7.4 Surface Water Hydrology

This assessment includes the characterization of stream flow in the creeks and rivers in the vicinity of the project, including prediction of the magnitude and frequency of occurrence of peak flows (floods) and low flows. Surface water hydrology integrates information on climate (rainfall and snowfall data) (Section 7.1: Climate) and groundwater hydrology (Section 7.6: Groundwater), as well as the effects of processes such as snowmelt and evaporation. Understanding the range of natural variability of surface water hydrology is important for project design and for understanding the sensitivity of stream and lake ecosystems to potential project effects.

Potential project effects on hydrologic conditions are evaluated and remediation and mitigation measures are described. The significance and likelihood of residual project and cumulative effects is characterized along with recommended monitoring programs and adaptive management measures. This section describes the effects of routine project activities on hydrology. Effects associated with accidents and malfunctions are discussed in Section 8: Accidents and Malfunctions.

7.4.1 Scope of Assessment

Issues and Selection of Valued Ecosystem and Cultural Components

The underground mine and industrial complex are located in the headwaters of Wolverine Creek, near the divide with Go Creek. The airstrip and proposed camp and tailings facility are located in the Go Creek drainage. The proposed access road traverses the headwaters of Hawkowl and Pup Creeks in the Go Creek drainage, before crossing into tributaries of Money and Light creeks on its route north to the Robert Campbell Highway.

It is YZC's intention to concentrate the project footprint and associated effects on hydrology, as much as possible, within the Go Creek drainage upstream of Hawkowl Creek and within the Wolverine Creek drainage, and to manage impacts to minimize downstream effects.

Surface water hydrology is identified as a VECC for the project assessment as it is a key factor with respect to both project design and operation and associated environmental effects. Issues of concern with respect to hydrology include:

- water availability for project use (domestic and process water uses)
- input to project water balance during all project phases including closure (long term saturation of tailings for ARD management)
- design of site water management facilities and access road stream crossings (sizing of diversion and drainage ditches, settling ponds, culverts)
- assimilative capacity of surface waters for project-related discharges
- availability of physical instream habitat for fish and aquatic life

Based on the above considerations, the EA Report Guidelines and the Biophysical Workplan submitted to the Technical Committee, the following factors were selected for further analysis to characterize and assess project effects on the surface water hydrology VECC (Table 7.4-1).

Table 7.4-1 Hydrologic Processes Analyzed and Selection Rationale, and Data Sources

Parameter	Rationale for Selection	Linkage to EA Report Guidelines or Other Regulatory Drivers	Baseline Data for EA
Runoff (mean annual and mean monthly stream flow)	• Key input to stream flow analysis • Influences sediment transport	• Identified in EA Report guidelines and Biophysical Workplan • Mine Water License	• Project field manual and automated data collection • Water Survey of Canada regional hydrology data • Climate data and climatic modelling of precipitation
Peak/flood flows (magnitude and timing)	• Required for water management facility and stream crossing designs • Affects stream channels (stability and morphology) and sediment transport • Floods are a natural hazard that must be considered in project design	• Identified in EA Report guidelines and Biophysical Workplan	• Field data • Regional data • Flood frequency modeling
Low flows (magnitude and timing)	• Affects water quality and assimilative capacity of streams for project effluents • Affects instream habitat for fish and aquatic life • Affects availability of water for mine and camp	• Mine Water License • Identified in EA Report guidelines and Biophysical Workplan	• Field data • Regional data • Low flow modeling
Evaporation	• Affects water levels in tailings dam and other storage facilities • Evaporation affects site water balance	• Identified in EA Report guidelines and Biophysical Workplan	• Regional data • Modelling
Snowmelt rate	• Together with rainfall (Section 7.1), snowmelt forms the principal hydrologic inputs to the system	• Identified in Biophysical Workplan • Implied in EA Report guidelines	• Regional data • Field data • Modelling

Temporal Boundaries

Baseline data collection in the project area began in 1996 with the identification of drainages of interest and the installation of manual and automated gauging stations. Supplementing this data is regional hydrometric data from Water Survey of Canada, which extends back to 1960 for some streams, providing up to 45 years of record for flow frequency analysis.

The assessment timeframe includes the period of record for applicable baseline data collection stations; project construction, operation and decommissioning, and the closure period up to the time when the groundwater table in the mine area has reestablished and contributions to stream baseflows have stabilized. It is anticipated that manual and automated data collection will continue throughout the project life, using the established station network.

Study Area

With respect to surface water hydrology, there are three scales of interest: site-specific, local and regional. The site-specific scale covers areas directly affected or potentially directly affected by the mine and associated infrastructure. This includes the headwaters of Go and Wolverine Creeks. The site-specific area of interest amounts to approximately 10 km^2.

The local scale incorporates the larger drainages of which the tributaries discussed above are part. This includes the entire drainages of Go Creek and Little Wolverine Lake. The local scale covers an area of approximately 100 km^2.

The site-specific scale and local scale together comprise the Local Study Area (LSA), in which hydrology will affect and be affected by project design (Figure 7.4-1).

