Precipitation with Low Dry Density	1.628	1.671	2.7%	1.581	1.621	2.5%	0.964	1.005	4.2%	0.409	0.450	9.9%	0.150	0.189	26.2%	0.121	0.162	34.1%
Average Annual Precipitation with High Hydraulic Conductivity	1.628	1.804	10.8%	1.581	1.757	11.1%	0.964	1.144	18.6%	0.409	0.577	41.1%	0.150	0.305	103.9%	0.121	0.272	125.1%
Average Annual Precipitation with Low Hydraulic Conductivity	1.628	1.638	0.6%	1.581	1.587	0.4%	0.964	0.970	0.6%	0.409	0.416	1.7%	0.150	0.157	4.7%	0.121	0.131	8.5%
Average Annual Precipitation with East Lake Contribution during Freshet	1.628	1.671	2.7%	1.581	1.621	2.5%	0.964	1.005	4.2%	0.409	0.450	9.9%	0.150	0.189	26.2%	0.121	0.162	34.1%
Average Annual Precipitation with 50% Increase in April-May Snowmelt	1.480	1.527	3.1%	0.957	0.995	3.9%	0.884	0.926	4.8%	0.401	0.441	10.1%	0.148	0.187	26.6%	0.119	0.160	34.5%
Variable Annual Precipitation based on Synthetic Long-term Flows	1.561	1.604	2.8%	1.429	1.471	3.3%	1.135	1.177	4.3%	0.428	0.468	9.9%	0.153	0.192	25.7%	0.123	0.164	33.6%

Table 10.6-4. Monthly Flows in Brucejack Creek (BJL-H1) for the Baseline Condition and during Closure

	January			February			March			April			May			June		
Assessment Scenario	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)
Average Annual Precipitation (Base Case)	0.095	0.077	-19.4%	0.085	0.068	-20.7%	0.069	0.052	-24.1%	0.127	0.109	-14.4%	0.647	0.629	-2.7%	1.831	1.811	-1.1%
100-Year Dry Annual Precipitation	0.093	0.074	-20.1%	0.083	0.066	-21.3%	0.069	0.052	-24.1%	0.125	0.107	-14.7%	0.615	0.597	-2.9%	1.699	1.679	-1.2%
100-Year Wet Annual Precipitation	0.103	0.085	-17.9%	0.092	0.074	-19.3%	0.071	0.054	-23.5%	0.133	0.114	-13.8%	0.697	0.680	-2.5%	1.998	1.977	-1.0%
Average Annual Precipitation with Low Dry Density*	0.095	0.077	-19.4%	0.085	0.068	-20.7%	0.069	0.052	-24.1%	0.127	0.109	-14.4%	0.647	0.629	-2.7%	1.831	1.811	-1.1%
Average Annual Precipitation with High Hydraulic Conductivity*	0.095	0.077	-19.4%	0.085	0.068	-20.7%	0.069	0.052	-24.1%	0.127	0.109	-14.4%	0.647	0.629	-2.7%	1.831	1.811	-1.1%
Average Annual Precipitation with Low Hydraulic Conductivity*	0.095	0.077	-19.4%	0.085	0.068	-20.7%	0.069	0.052	-24.1%	0.127	0.109	-14.4%	0.647	0.629	-2.7%	1.831	1.811	-1.1%
Average Annual Precipitation with East Lake Contribution during Freshet	0.095	0.077	-19.4%	0.085	0.068	-20.7%	0.069	0.052	-24.1%	0.127	0.109	-14.4%	0.974	0.957	-1.8%	1.831	1.811	-1.1%
Average Annual Precipitation with 50% Increase in April-May Snowmelt	0.094	0.075	-19.9%	0.085	0.067	-21.1%	0.069	0.052	-24.1%	0.164	0.108	-34.0%	0.992	0.967	-2.6%	2.273	2.428	6.8%
Variable Annual Precipitation based on Synthetic Long-term Flows	0.094	0.076	-19.8%	0.085	0.067	-21.0%	0.069	0.052	-24.1%	0.127	0.108	-14.5%	0.651	0.633	-2.8%	1.860	1.840	-1.1%

	July			August			September			October			November			December		
Assessment Scenario	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)
Average Annual Precipitation (Base Case)	1.628	1.608	-1.2%	1.581	1.581	0.1%	0.964	0.950	-1.5%	0.409	0.397	-3.1%	0.150	0.141	-5.9%	0.121	0.114	-5.4%
100-Year Dry Annual Precipitation	0.718	0.698	-2.8%	0.476	0.458	-4.0%	0.550	0.533	-3.0%	0.347	0.334	-3.6%	0.133	0.125	-6.6%	0.111	0.104	-5.9%
100-Year Wet Annual Precipitation	1.741	1.721	-1.1%	1.937	1.938	0.0%	2.033	2.019	-0.7%	0.485	0.472	-2.6%	0.169	0.160	-5.3%	0.131	0.125	-5.0%
Average Annual Precipitation with Low Dry Density*	1.628	1.608	-1.2%	1.581	1.581	0.1%	0.964	0.950	-1.5%	0.409	0.397	-3.1%	0.150	0.141	-5.9%	0.121	0.114	-5.4%
Average Annual Precipitation with High Hydraulic Conductivity*	1.628	1.608	-1.2%	1.581	1.581	0.1%	0.964	0.950	-1.5%	0.409	0.397	-3.1%	0.150	0.141	-5.9%	0.121	0.114	-5.4%
Average Annual Precipitation with Low Hydraulic Conductivity*	1.628	1.608	-1.2%	1.581	1.581	0.1%	0.964	0.950	-1.5%	0.409	0.397	-3.1%	0.150	0.141	-5.9%	0.121	0.114	-5.4%
Average Annual Precipitation with East Lake Contribution during Freshet	1.628	1.608	-1.2%	1.581	1.581	0.1%	0.964	0.950	-1.5%	0.409	0.397	-3.1%	0.150	0.141	-5.9%	0.121	0.114	-5.4%
Average Annual Precipitation with 50% Increase in April-May Snowmelt	1.480	1.397	-5.6%	0.957	0.879	-8.2%	0.884	0.862	-2.5%	0.401	0.387	-3.4%	0.148	0.138	-6.2%	0.119	0.113	-5.6%
Variable Annual Precipitation based on Synthetic Long-term Flows	1.648	1.629	-1.2%	1.695	1.676	-1.1%	1.035	1.018	-1.6%	0.435	0.423	-3.0%	0.152	0.143	-5.9%	0.122	0.116	-5.4%

** Closure flows were assumed to be similar to those of the average annual precipitation (base case) scenario.*

Table 10.6-5. Monthly Flows in Brucejack Creek (BJL-H1) for the Baseline Condition and at Post-closure

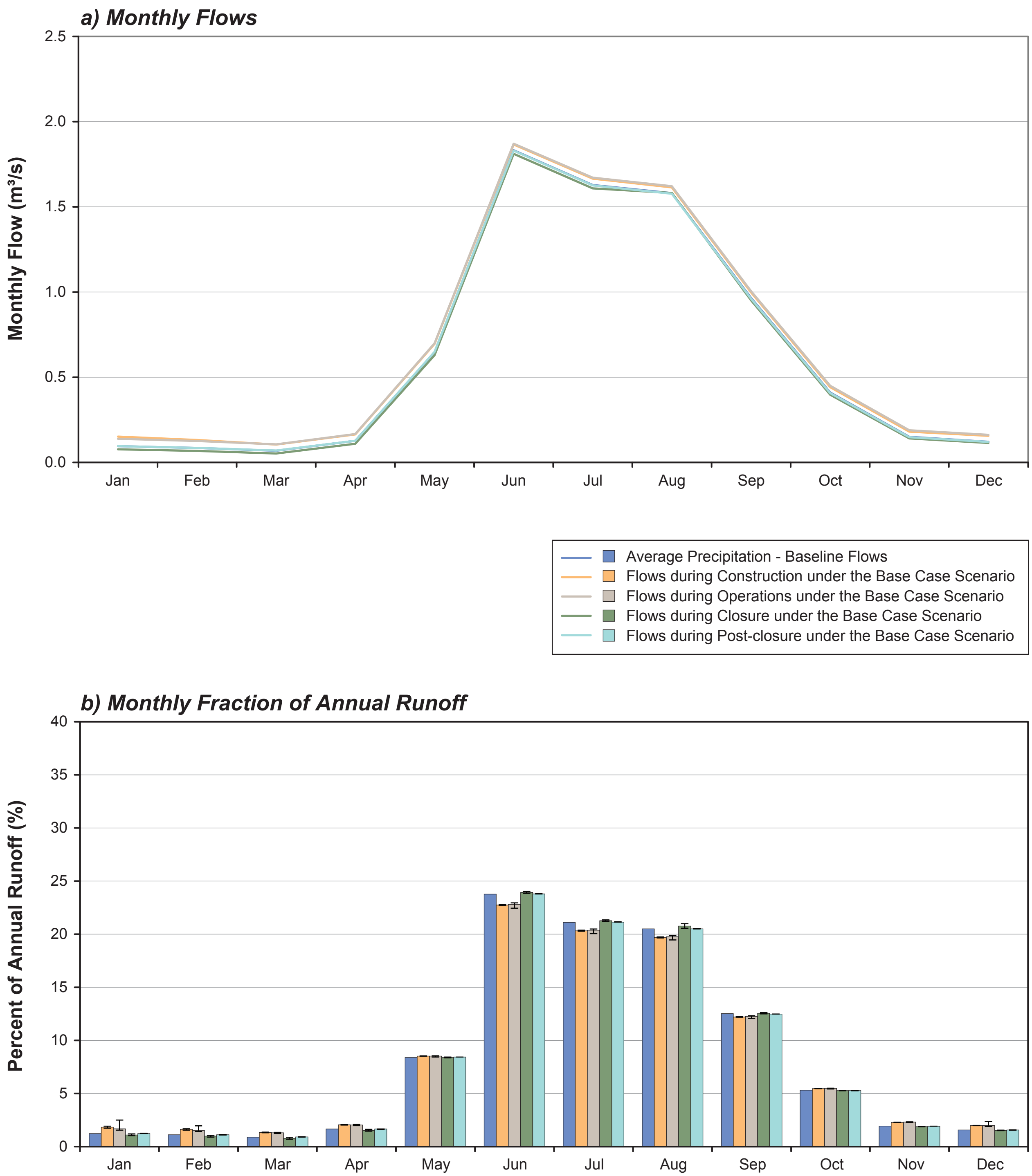
	January			February			March			April			May			June		
Assessment Scenario	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)
Average Annual Precipitation (Base Case)	0.095	0.095	-0.4%	0.085	0.085	-0.1%	0.069	0.069	0.7%	0.127	0.127	-0.1%	0.647	0.649	0.2%	1.831	1.829	-0.1%
100-Year Dry Annual Precipitation	0.093	0.092	-0.4%	0.083	0.083	-0.1%	0.069	0.069	0.7%	0.125	0.125	0.0%	0.615	0.617	0.2%	1.699	1.697	-0.1%
100-Year Wet Annual Precipitation	0.103	0.103	-0.4%	0.092	0.091	-0.1%	0.071	0.071	0.6%	0.133	0.133	-0.1%	0.697	0.699	0.2%	1.998	1.996	-0.1%
Average Annual Precipitation with Low Dry Density*	0.095	0.095	-0.4%	0.085	0.085	-0.1%	0.069	0.069	0.7%	0.127	0.127	-0.1%	0.647	0.649	0.2%	1.831	1.829	-0.1%
Average Annual Precipitation with High Hydraulic Conductivity*	0.095	0.095	-0.4%	0.085	0.085	-0.1%	0.069	0.069	0.7%	0.127	0.127	-0.1%	0.647	0.649	0.2%	1.831	1.829	-0.1%
Average Annual Precipitation with Low Hydraulic Conductivity*	0.095	0.095	-0.4%	0.085	0.085	-0.1%	0.069	0.069	0.7%	0.127	0.127	-0.1%	0.647	0.649	0.2%	1.831	1.829	-0.1%
Average Annual Precipitation with East Lake Contribution during Freshet	0.095	0.095	-0.4%	0.085	0.085	-0.1%	0.069	0.069	0.7%	0.127	0.127	-0.1%	0.974	0.976	0.2%	1.831	1.829	-0.1%
Average Annual Precipitation with 50% Increase in April-May Snowmelt	0.094	0.094	-0.5%	0.085	0.084	-0.2%	0.069	0.069	0.7%	0.164	0.126	-22.8%	0.992	0.986	-0.6%	2.273	2.447	7.6%
Variable Annual Precipitation based on Synthetic Long-term Flows	0.098	0.098	-0.2%	0.088	0.088	0.0%	0.070	0.070	0.5%	0.129	0.129	0.0%	0.646	0.649	0.4%	1.830	1.832	0.1%

	July			August			September			October			November			December		
Assessment Scenario	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)
Average Annual Precipitation (Base Case)	1.628	1.625	-0.2%	1.581	1.577	-0.2%	0.964	0.960	-0.5%	0.409	0.406	-0.8%	0.150	0.147	-1.7%	0.121	0.119	-1.0%
100-Year Dry Annual Precipitation	0.718	0.715	-0.4%	0.476	0.472	-0.9%	0.550	0.546	-0.8%	0.347	0.344	-0.9%	0.133	0.131	-1.7%	0.111	0.110	-1.0%
100-Year Wet Annual Precipitation	1.741	1.738	-0.1%	1.937	1.933	-0.2%	2.033	2.028	-0.2%	0.485	0.481	-0.7%	0.169	0.166	-1.5%	0.131	0.130	-1.0%
Average Annual Precipitation with Low Dry Density*	1.628	1.625	-0.2%	1.581	1.577	-0.2%	0.964	0.960	-0.5%	0.409	0.406	-0.8%	0.150	0.147	-1.7%	0.121	0.119	-1.0%
Average Annual Precipitation with High Hydraulic Conductivity*	1.628	1.625	-0.2%	1.581	1.577	-0.2%	0.964	0.960	-0.5%	0.409	0.406	-0.8%	0.150	0.147	-1.7%	0.121	0.119	-1.0%
Average Annual Precipitation with Low Hydraulic Conductivity*	1.628	1.625	-0.2%	1.581	1.577	-0.2%	0.964	0.960	-0.5%	0.409	0.406	-0.8%	0.150	0.147	-1.7%	0.121	0.119	-1.0%
Average Annual Precipitation with East Lake Contribution during Freshet	1.628	1.625	-0.2%	1.581	1.577	-0.2%	0.964	0.960	-0.5%	0.409	0.406	-0.8%	0.150	0.147	-1.7%	0.121	0.119	-1.0%
Average Annual Precipitation with 50% Increase in April-May Snowmelt	1.480	1.414	-4.5%	0.957	0.894	-6.6%	0.884	0.875	-1.1%	0.401	0.397	-1.0%	0.148	0.145	-1.8%	0.119	0.118	-1.1%
Variable Annual Precipitation based on Synthetic Long-term Flows	1.513	1.543	2.3%	1.273	1.280	0.8%	1.265	1.276	1.1%	0.445	0.446	0.2%	0.156	0.154	-1.3%	0.124	0.123	-0.8%

** Post-closure flows were assumed to be similar to those of the average annual precipitation (base case) scenario.*

Figure 10.6-10

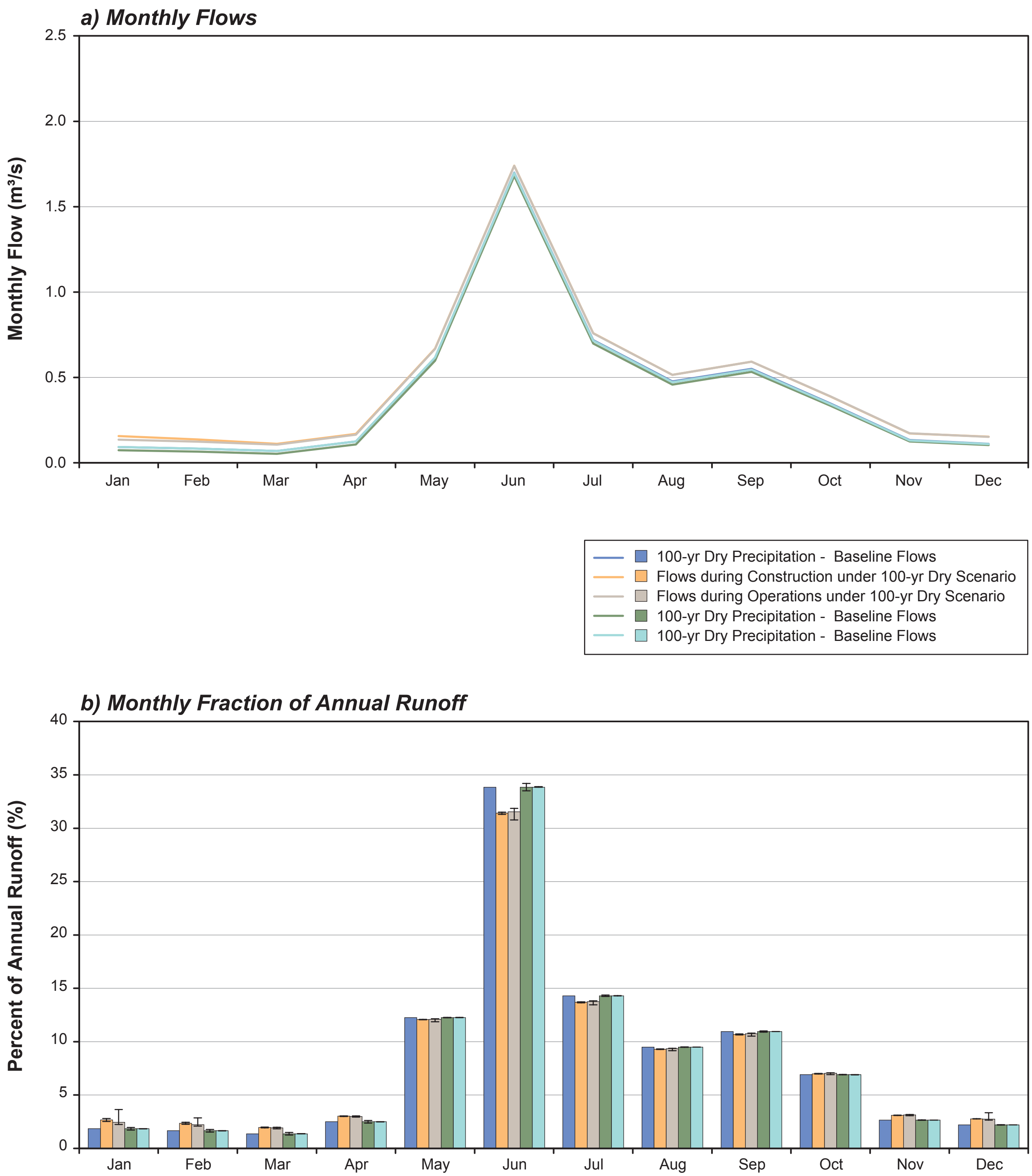
Monthly Distribution of Runoff at Brucejack Creek (Station BJL-H1) for the Baseline Condition and during Different Phases of the Project under the Base Case Scenario



Note: Error bars show the range of minimum to maximum contribution of monthly runoff during each phase of the Project.

Figure 10.6-11

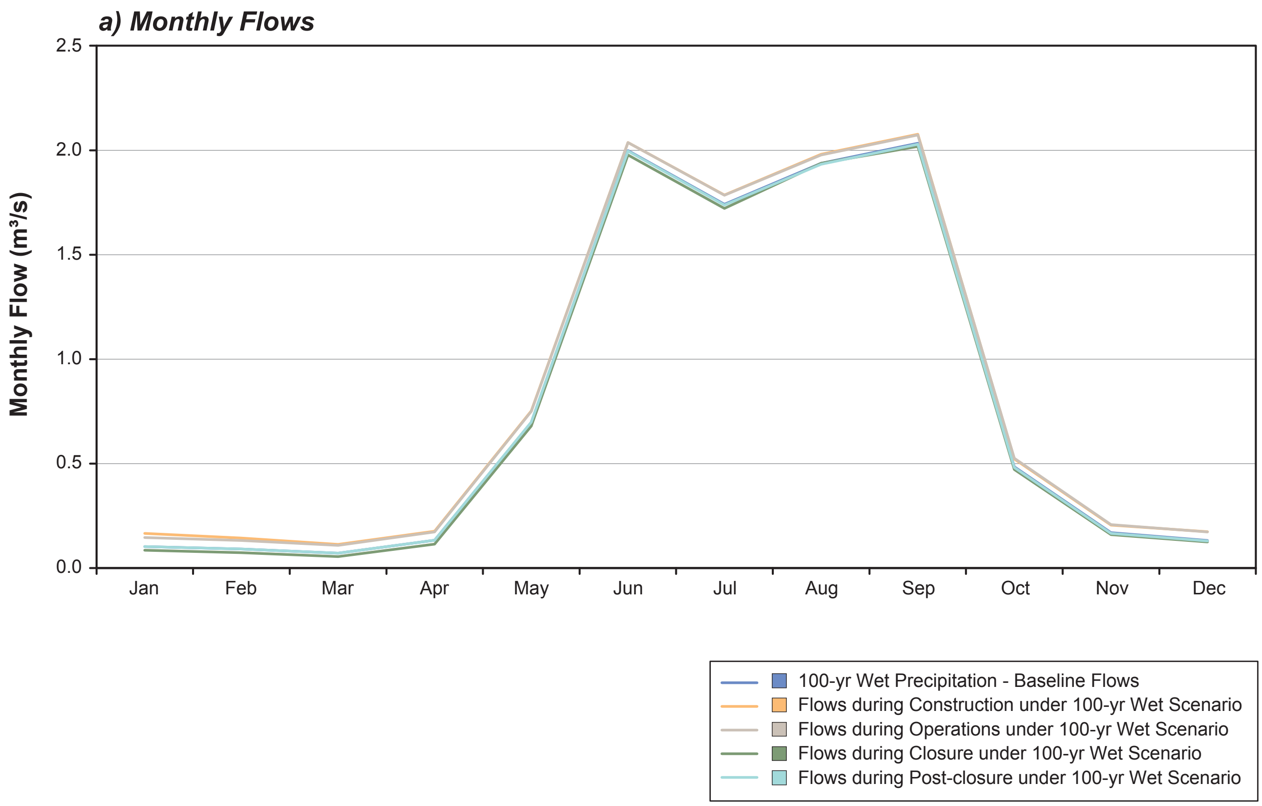
Monthly Distribution of Runoff at Brucejack Creek (Station BJL-H1) for the Baseline Condition and during Different Phases of the Project under the 100-Year Dry Precipitation Scenario

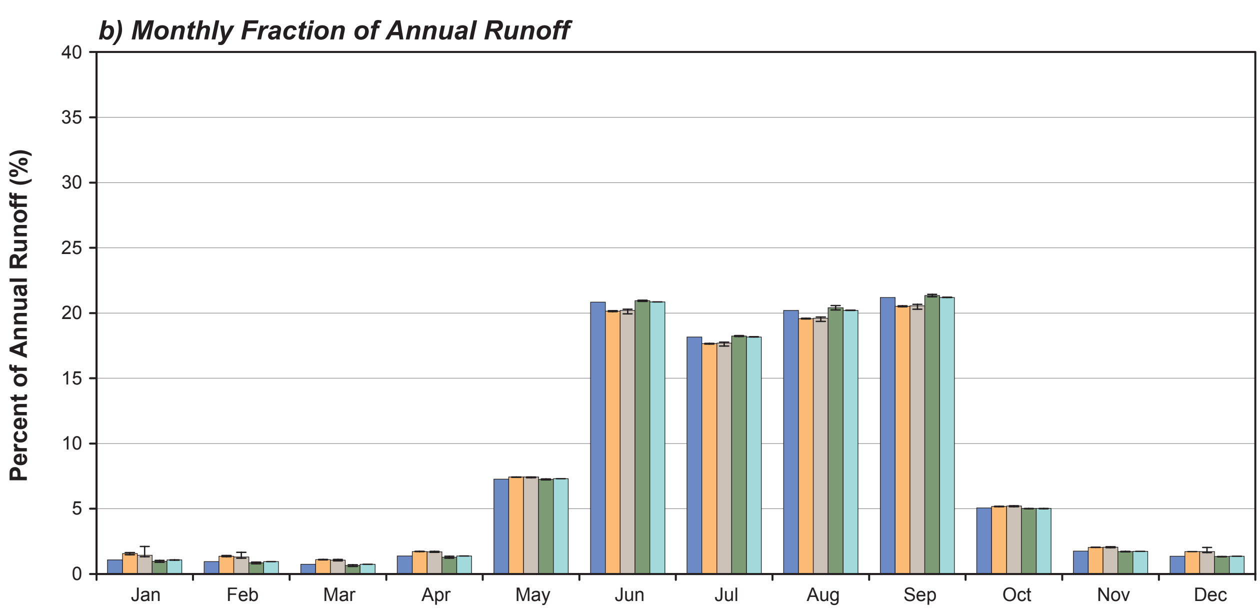


Note: Error bars show the range of minimum to maximum contribution of monthly runoff during each phase of the Project.

Figure 10.6-12

Monthly Distribution of Runoff at Brucejack Creek (Station BJL-H1) for the Baseline Condition and during Different Phases of the Project under the 100-Year Wet Precipitation Scenario

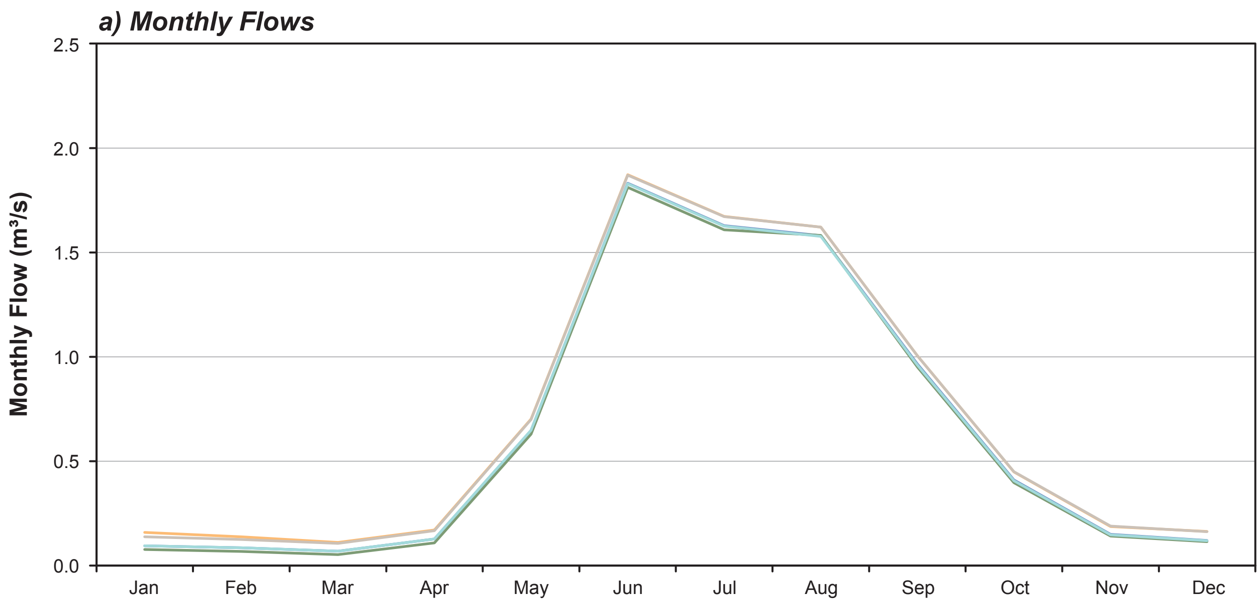


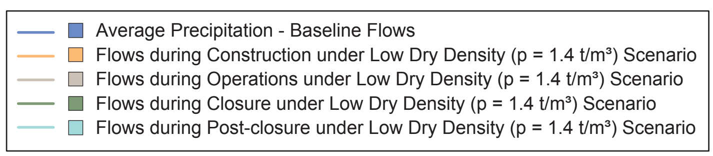


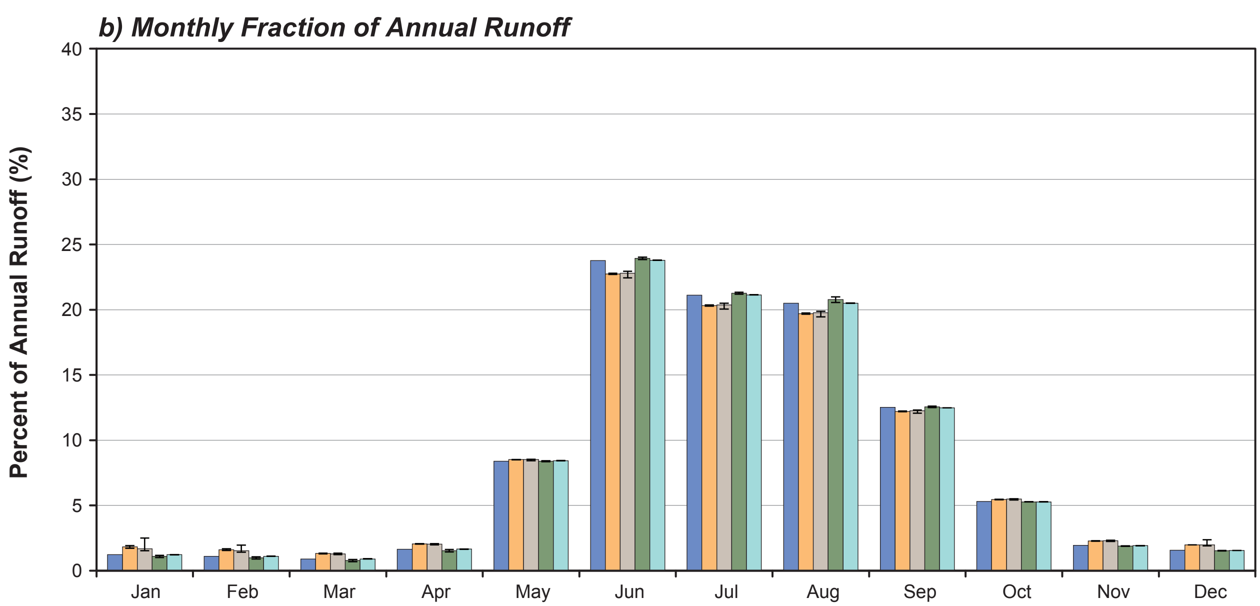
Note: Error bars show the range of minimum to maximum contribution of monthly runoff during each phase of the Project.

Figure 10.6-13

Monthly Distribution of Runoff at Brucejack Creek (Station BJL-H1) for the Baseline Condition and during Different Phases of the Project under the Average Precipitation with Low Dry Density Scenario



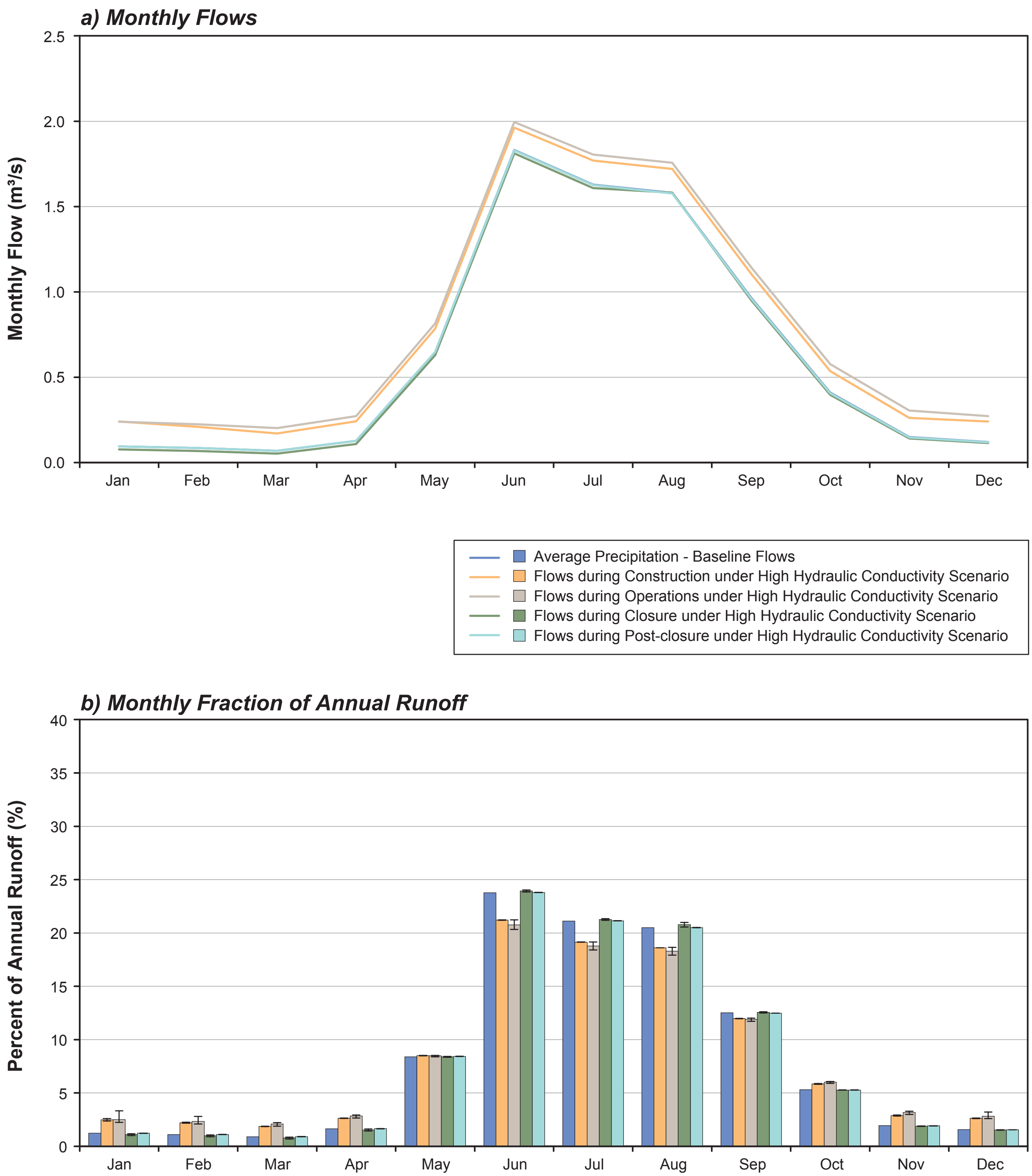




Note: Error bars show the range of minimum to maximum contribution of monthly runoff during each phase of the Project.

Figure 10.6-14

Monthly Distribution of Runoff at Brucejack Creek (Station BJL-H1) for the Baseline Condition and during Different Phases of the Project under the Average Precipitation with High Hydraulic Conductivity Scenario

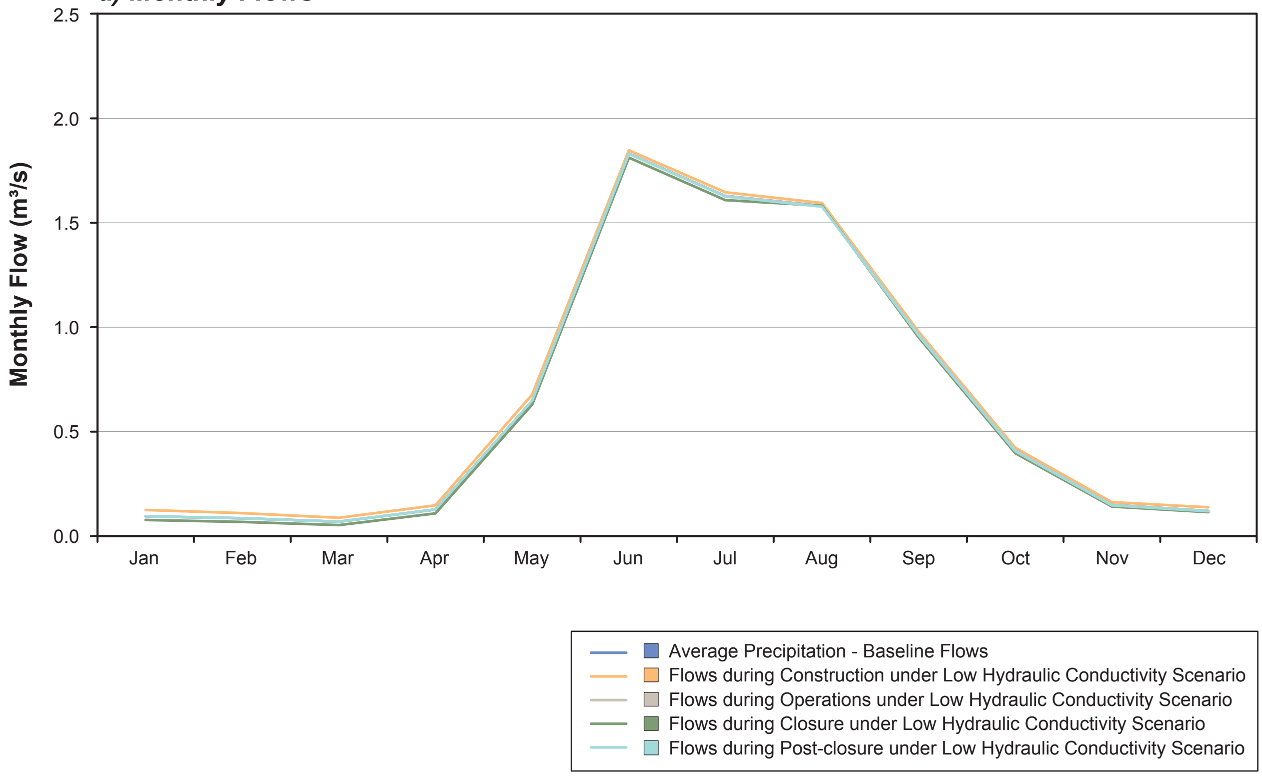


Note: Error bars show the range of minimum to maximum contribution of monthly runoff during each phase of the Project.

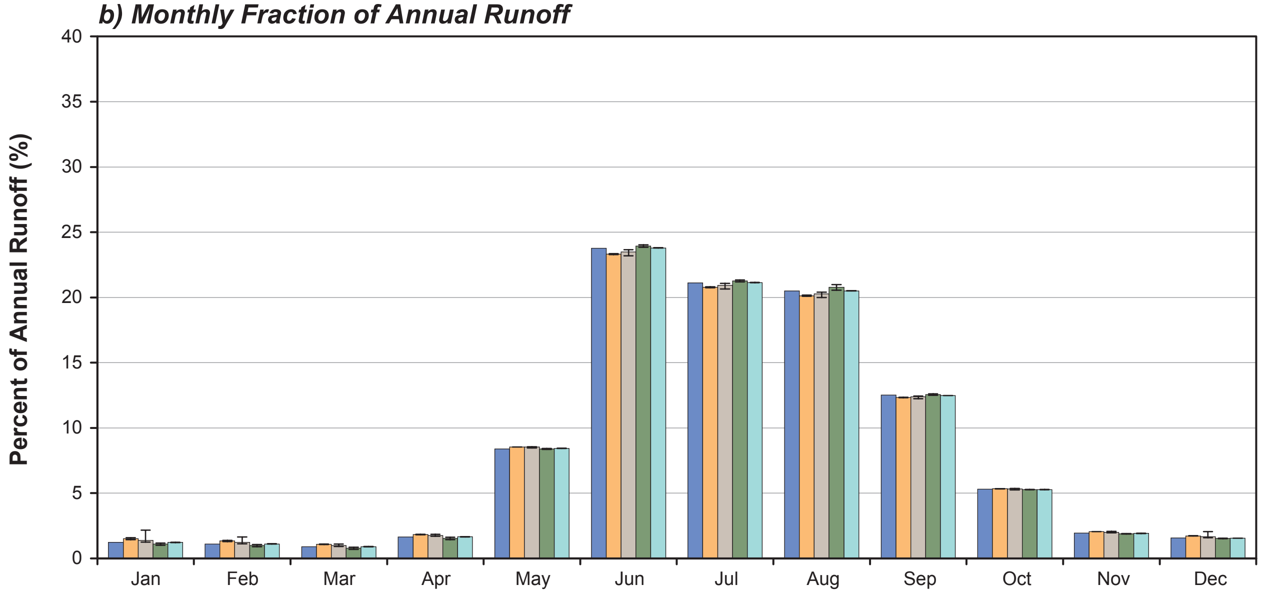
Figure 10.6-15

Monthly Distribution of Runoff at Brucejack Creek (Station BJL-H1) for the Baseline Condition and during Different Phases of the Project under the Average Precipitation with Low Hydraulic Conductivity Scenario

a) Monthly Flows



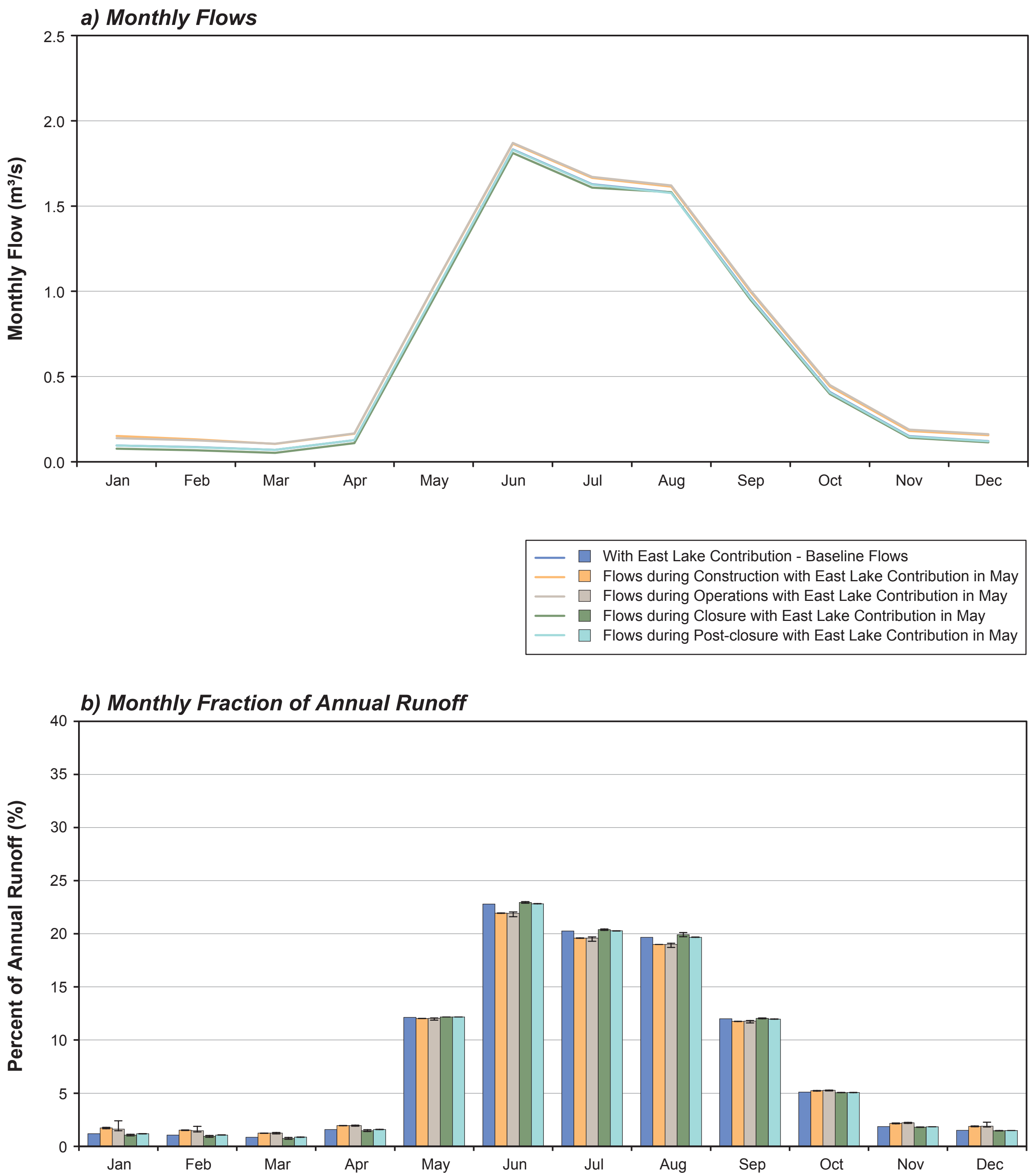
b) Monthly Fraction of Annual Runoff



Note: Error bars show the range of minimum to maximum contribution of monthly runoff during each phase of the Project.

Figure 10.6-16

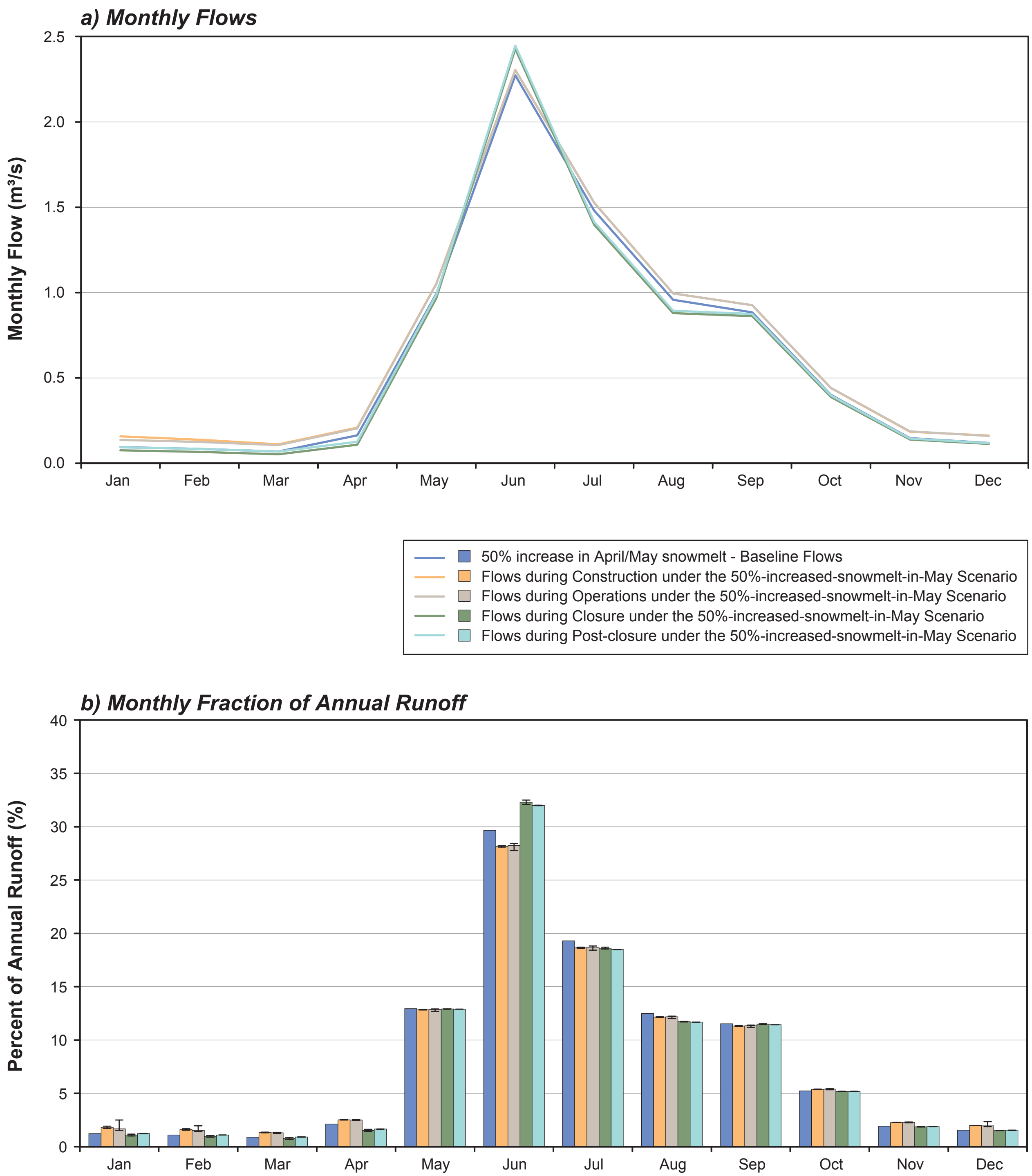
Monthly Distribution of Runoff at Brucejack Creek (Station BJL-H1) for the Baseline Condition and during Different Phases of the Project under the Average Precipitation with East Lake Contribution



Note: Error bars show the range of minimum to maximum contribution of monthly runoff during each phase of the Project.

Figure 10.6-17

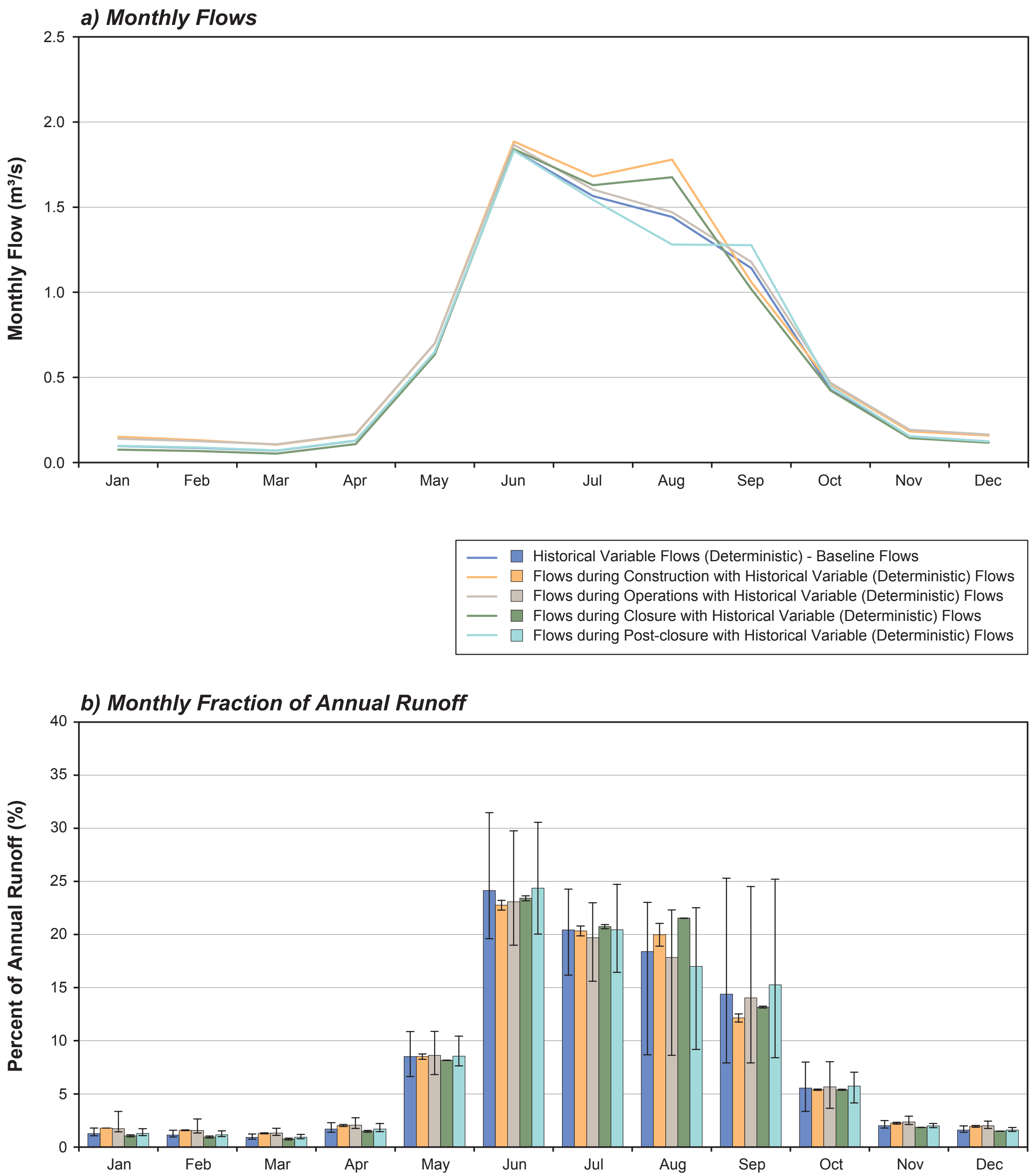
Monthly Distribution of Runoff at Brucejack Creek (Station BJL-H1) for the Baseline Condition and during Different Phases of the Project under the Average Precipitation with Increased Snowmelt in April-May Scenario



Note: Error bars show the range of minimum to maximum contribution of monthly runoff during each phase of the Project.

Figure 10.6-18

Monthly Distribution of Runoff at Brucejack Creek (Station BJL-H1) for the Baseline Condition and during Different Phases of the Project under the Synthetic Variable Flow Scenario



Note: Error bars show the range of minimum to maximum contribution of monthly runoff during each phase of the Project.

The effects during each phase of the Project under the base case (i.e., average annual precipitation) scenario are:

- **Construction**: low flows are increased by 62%, i.e., no negative effect on low flows is expected;
- **Operation**: the low flows are increased by 54%, i.e., no negative effect on low flows is expected;
- **Closure**: the low flows are expected to be decreased by 24%. Although this is a noticeable decrease in low flows, it will only occur during two years of Closure; and
- **Post-closure**: the low flows are estimated to be increased by 1%, which is within the data and modelling uncertainty (5%; Section 1.5.1), at Post-closure.

For the high and low hydraulic conductivity scenarios, the effects of the Project on low flows are greater and less than the base case, respectively. These changes are due to the variations of the underground seepage volumes under these scenarios. Under all other scenarios, the effects of the Project on low flows are approximately the same as those of the base case scenario (Table 10.6-6).

WBM results (Appendix 5-C, Brucejack Project Environmental Assessment — Water Management Plan) do not include simulated streamflows during the Closure and Post-closure phases of the Project under the low dry density, high hydraulic conductivity, and low hydraulic conductivity scenarios. The Closure and Post-closure streamflows under these scenarios were assumed to be the same as those of the base case scenario.

The drainage areas of SL-H1 (84 km^2), SC-H1 (298 km^2), and UR2 (1,480 km^2) are 7, 25, and 126 times of the BJL-H1 drainage area (11.7 km^2), respectively. Based on a comparison of drainage areas, the low flow reductions estimated under the base case scenario are expected to have minimal impact on these watersheds. Estimated reductions include 3% (SL-H1), 1% (SC-H1), and 0.2% (UR2), which are all within the data and modelling uncertainty range (5%; Section 1.5.1). Therefore, the changes at these locations are considered negligible.

10.6.1.5 Potential Effects of Climate Change on Streamflow

As previously mentioned (Section 10.3.5.3), streamflow changes are expected to be manifested after year 2050 (i.e., after the Project lifespan). In a preliminary study, BGC (2014) shows that existing streamflows in Brucejack Creek are expected to increase by 12% over 90 years.

The Project increases the Brucejack Creek baseflow (by pumping groundwater seepage to Brucejack Lake) during the Construction and Operation phases, and decreases the baseflow (by flooding the underground mine) during the Closure phase. At Post-closure, the Brucejack Creek base streamflows will return to baseline conditions. Tables 10.6-1 to 10.6-6 show that streamflow effects under high flow scenarios (e.g., the 100-year-wet scenario) are less profound than those of normal flow scenarios (e.g., base case scenario). Baseline flows under these conditions are higher than baseline flows under the base case scenario. Therefore, increased or decreased baseflows represent a lower percentage of baseline flows.

Therefore, if during the Project lifespan streamflows are increased due to climate change, effects of the Project on streamflows are not anticipated to be more than those of the base case scenario.

Table 10.6-6. Changes in March Flows in Brucejack Creek (BJL-H1) Compared to Baseline Conditions

Assessment Scenario	Construction			Operation			Closure			Post-closure		
	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)	Baseline Flows (m^3/s)	Operational Flows (m^3/s)	Change from Baseline (%)
Average Annual Precipitation (Base Case)	0.069	0.111	61.7%	0.069	0.106	53.9%	0.069	0.052	-24.1%	0.069	0.069	0.7%
100-Year Dry Annual Precipitation	0.069	0.111	61.7%	0.069	0.106	53.9%	0.069	0.052	-24.1%	0.069	0.069	0.7%
100-Year Wet Annual Precipitation	0.071	0.113	59.6%	0.071	0.108	52.4%	0.071	0.054	-23.5%	0.071	0.071	0.6%
Average Annual Precipitation with Low Dry Density*	0.069	0.111	61.7%	0.069	0.106	53.9%	0.069	0.052*	-24.1%	0.069	0.069*	0.7%
Average Annual Precipitation with High Hydraulic Conductivity*	0.069	0.171	148.2%	0.069	0.202	192.7%	0.069	0.052*	-24.1%	0.069	0.069*	0.7%
Average Annual Precipitation with Low Hydraulic Conductivity*	0.069	0.088	27.9%	0.069	0.078	13.5%	0.069	0.052*	-24.1%	0.069	0.069*	0.7%
Average Annual Precipitation with East Lake Contribution during Freshet	0.069	0.111	61.7%	0.069	0.106	53.9%	0.069	0.052	-24.1%	0.069	0.069	0.7%
Average Annual Precipitation with 50% Increase in April-May Snowmelt	0.069	0.111	61.7%	0.069	0.106	53.9%	0.069	0.052	-24.1%	0.069	0.069	0.7%
Variable Annual Precipitation based on Synthetic Long-term Flows	0.069	0.111	61.7%	0.069	0.106	53.5%	0.069	0.052	-24.1%	0.070	0.070	0.5%

** Closure and post-closure flows were assumed to be similar to those of the average annual precipitation (base case) scenario.*

10.6.2 Channel Morphology Alteration

Characteristics of the Brucejack Access Road, as well as major watersheds though which the access road passes, are summarized in Table 10.6-7. Summary statistics used for culvert assessment are provided in Figure 10.6-19. Channel types in this figure are based on BC Forest Service (1998). For bridge crossings, channel classification based on the Johnson technique (Johnson 2005) is summarized in Table 10.6-8. In this classification technique, a series of geomorphic, hydrologic, and hydraulic assessments were made to classify the channel. Unstable channels receive high grades and stable channels receive low grades (see Appendix 10-B, Potential Interactions between the Brucejack Gold Mine Project and Channel Morphology: Preliminary Results).

Table 10.6-7. Brucejack Access Road Summary, Classified by Watershed

Indicator	Wildfire Creek Watershed	Scott Creek Watershed	Todedada Creek Watershed	Bowser River Watershed (at Bowser Lake Inlet)	Sum
Watershed area (km^2)	67	75	61	819	1,022
Median elevation (m)	950	1,180	1,179	1,400	n/a
Q_2 (m^3/s)	44	48	41	325	n/a
Q_{100} (m^3/s)	155	168	145	933	n/a
Road length (km)	15.0	10.3	6.8	36.3	68.4
Road density (km/km^2)	0.22	0.14	0.11	0.04	n/a
Number of bridges	4	2	1	7	14
Bridge density ($bridges/km^2$)	0.04	0.03	0.02	0.01	n/a
Bridge rate of occurrence (bridges/km)	0.27	0.19	0.15	0.19	n/a
Number of culverts	106	63	52	25	246
Culvert density ($culverts/km^2$)	1.58	0.84	0.85	0.03	n/a
Culvert rate of occurrence (culverts/km)	7.04	6.10	7.66	0.69	n/a

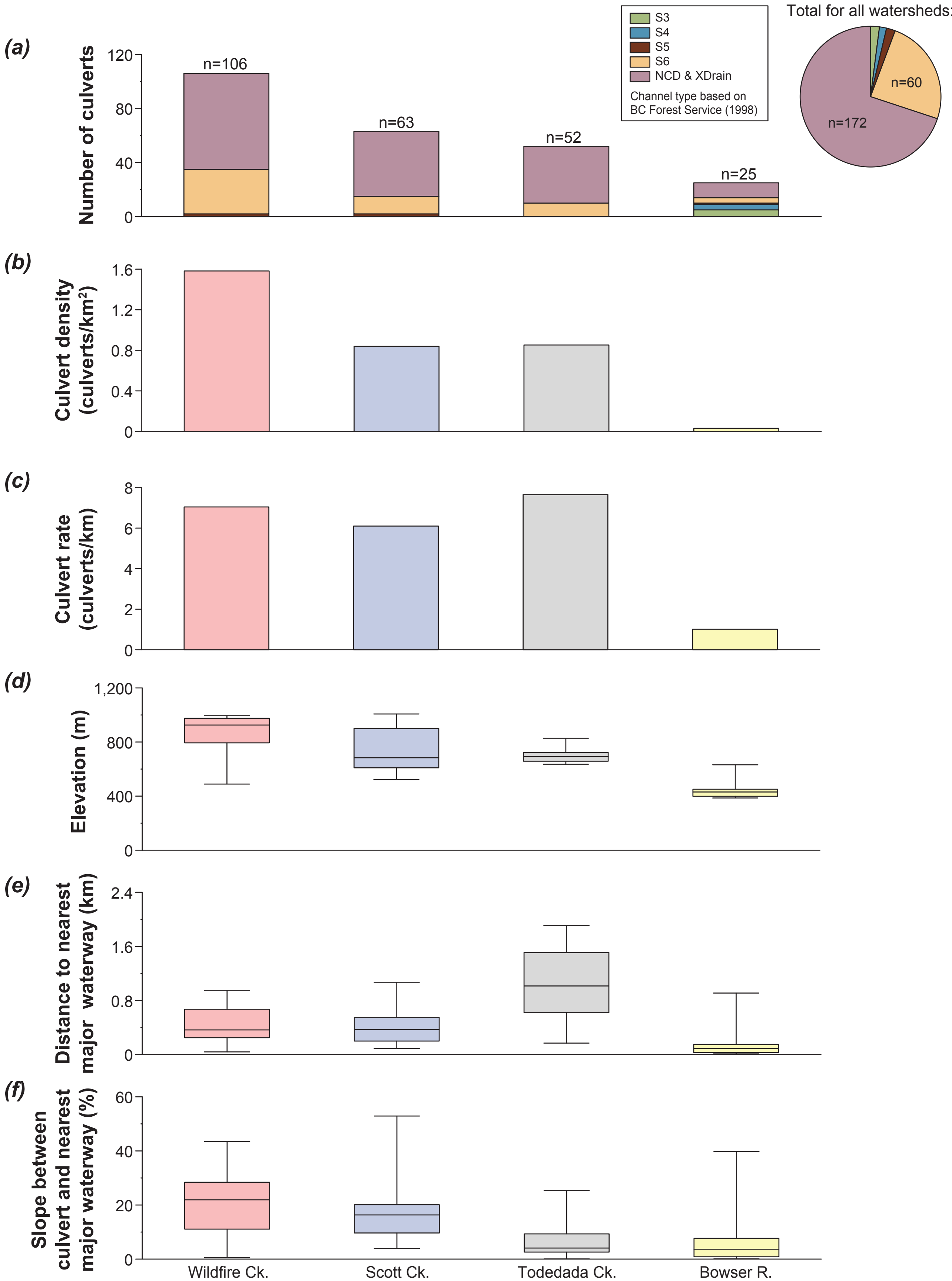
Table 10.6-8. Preliminary Classification and Stability Scores for Bridge Reaches

Watershed	Bridge	Johnson Classification Score*
Wildfire Creek	Bell-Irving Bridge	62
	Wildfire Creek Bridge	75
	#3	61
	#5 Pinch Point Creek	56
Todedada Creek	#6 Gassy Creek	63
Scott Creek	#7 Little Scott Creek Bridge	63
	#8 Scott Creek Bridge	59
Bowser River	#9	59
	#11	65
	#16	68
	#18	76
	#19	80
	#20	93
	#21	130

** Based on Johnson (2005). Unstable channels receive high grades and stable channels receive low grades.*

Figure 10.6-19

Summary Statistics for Culverts on the Brucejack Access Road



Note: in panels 'd' to 'f', whiskers are max. and min., boxes are quartiles, and horizontal line is median.

Detailed assessment for culvert and bridge crossings are provided in Appendix 10-B and summarized in the following sections.

10.6.2.1 Wildfire Creek Watershed

Due to the steep slopes, high culvert density (1.58 culverts per square kilometre of the watershed), evidence of mass movements, and potential logging-related impacts, Wildfire Creek is the likeliest of the Project area watersheds to experience channel morphology changes associated with drainage by culverts. This is especially true for the first 10 to 15 km of the road, where down-drainage slopes are steep. Increased gully formation and potentially increased downslope mass movements would be expected in this area (see Appendix 10-B, Potential Interactions between the Brucejack Gold Mine Project and Channel Morphology: Preliminary Results).

Among the bridges in this watershed, Wildfire Creek Bridge is likely to experience channel morphology challenges primarily due to bank stability issues (see Appendix 10-B).

10.6.2.2 Scott Creek Watershed

Culvert density is moderate (0.84 culverts per square kilometer of the watershed) compared to other watersheds affected by the access road. Overall, Scott Creek culverts are placed in variable settings, and crossing morphologies will likely reflect this variability (see Appendix 10-B, Potential Interactions between the Brucejack Gold Mine Project and Channel Morphology: Preliminary Results).

Channel morphology stability at bridge crossings within the Scott Creek watershed was estimated to be above the average compared to other watersheds that the road crosses (see Appendix 10-B).

10.6.2.3 Todedada Creek Watershed

Culvert density is moderate (0.85 culverts per square kilometre of the watershed) compared to other watersheds that the road crosses. The largest potential morphological change within this watershed is related to backwatering associated with blocked culverts (i.e., snow, ice, or debris). Undersized culverts could increase the potential of backwatering leading to excess aggradation and over-widening of the channel upstream of the road crossing. Over time, these morphological changes could compound, affect aquatic passage, and increase the risk associated with flooding during a low-frequency flood. Properly located and sized culverts will reduce the potential of adverse effects associated with hydraulic structures.

Channel morphology stability at Bridge #6 within the Todedada Creek watershed was estimated to be above the average compared to other watersheds that the road crosses (see Appendix 10-B, Potential Interactions between the Brucejack Gold Mine Project and Channel Morphology: Preliminary Results).

10.6.2.4 Bowser River Watershed

Given the large size of Bowser River, the low number and density of culverts (0.03 culverts per square kilometre of the watershed), and the low downstream slopes, culverts are unlikely to significantly affect Bowser River channel morphology (although the reverse is possible). The possible exception is where the road passes near rockslides (see Appendix 10-B, Potential Interactions between the Brucejack Gold Mine Project and Channel Morphology: Preliminary Results).

In this watershed, bridges cross low-gradient, unconfined, perennial streams. Channel morphology stability at bridges within the Bowser River watershed was estimated to be the lowest among all the watersheds that the access road passes. Specifically, bridges #18 to 21 were assessed to reflect low channel morphology stability compared to other access road bridges of the Project (see Appendix 10-B).

10.6.3 Effects on Knipple Glacier

10.6.3.1 Effects of the Brucejack Access Road on Knipple Glacier

The glacier portion of the access road covers about 0.1% of the Knipple Glacier area. Based on an initial approximation analysis of the glaciohydrology (Appendix 10-C, Potential Interactions between the Glacier Section of Brucejack Access Road and Knipple Glacier Ablation), the change in Knipple Glacier summer ablation due to the Brucejack Access Road is expected to be less than 1% of the baseline summer ablation values.

10.6.3.2 Effects of the Fugitive Dust Deposition on Knipple Glacier

The air quality dispersion model predicted increased dustfall levels due to access road dust covering approximately 3 km of the southeast end of Knipple Glacier during the Construction and Operation phases of the Project (Figures 10.6-20 and 10.6-21). The dustfall level on this portion of Knipple Glacier is predicted to be up to 0.95 mg/dm^2/day based on the highest 30-day average (see Chapter 7, Air Quality Predictive Study, for details). Compared to the baseline level of 0.71 gm/dm^2/day, this is approximately an increase of 34%, but it is still lower than the provincial objectives of 1.7 to 2.9 mg/dm^2/day (BC MOE 1979). Effects of the dustfall on albedo, and therefore on glacier ablation, has been identified in the literature (Oerlemans et al. 2009; Adhikary et al. 2000). Quantified effects of increased dustfall on glacier ablation are case specific, and the increased dust may be washed away by the melt during the ablation season. The glacier monitoring program (see Appendix 10-C, Potential Interactions between the Glacier Section of Brucejack Access Road and Knipple Glacier Ablation, and Section 29.16, Transportation and Access Management Plan) will assess glacier melt on an annual basis, and additional road dust suppression measures will be taken if necessary.

On the northwest end, the air quality dispersion model predicted increased dustfall levels due to ore processing for an area approximately 200 m along the Knipple Glacier. That is, 2.0% of the Knipple Glacier (11 km long) is expected to be affected. The dustfall level on this portion of Knipple Glacier is predicted to be up to 0.95 mg/dm^2/day based on the highest 30-day average (Chapter 7, Air Quality Predictive Study). Note that the baseline dustfall monitoring results from July to September 2012 varied from 0.14 to 2.67 mg/dm^2/day, indicating natural variation of dustfall levels based on seasons or activities in the area.

10.6.4 Potential Receptor VCs

The increase in the mean annual flow and low flow during the construction and operation phases is not expected to negatively affect any receptor VC. However, the 24% reduction in the low flow at BJL-H1 could potentially affect the seven receptor VCs which have linkages with surface water hydrology. Effects of the Project on these receptor VCs are assessed in:

- Chapter 13, Assessment of Potential Surface Water Quality Effects;
- Chapter 14, Assessment of Potential Aquatic Resources Effects;
- Chapter 15, Assessment of Potential Fish and Fish Habitat Effects;
- Chapter 16, Assessment of Potential Terrestrial Ecology Effects;
- Chapter 17, Assessment of Potential Wetlands Effects;
- Chapter 23, Assessment of Potential Navigation Effects;
- Chapter 24, Assessment of Potential Commercial and Non-commercial Land Use Effects; and
- Chapter 25, Assessment of Potential Effects to Current Use of Lands and Resources for Traditional Purposes.

Figure 10.6-20
Maximum 30-day Dust Deposition during Construction

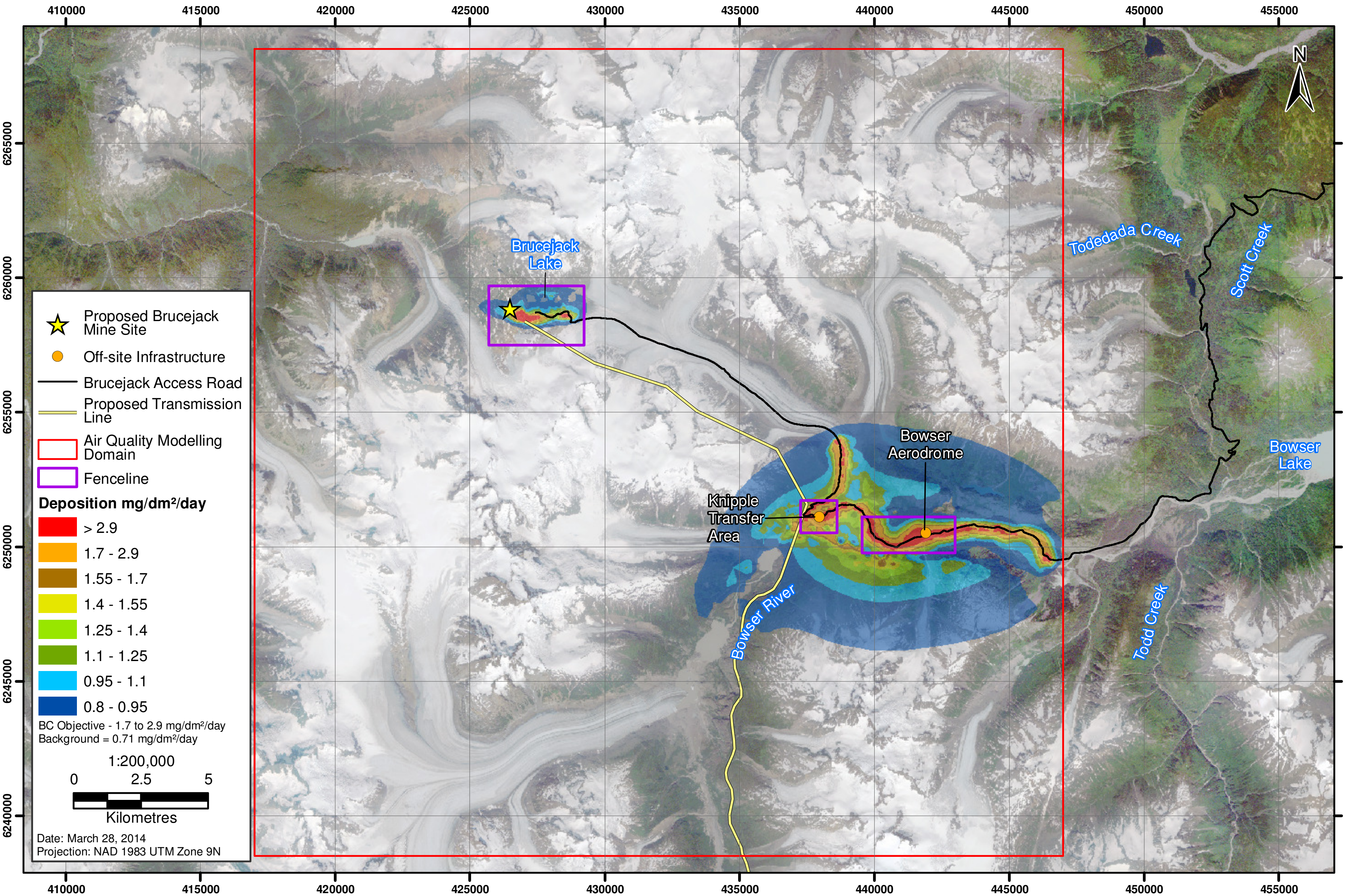
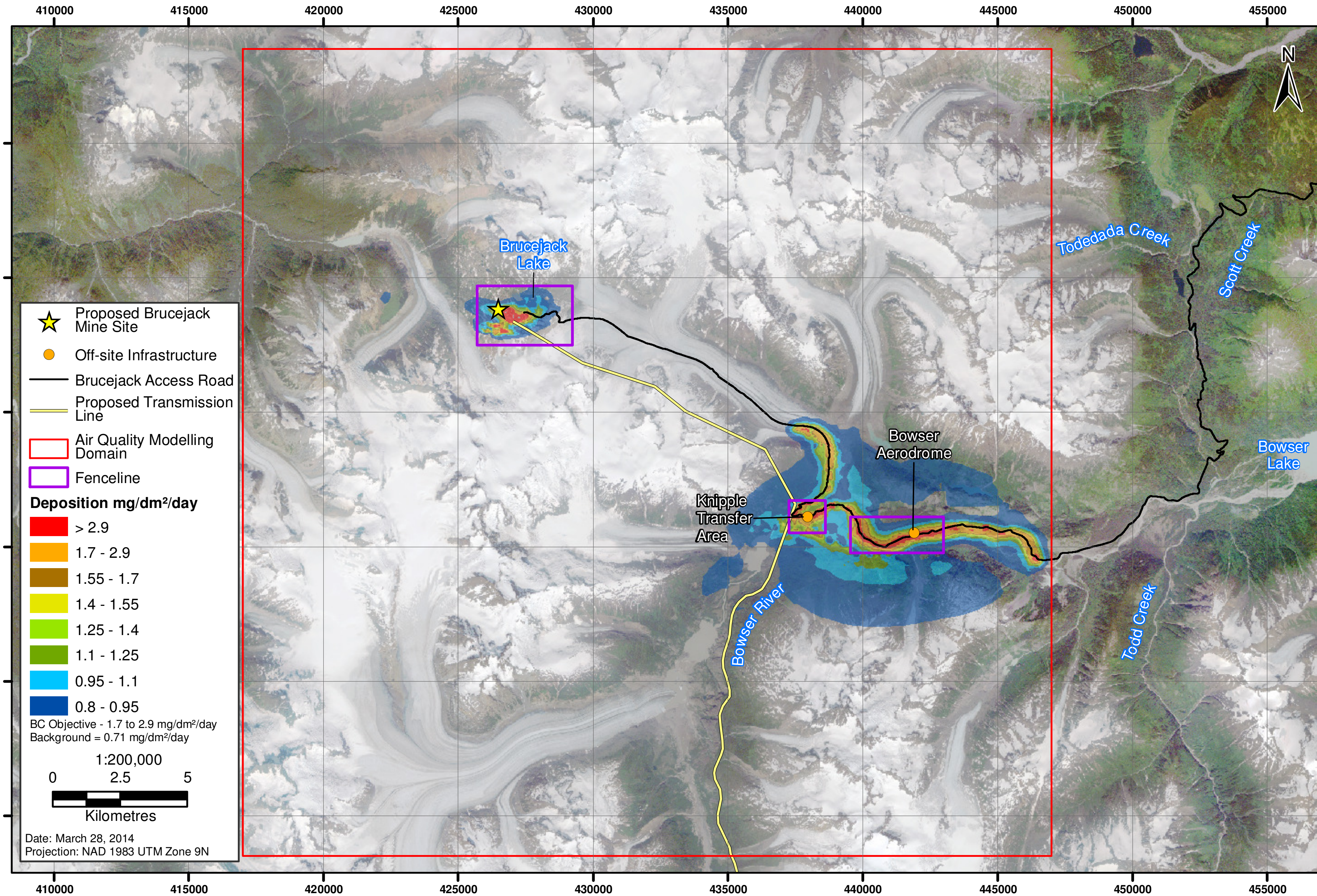


Figure 10.6-21
Maximum 30-day Dust Deposition during Operation

ERM



10.7 MITIGATION MEASURES FOR SURFACE WATER HYDROLOGY

A variety of diversion, collection, and treatment structures will be developed to manage water for the Project. The primary goals of water management activities are to divert non-contact water and collect contact water for treatment. By minimizing the amount of contact water that is produced on the Project site, surface water diversion reduces the volume of water that must be treated. Additionally, surface water diversion decreases the potential for erosion and sediment production by limiting the volume of water that enters a work area.

The Water Management Plan (Section 29.19) describes a range of mitigation measures to reduce or eliminate the potential effects of the Project on surface water hydrology. A summary of these measures during different phases of the Project are presented in the following sections.

Regular and incidental (e.g., after high rainfall or snowmelt events) inspections are planned to identify potential significant sediment scour or deposition at the stream crossings along the Brucejack Access Road (see Section 27.13, Soil Management Plan). The road and all associated culverts and bridges are planned to be removed during the Closure phase.

10.7.1 Construction

Water management and erosion prevention and sediment control measures will be implemented soon after Project approvals and before construction/pre-production mining commences. Specific construction-related water management measures are described below, organized by their application to each construction activity.

10.7.1.1 Clearing and Grubbing

Clearing and grubbing activities expose large quantities of soil, leaving it highly susceptible to erosion. To minimize erosion during clearing and grubbing, the following measures will be implemented:

- 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 (e.g., temporary sediment fences around the perimeter of stockpiles, sediment pools at culvert inlets).
- Erosion prevention and sediment control Best Management Practices (BMPs) will be implemented. These include isolation of work areas from surface waters and proper use of structural practices such as sediment traps, geotextile cloth, sediment fences, gravel berms, and straw bales to mitigate and control erosion and sediment.
- Baseline data on surface water quantity (Appendix 10-A, 2012 Surface Water Hydrology Baseline Report) and soils and terrain (Appendix 16-A, 2012-2013 Terrestrial Ecosystem Baseline Studies) should be used along with visual surveys of construction activities to identify potential sites that require focused attention for water management. Vulnerable sites, such as potential ditch failures or culvert blockages, will be identified in advance, and risks in these areas will be addressed by site-specific mitigation measures.
- When feasible, development activities will be kept away from hydrologically important features (seepage sites, springs, rivulets, and open water). In areas affected by seepage or where the water table is near the surface, construction activities or soil salvaging operations will preferentially be performed during dry or frozen conditions.

10.7.1.2 Earthworks

The BMPs for clearing and grubbing described in Section 10.7.1.1 are also generally applicable to earthworks. In addition, several BMPs that are specific to earthworks, and will be applied where applicable, are noted below:

- Soil should only be stripped from areas that will be disturbed by construction.
- Stripping should be immediately discontinued in an area where unanticipated groundwater is encountered.
- Stockpiles should be located at geologically stable sites away from streams and seeps.
- Stockpile sites should be graded to create a smooth, slightly sloping (less than 5%) pad to promote water drainage away from the piles.
- Where possible, stockpiles should be re-vegetated for long-term stabilization.
- Equipment traffic should be kept to a minimum on stockpiles to minimize compaction.
- For some Construction phase activities the entire overburden layer will be removed. In these cases, erosion potential will be progressively reduced as erodible materials are removed from the site. However, overburden removal will impact site topography, which will likely require installation of water management measures.

10.7.1.3 Access Road Upgrades and Transmission Line Construction

The existing 73-km exploration access road crosses steep slopes and areas of erodible soils. Planned road upgrades have the potential to cause erosion due to soil disturbing activities. Erosion prevention and sediment control BMPs that will be implemented, where applicable, during road upgrades include the following:

- The clearing, grubbing, and earthworks BMPs described in Sections 10.7.1.1 and 10.7.1.2 will be used for road upgrades and transmission line construction, where applicable.
- Cross-drain culverts will not discharge directly into streams. Unless they are in use as part of a stream crossing, culverts will discharge onto rock or another stable energy dissipater.
- Hydraulic structures (culverts/bridges) are properly located and placed to minimize potential adverse channel morphology effects.
- If drainage stability issues are observed, design of the hydraulic structures will be re-evaluated.
- Catch basins will be installed at culvert inlets to trap the coarse material that is transported in drainage ditches.
- Following earthworks, exposed slopes will be re-vegetated as soon as feasible. Temporary cover may be used if re-vegetation is not imminently possible. Sections 29.5, Ecosystem Management Plan; Section 29.9, Invasive Plants Management Plan; and Section 29.13, Soil Management Plan, describe the envisaged BMPs for these activities.
- Unpaved access roads will be watered to mitigate road dust.
- A glacier monitoring program (see Appendix 10-C, Potential Interactions between the Glacier Section of Brucejack Access Road and Knipple Glacier Ablation, and Section 29.16, Transportation and Access Management Plan), similar to that conducted during 2013, will be undertaken.
- Additional road dust suppression measures will be taken if necessary.

The proposed transmission line alignment follows bedrock-dominated terrain that is characterized by gentle to moderate slopes, bedrock hummocks, and discrete debris flow/snow avalanche tracks. Transmission line construction is anticipated to have minimal implications for water management. Construction will be using helicopter access so disturbance or construction and maintenance of stream crossings along the transmission line alignment is unlikely, but if required, will be consistent with the Fisheries and Oceans Canada *Operational Statement for Overhead Line Construction (*Fisheries and Oceans Canada 2007b*)* and *Operational Statement for Maintenance of Riparian Vegetation in Existing Rights-of-Way* (Fisheries and Oceans Canada 2007a). Watercourse crossings will also be assessed against the *Minor Works and Water Order*, under the *Navigation Protection Act* (1985d).

10.7.2 Operation

In addition to applicable water management measures described in Section 10.7.1, the following specific measures will be implemented during site operation:

- Water management and sediment control structures will be regularly inspected and maintained. Maintenance procedures will include prompt attention to potential erosion sites, ditch or culvert failure, ditch or culvert blockage, or outside seepage, because such problems could lead to structure failure and sediment transport. Maintenance will also include routine removal of accumulated sediment from ditches and retention structures. The sediment removed will be used as fill or deposited on stockpiles.
- The Project site will be positively drained at all times. Existing drainage courses will be preserved as much as possible as this typically leads to the most efficient and economical drainage design.
- Culverts and adjacent slopes will be inspected as required, especially after high rainfall and/or melt events. Identified erosion and sediment concerns, such as blockages, siltation, gullying, or slope failure, will be addressed immediately to protect road infrastructure and the adjacent environment (see Sections 29.13, Soil Management Plan, and 29.16, Transportation and Access Management Plan).
- Channel morphology associated with bed and bank instability along the access road and at culvert and bridge crossing locations will be assessed regularly. Instability will be assessed for risk and addressed accordingly.
- Camp sewage will be treated and discharged in a manner that does not impair the receiving environment. Effluent from the sewage treatment plant will be of appropriate quality for direct discharge to Brucejack Lake. Sludge from the plant will be incinerated or hauled offsite for disposal at a licensed facility. Further information on the disposal of sewage can be found in the Section 29.17, Waste Management Plan.

10.7.3 Closure and Reclamation

Closure will involve the removal of all structures and equipment, closure of the portals, flooding of the underground mine, and rehabilitation of site disturbances. The goal is to minimize the long-term effects on the environment and return the site to as close to its pre-disturbance condition as practical.

Similar erosion prevention and sediment control BMPs as those used during the Construction and Operation phases will be used during Closure activities that require ground disturbance, especially the use of perimeter diversion ditches. Monitoring and reclamation reporting will continue during Closure and Post-closure until land use objectives are met.

When no longer needed, temporary sediment control ponds will be completely dewatered, and retained sediment will be buried or, if suitable, reclaimed. Alternately, if the pond site is not located in an active floodplain, sediments may be stabilized with a cap of coarse material. After sediment removal or capping, the pond site will be re-contoured to conform as much as possible to the surrounding topography, followed by topsoil application and re-vegetation if appropriate for the site. At final closure, all diversion channels will be decommissioned to restore stream hydrological patterns back to baseline conditions.

The underground workings will be progressively backfilled with cemented paste backfill (tailings) and waste rock throughout mine operations and, once mining is completed, the remaining underground voids will be allowed to flood. The ventilation shafts and underground portals will be sealed with concrete plugs. The plugs will be equipped with outlets in the event the water table rises in the underground workings and some seepage occurs, which is not expected in the two new mine portals but may occur in the existing portal. The seepage water from the existing portal will be monitored during Post-closure and directed to Brucejack Creek if it meets discharge criteria.

Following the removal of all above-ground buildings and structures, all gravel surfaces (e.g., the helicopter pad and the roads), will be ripped to increase water infiltration and reduce the potential for surface erosion and instability. The above-ground pipes that carry tailings to the lake will be removed from the site.

For all underground and above ground equipment, all oil, fuels, and processing fluids will be drained before the equipment is removed, and disposed of in a regulated facility off-site.

The access road will be decommissioned. A deactivation plan will be prepared and submitted to the authorities for approval prior to the start of deactivation activities. The culverts will be removed and natural drainage will be restored. Cross ditches, water bars and drains will be constructed where necessary. The road surface will be ripped to increase water infiltration, reduce the potential for surface runoff, and prepare for re-vegetation. Soils will be spread on the surface where soil is available and the areas will be re-vegetated.

10.7.4 Residual Effects

In estimating the effects of the Project on surface water hydrology indicators (Section 10.6), it was assumed that all aforementioned mitigation measures were in place. That is, the predictive study results (Section 10.6) represent the predicted residual effects on surface water hydrology.

10.8 PREDICTED CHANGES ON SURFACE WATER HYDROLOGY

The key changes to surface water hydrology that are predicted to remain after the implementation of mitigation measures are summarized in Table 10.8-1. Only changes that were expected to negatively affect the receptor VCs, and were beyond the reasonable range of data and modelling uncertainty, are discussed here. The positive changes in streamflows (i.e., the increase in mean annual flows and low flows) during the Construction and Operation phases are not expected to negatively affect any receptor VCs, and therefore, are not discussed here. The key negative effects on surface water hydrology indicators include:

- *Streamflows*: Brucejack Mine Site water management components and activities are expected to decrease the low flows at BJL-H1 by a magnitude up to 24% during Closure. The geographic extent of these changes are confined to the LSA boundary. That is, the low flow reductions at the downstream assessment points (i.e., SL-H1, SC-H1, and UR2) are within the reasonable range of data and modelling uncertainty (i.e., less than 5%). In addition, the duration of these low flow reductions is limited to the Closure phase (i.e., two years).

- *Channel Morphology*: Culverts in the Wildfire Creek watershed are expected to affect the morphology of their down-drainage slopes by increasing gully formation and potentially downslope mass movements. Based on a preliminary assessment, channel morphology at the Wildfire Creek Bridge, and at low-gradient unconfined bridges (i.e., bridges #18 to 21), is less stable than other access road bridges. Channel morphology could be sensitive to maintenance and decommissioning activities at these bridges.
- *Glaciers*: Dustfall levels are predicted to increase by a magnitude of up to 0.95 $mg/dm^2/day$ with duration extending for the length of the Construction and Operation phases (34% increase from the background level of 0.71 $mg/dm^2/day$). The geographical extent of the predicted increase is expected to be limited to the lower 3 km of the Knipple Glacier. These levels are lower than the provincial objectives of 1.7 to 2.9 $mg/dm^2/day$ (BC MOE 1979). Quantification of the effects of the dustfall on albedo, and therefore on glacier ablation, will be possible with glacier mass balance studies.

Table 10.8-1. Summary of Predicted Changes after Mitigation for Surface Water Hydrology

Sub-component	Project Phase (timing of effect)	Project Component/ Physical Activity	Description of Cause-effect*	Description of Mitigation Measure(s)	Description of Predicted Change(s)
Streamflows	Closure	Brucejack Mine Site	During the Closure phase, underground seepage is not pumped into Brucejack Lake. This would reduce streamflows during the low-flow period when streamflows are dependent on the baseflow.	The Water Management Plan (Section 29.19) will be followed; natural flow drainages will be re-established during the Closure phase.	The 24% decrease in low flows has the potential to affect receptor VCs.
Channel Morphology	Construction, Operation, and Closure	Brucejack Access Road	Effects of culverts and bridges on channel morphology.	The Soil Management Plan (Section 29.13), and Transportation and Access Management Plan (Section 29.16), will be followed. If drainage stability issues are observed, design of hydraulic structures will be re-evaluated.	Culverts in the Wildfire Creek watershed can increase gully formation and downslope mass movement; channel morphology at the Wildfire Creek bridge and at Bridges #18 to 21 are less stable than other bridges.
Glaciers	Construction and Operation	Brucejack Access Road	Dust generated by access road operation may be deposited on Knipple Glacier. The increased dustfall could change the albedo, and therefore the glacier ablation.	Unpaved access roads will be watered to mitigate road dust. Glacier monitoring program will assess glacial melt, additional road dust suppression measures will be taken if necessary.	A conservative estimate suggests a 34% increase in dustfall on the lower 3 km of Knipple Glacier.

** "Cause-effect" refers to the relationship between the Project component/physical activity that is causing the change or effect in the condition of the intermediate component, and the actual change or effect that results.*

10.9 SURFACE WATER HYDROLOGY AS A PATHWAY TO RECEPTOR VALUED COMPONENTS

As previously discussed, surface water hydrology was identified as an intermediate component. Changes in surface water hydrology indicators (i.e., streamflows, channel morphology, and glaciers) have the potential to affect receptor VCs. Pathways between the surface water hydrology and receptor VCs (Figure 10.4-1), as well as potential hydrology-related effects on such VCs are summarized here.

- Surface water quality (Chapter 13, Assessment of Potential Surface Water Quality Effects) — Changes in surface water hydrology have the potential to affect surface water quality. The interactions include:
  - changes in streamflows that could alter the concentration of water quality constituents;
  - channel morphology alteration that would affect sediment transport, and thereby, water quality; and
  - glacier ablation which may result in introduction of more solids into the streams.
- Fish and fish habitat (Chapter 15, Assessment of Potential Fish and Fish Habitat Effects), and aquatic resources (Chapter 14, Assessment of Potential Aquatic Resources Effects) — Streamflows and channel morphology are critical components of fish/aquatic habitat. Significant flow alteration or major sediment scour/deposit during a sensitive life stage could affect fish and aquatic resources.
- Terrestrial ecology (Chapter 16, Assessment of Potential Terrestrial Ecology Effects) — Changes in surface water hydrology indicators could affect the riparian vegetation, and thereby the terrestrial ecology; and
- Wetlands (Chapter 17, Assessment of Potential Wetlands Effects), Navigation (Chapter 23, Assessment of Potential Navigation Effects), and Land Use (Chapters 24, Assessment of Potential Commercial and Non-commercial Land Use Effects, and 25, Assessment of Potential Effects to Current Use of Lands and Resources for Traditional Purposes) — Streamflow alteration could affect (e.g., degrade) wetlands, navigability, available water resources.

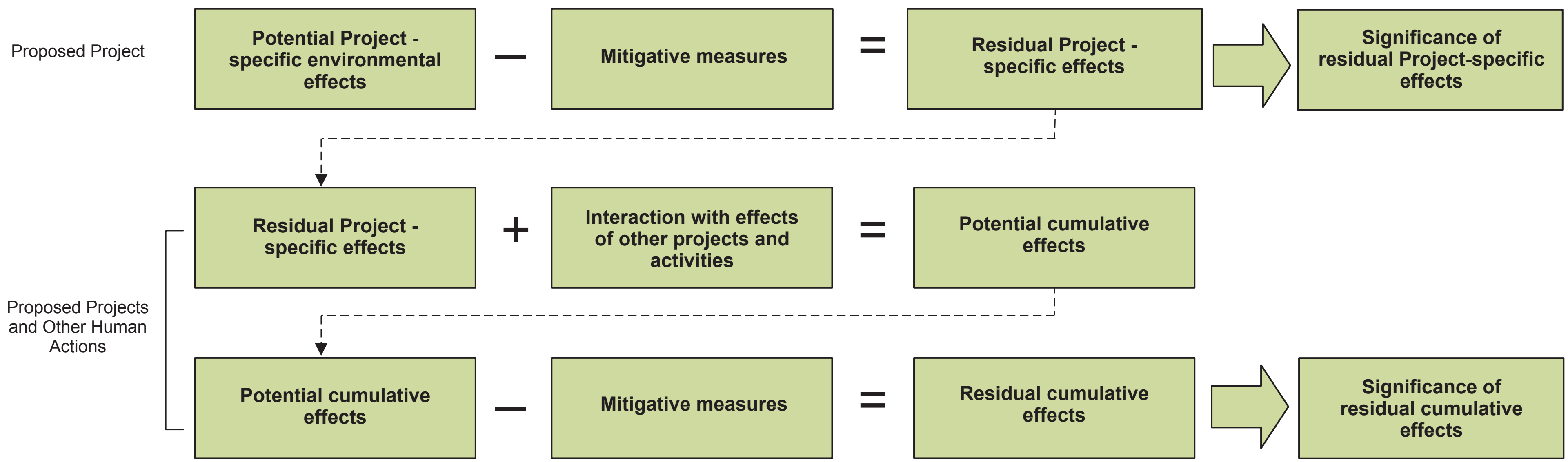
10.10 CUMULATIVE EFFECT ASSESSMENT FOR SURFACE WATER HYDROLOGY

Cumulative changes relate to changes "which are likely to result from the designated project in combination with other projects and activities that have been or will be carried out." This definition follows that for cumulative effects in section 19(1) of the *Canadian Environmental Assessment Act, 2012* (2012) and is consistent with the Good Practice Note on Cumulative Impact Assessment (ESSA Technologies Ltd. and IFC) which refers to consideration of other existing, planned, and/or reasonably foreseeable future projects and developments. This cumulative change assessment provides information to supplement the Cumulative Effects Assessment (CEA) for the receptor VCs, which is a requirement of the AIR (BC EAO 2014) and the EIS Guidelines and is necessary for the proponent to comply with the *Canadian Environmental Assessment Act, 2012* (2012) and the BC *Environmental Assessment Act* (2002).

The assessment method adopted here (Figure 10.10-1) complies with the Canadian Environmental Assessment Agency's (CEA Agency) Operational Policy Statement *Assessing Cumulative Environmental Effects under the Canadian Environmental Assessment Act 2012* (CEA Agency 2013) and the *Guideline for the Selection of Valued Components and the Assessment of Potential Effects* (BC EAO 2013). The method involves the following key steps which are further discussed in the proceeding sub-sections:

- scoping;
- analysis;

Figure 10.10-1
Steps to Cumulative Effects Assessment



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

10.10.1 Establishing the Scope of the Cumulative Change Assessment

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

10.10.1.1 Identifying Intermediate Components for the Cumulative Effects Assessment

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

- there must be a residual change as a result of the Project being proposed;
- that predicted change in the condition of the intermediate component must be demonstrated to interact cumulatively with residual environmental effects from other projects or activities;
- it must be known that the other projects or activities have been or will be carried out and are not hypothetical; and
- the cumulative environmental effect must be likely to occur.

The surface water hydrology sub-components with expected residual effects are:

- *Streamflows:* Estimated effects of the Project on streamflows are described in Section 10.6.1. Low flows at BJL-H1 are estimated to be reduced by up to 24% during the Closure phase. These changes are confined to the LSA boundary. Downstream of the LSA boundary, where interactions with other projects are possible, low flow reductions beyond the reasonable range of data and modelling uncertainty are not expected. Thus, no interactions between the Brucejack Gold Mine Project and other projects are expected with regards to streamflow changes, and therefore no CEA regarding streamflows is undertaken;
- *Channel Morphology:* Effects of the Project on channel morphology are assessed in Section 10.6.2. Operation and maintenance of the access road and hydraulic structures can affect channel morphology within the LSA. Likewise, forestry activities and the existing exploration road could affect the drainage morphology; and
- *Glaciers:* Predicted effects of the Project on glaciers are described in Section 10.6.3. Increased dustfall levels over a portion of Knipple Glacier are predicted. No other past, present, or foreseeable future project is expected to affect Knipple Glacier. Therefore, no CEA regarding glaciers is undertaken.

Based on the aforementioned four criteria (following BC EAO 2013) and expected residual effects, channel morphology is the only sub-component for surface water hydrology that is included in this CEA.

10.10.1.2 Potential Interaction of Projects and Activities with the Brucejack Gold Mine Project for Surface Water Hydrology

A review of the interaction between predicted changes on intermediate components from the Brucejack Gold Mine Project and effects of other projects and activities on channel morphology was undertaken. The review assessed the projects and activities identified in Section 6.9.2 of the Assessment Methodology, including:

- regional projects and activities that are likely to affect the channel morphology;
- effects of past and present projects and activities that are expected to continue into the future (i.e., beyond the effects reflected in the existing conditions of the intermediate component); and
- activities not limited to other reviewable projects, if those activities are likely to affect the channel morphology cumulatively (e.g., forestry, mineral exploration, commercial recreational activities).

A matrix identifying the potential cumulative effect interactions for surface water hydrology (focusing on channel morphology) is provided in Table 10.10-1.

Table 10.10-1. Potential Cumulative Effect Interactions for Surface Water Hydrology

Projects and Activities	Interaction with Surface Water Hydrology (Channel Morphology)
Historical	
Eskay Creek Mine	
Galore Creek Project - Access Road Only	
Goldwedge Mine	
Granduc Mine	
Johnny Mountain Mine	
Kitsault Mine	
Silbak Premier Mine	
Snip Mine	
Snowfield Exploration Project	
Sulphurets Advanced Exploration Project	
Swamp Point Aggregate Mine	
Present	
Brucejack Exploration Program	
Forrest Kerr Hydroelectric Power Facility	
Long Lake Hydroelectric Power Facility	
McLymont Creek Hydroelectric Project	
Northwest Transmission Line	
Red Chris Project	
Reasonably Foreseeable Future	
Arctos Anthracite Coal Project	
Bear River Gravel Project	
Bronson Slope Project	
Coastal GasLink Pipeline Project	
Galore Creek Project	

(continued)

Table 10.10-1. Potential Cumulative Effect Interactions for Surface Water Hydrology (completed)

Projects and Activities	**Interaction with Surface Water Hydrology (Channel Morphology)**
Reasonably Foreseeable Future (cont'd)	
Granduc Copper Mine	
KSM Project	
Kinskuch Hydroelectric Project	
Kitsault Mine	
Kutcho Project	
LNG Canada Export Terminal Project	
Northern Gateway Pipeline Project	
Prince Rupert Gas Transmission Project	
Prince Rupert LNG Project	
Schaft Creek Project	
Spectra Energy Gas Pipeline	
Storie Moly Project	
Treaty Creek Hydroelectric Project	
Turnagain Project	
Volcano Hydroelectric Project	
Land Use Activities – All Stages (past, present, future)	
Parks and Protected Areas	
Guide Outfitting	
Aboriginal Harvest (fishing, hunting/trapping, plant gathering)	
Hunting	
Trapping	
Commercial Recreation (including fishing)	
Forestry	■
Transportation	

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

10.10.1.3 Spatio-temporal Boundaries of the Cumulative Effects Assessment

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

Spatial Boundaries

The CEA boundaries (Figure 10.10-2) are aligned with the surface water hydrology RSA (Figure 10.4-2). Similar to the RSA, the CEA boundaries encompass three major groups of watersheds. These are:

1. Brucejack Mine Site watersheds: Brucejack Creek and its downstream watersheds (i.e., Sulphurets Creek and Unuk River).
2. Brucejack Access Road watersheds: Bowser River (downstream of Knipple Lake), Scott Creek, Todedada Creek, and Wildfire Creek. The access road passes through these watersheds.
3. Brucejack Transmission Line watersheds: Salmon River and Bowser River (upstream of Knipple Lake).

Among all projects in Figure 10.10-2, only the existing exploration access road, which was built as part of the Sulphurets Project and Brucejack Exploration Program, and forestry activities along the access road have the potential to interact with the Project to affect channel morphology.

Temporal Boundaries

Temporal boundaries for the CEA are aligned with the four phases of the Project:

- **Construction:** 2 years;
- **Operation**: 22 years;
- **Closure**: 2 years (includes Project decommissioning, abandonment, and reclamation activities); and
- **Post-closure:** minimum of 3 years (includes ongoing reclamation activities and Post-closure monitoring).

10.10.1.4 Potential for Cumulative Changes

The access road and forestry activities along the access road could potentially affect channel morphology throughout these phases (Table 10.10-2).

Table 10.10-2. Potential Cumulative Effects between the Brucejack Gold Mine Project Surface Water Hydrology and Other Projects and Activities

Potential Cumulative Effect	Brucejack Gold Mine Project	Past Project or Activity	Existing Project or Activity	Reasonably Foreseeable Future Project or Activity	Type of Potential Cumulative Effect
Change in channel morphology	X	Sulphurets Project (access road); Forestry	Brucejack Exploration Program (access road); Forestry	Forestry	Physical-chemical transport, nibbling loss, and spatial crowding

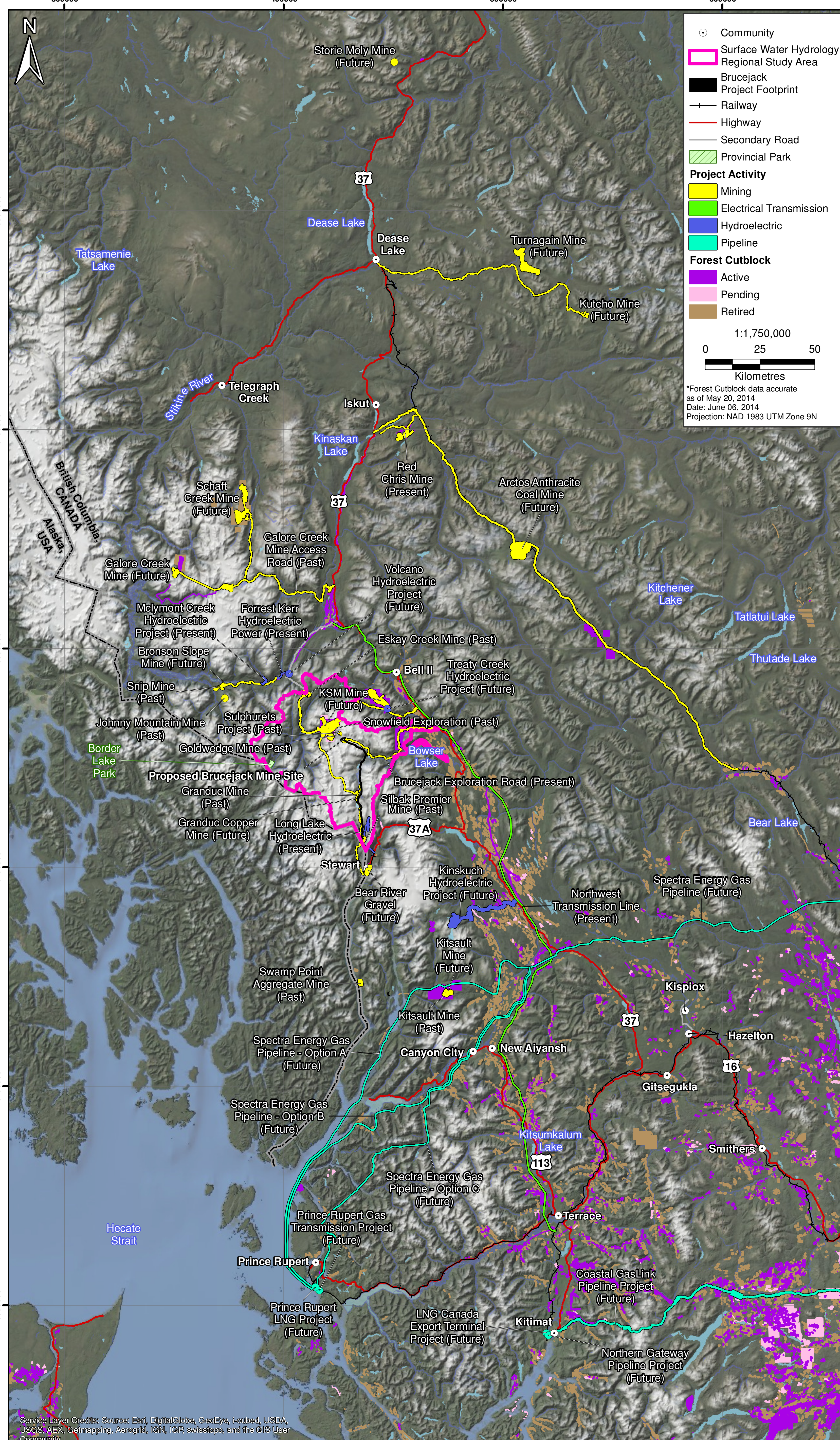
10.10.2 Analysis of Cumulative Changes

10.10.2.1 Cumulative Changes on Channel Morphology

Morphologic changes (e.g., gully formation and increased mass transport on the down-drainage slope of a culvert) could be caused by a combination of forestry activities, access road construction, stream impairments associated with bridges and culverts, and operation/decommissioning of the access road. For example, a culvert could be built on a slope that is affected by forestry activities. Construction may include diversion ditches that divert runoff from the road to the culvert (i.e., increasing the natural drainage area of the culvert). In addition, poor operations and maintenance could lead to sediment transport issues (i.e., culvert blockage/overflow).

Figure 10.10-2

Surface Water Hydrology CEA Boundary Showing all Other Projects and Activities Relevant to Surface Water Hydrology in the Vicinity of the Brucejack Gold Mine Project



Given the spatial and temporal resolution of the preliminary channel morphology assessment (Appendix 10-B, Potential Interactions between the Brucejack Gold Mine Project and Channel Morphology: Preliminary Results, and Section 10.6.2), the morphologic changes due to individual activities (i.e., forestry, road construction, or road maintenance) could not be differentiated from each other. Rather, the assessment considered the collective effects of:

- the existing infrastructure (e.g., ditches that funnel the flow towards the culverts and alter the natural drainage area);
- forestry activities (e.g., land cover was considered in stability assessment); and
- access road operation, maintenance, and upgrade activities.

Therefore, the channel morphology assessment (Appendix 10-B, Potential Interactions between the Brucejack Gold Mine Project and Channel Morphology: Preliminary Results, and Section 10.6.2) may be considered as the CEA for channel morphology. That is, due to the steep slopes, high culvert density, evidence of mass movements, and potential logging-related impacts, Wildfire Creek is the likeliest of the Project area watersheds to experience channel morphology changes associated with drainage by culverts.

Channel morphology stability at Bridges #18 to 21 within the Bowser River watershed (with low gradient, unconfined, perennial streams) were estimated to be the lowest among all bridges. Likewise, channel morphology is not expected to be very stable at Wildfire Creek Bridge primarily due to bank stability issues.

10.10.3 Mitigation Measures to Address Cumulative Predicted Changes

10.10.3.1 Mitigation Measures to Address Cumulative Changes on Channel Morphology

Mitigation measures as described in Section 10.7 will also be applicable to the cumulative effects. Most relevant mitigation measures include:

- Culverts and adjacent slopes will be inspected as required, especially after high rainfall and/or melt events. Identified erosion and sediment concerns, such as blockages, siltation, gullying, or slope failure, will be addressed immediately to protect road infrastructure and the adjacent environment (see Sections 29.13, Soils Management Plan, and 29.16, Transportation and Access Management Plan);
- Channel morphology associated with bed and bank instability along the access road and at culvert and bridge crossing locations will be assessed regularly. Instability will be accessed for risk and addressed accordingly; and
- If drainage stability issues are observed, design of the hydraulic structures will be re-evaluated.

10.10.4 Predicted Cumulative Changes for Surface Water Hydrology

Predicted cumulative changes are those effects remaining after the implementation of all mitigation measures and are summarized in Table 10.10-3.

10.10.5 Characterizing Predicted Cumulative Changes for Surface Water Hydrology

As previously mentioned, the channel morphology assessment (Appendix 10-B, Potential Interactions between the Brucejack Gold Mine Project and Channel Morphology: Preliminary Results, and Section 10.6.2) considered the collective effects of the existing road, forestry activities, and maintenance and upgrade of the access road. Therefore, the channel morphology assessment may be considered as the CEA for channel morphology.

Table 10.10-3. Summary of Predicted Cumulative Changes on Surface Water Hydrology

Subject Area or Sub-component	Timing of Predicted Cumulative Change*	Description of Cause-Effect	Description of Additional Mitigation (if any)	Description of Predicted Cumulative Change
Channel Morphology	Construction, Operation, Closure	Effects of culverts and bridges on channel morphology	n/a (mitigation measures as per Section 10.7)	Culverts in the Wildfire Creek watershed can increase gully formation and downslope mass movement; channel morphology at the Wildfire Creek bridge and at Bridges #18 to 21 are less stable than other bridges.

** Refers to the Project phase or other timeframe during which the effect will be experienced by the intermediate component.*

10.10.5.1 Cumulative Residual Change Characterization for Channel Morphology

Culverts in the Wildfire Creek watershed are expected to affect the morphology of their down-drainage slopes by increasing gully formation and potentially downslope mass movements.

Channel morphology at the Wildfire Creek Bridge, and at low gradient unconfined bridges (i.e., Bridges #18 to 21), are less stable than other access road bridges. That is, the channel morphology could be sensitive to maintenance and decommissioning activities at these bridges.

10.10.6 Surface Water Hydrology as a Pathway for Interaction with Receptor Valued Components

10.10.6.1 Channel Morphology Pathway for Interaction with Receptor Valued Components

Pathways for interaction with surface water quality, fish and fish habitat, aquatic resources, terrestrial ecology, wetlands, navigation, and land use are similar to those explained in Section 10.9.

10.11 SUMMARY AND CONCLUSIONS FOR SURFACE WATER HYDROLOGY

Predicted changes to surface water hydrology are summarized in Table 10.11-1. The key negative effects on surface water hydrology indicators include:

- *Streamflows:* Brucejack Mine Site activities are expected to decrease the low flows at BJL-H1 by up to 24% during the Closure phase. These changes are spatially confined to the LSA boundary, and temporally limited to the Closure phase (i.e., two years).
- *Channel Morphology:* Culverts in the Wildfire Creek watershed could affect the morphology of their down-drainage slopes by increasing gully formation and potentially downslope mass movements. Based on a preliminary assessment, channel morphology at the Wildfire Creek Bridge and at low-gradient unconfined bridges (i.e., Bridges #18 to 21) is less stable than at other access road bridges. Channel morphology could be sensitive to maintenance and decommissioning activities at these bridges.
- *Glaciers:* Conservative estimates of dustfall levels predict increases of up to 34% (compared to the baseline conditions) on the lower 3 km of the Knipple Glacier during the Construction and Operation phases of the Project. Quantification of the effects of the dustfall on albedo, and therefore on glacier ablation, may be possible through the glacier monitoring program.

Table 10.11-1. Predicted Changes to Surface Water Hydrology

Predicted Effects	Project Phase(s)	Mitigation Measures	Cumulative Residual Effects	Receptor VCs Affected
Streamflows				
Increased flows	Construction and Operation	n/a[1]	n/a[1]	n/a[1]
Decreased flows	Closure	Water Management Plan (Section 29.19) will be followed; natural flow drainages will be re-established during the Closure phase.	n/a[2]	n/a[2]
Channel Morphology				
Altered morphology	Construction, Operation, and Closure	Soils Management Plan (Section 29.13) and Transportation and Access Management Plan (Section 29.16) will be followed.	Altered morphology	Water quality, fish and fish habitat, aquatic resources, terrestrial ecology, wetlands, and navigation
Glaciers				
Increased albedo due to dustfall	Construction, Operation, and Closure	Unpaved access roads will be watered to mitigate road dust.	n/a[2]	n/a[2]
Increased summer ablation due to debris[3]	Construction, Operation, and Closure	Glacier monitoring program will assess glacier melt, additional road dust suppression measures will be taken if necessary.	n/a[2]	n/a[2]

[1] Increased annual runoff values and increased low flows were not considered as negative impacts, and therefore no further assessment was undertaken.
[2] No interaction with other projects was identified.
[3] The increase is expected to be less than 1%.

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