Figure 7.4-1 Surface Water Hydrology – Local Study Area (Vol.2)

The regional scale or Regional Study Area (RSA) includes the entire drainages of Money Creek, Nougha Creek and Light Creek, covering approximately 1000 km^2. Additionally, the regional scale considers the drainages where data from the Water Survey of Canada stations were used for regional analysis, that is, King Creek, Big Creek, Frances River, Rancheria River and Liard River. Figure 7.4-2 shows the location of Water Survey of Canada stations referenced in the regional analysis.

Figure 7.4-2 Surface Water Hydrology – Regional Study Area and Water Survey of Canada Stations (Vol. 2)

7.4.2 Baseline Conditions

In general, the streams in the project area share similar hydrology. During winter, streams are frozen over and flows are very low. The lowest flows typically occur during March or April. Snowmelt begins in late April and lasts into June with the peak of the freshet in late May or early June. Flows then decline steadily through fall until freeze-up. Because of the typically dry spring and wet summer, rain-on-snow events are most common in June. The magnitude of rainfall-derived flood peaks is generally less than the magnitude of the snowmelt flood peak, except in the smallest drainages where concentrated local rainfall from summer thunderstorms causes higher peak floods than are observed during snowmelt.

This section characterizes project area streamflow conditions based on local observations and extrapolation from long-term regional climate and hydrometric data.

7.4.2.1 Methods

Evaporation and Snowmelt Data

No direct measurements of evaporation or snowmelt rates have taken place at the project site. However, expected evaporation rates can be calculated from known values of air temperature and latitude. Regional evaporation data is also available, although the closest station with reliable evaporation data is at Carmacks, 330 km west of the project. Some regional measurements of snowmelt rate are also available from regional climate stations, primarily from Watson Lake, with an incomplete record from Tuchitua. The locations of these climate stations are described in Section 7.1: Climate.

Hydrometric Data (Stream Flow)

Various stream flow parameters were characterized for the purpose of project design and assessment of project effects; mean monthly and annual flows, wet and dry year flow conditions and extreme events (peak and low flows) for specified return periods. Data sources and analyses used to provide this characterization are described below. Regional Data

There are five Water Survey of Canada hydrometric stations in the RSA which have sufficiently long periods of record to provide useful data for regional hydrometric analysis. Table 7.4-2 lists these stations, their period of record, the drainage area of each, and their distance from the project.

Table 7.4-2 Regional Hydrometric Stations

Station ID	Station Name	Period of Record	Drainage Area (km²)	Distance from Station to Wolverine Mine
10AB003	King Creek at Nahanni Range Road	1975-1988	13.7	90 km
10AA005	Big Creek at Alaska Highway	1978-1999	607	150 km
10AA004	Rancheria River near the mouth	1984-1999	5100	150 km
10AB001	Frances River near Watson Lake	1962-1999	12800	130 km
10AA001	Liard River at Upper Crossing	1960-1999	33400	130 km

In general, the basins represented by regional data are considerably larger than those in the project area. King Creek is the only drainage that is comparable to the majority of the drainages of interest in the LSA. Big Creek is of a similar scale to the largest drainages in the project study area, Money Creek and Nougha Creek. Rancheria River, Frances River, and Liard River are all tens to hundreds of times larger than any drainage within the study area. In order to ensure that the regional data from large drainages is not misapplied to the smaller drainages within the LSA, it is necessary to understand how hydrology varies by scale. This is accomplished through statistical analysis and comparing flows per unit area rather than by total area.

Local Data

Flows have been measured manually at 34 sites in the LSA using a flow meter to measure discharge. Of these, 25 sites have been repeatedly sampled. The remaining nine sites, located along the proposed access route, were each measured once in conjunction with water quality sampling. Of the 25 sites which were sampled repeatedly, nine were sampled only in 1996 and 1997 and then discontinued because they were not representative of streams affected by the proposed project. Seven sites were sampled only in 2005 (four times each), and nine were sampled in 1996, 1997, 2000-2001, and 2005.

In addition to the manual sampling, five stations were equipped with staff gauges to allow measurement of stage (water depth). Of these five stations, two were rendered unusable by ice jams and beaver activity. Three staff gauges remained functional at the end of summer 2005.

Automated sampling stations were installed at three locations in fall 2004 to record continuous stage measurement. Equipment malfunctions at two stations caused the loss of some data, resulting in only a partial interval of record. The remaining station recorded data continuously between fall 2004 and summer 2005.

Table 7.4-3 lists the local hydrometric stations, their drainage areas and hydrometric data collection methods.

Table 7.4-3 Local Hydrologic Stations Sampled, 1996-2005

Station ID	Name	Drainage Area (km²)	Manual Sampling	Staff Gauge	Automated Sampling
W1	Nougha Creek at Wolverine Lake outlet	209	X		
W8	Campbell Creek at Little Wolverine Lake	7.2	X	X	
W9	Wolverine Creek at Little Wolverine Lake	3.3	X		
W11	Money Creek above Go Creek	194	X		
W12	Go Creek above Pup Creek	36.5	X	X	X
W13	Pup Creek above Go Creek	7	X		
W14	Money Creek below Go Creek	238	X	X	
W15	Go Creek above Hawkowl Creek	9.8	X	X	
W16	Hawkowl Creek above Go Creek	10.16	X		
W18	Upper Go Creek	3.5	X		
W19	Upper Hawkowl Creek	6.5	X		
W21	Nougha Creek at Robert Campbell Highway	287	X	X	X
W22	Money Creek above Robert Campbell Highway	425	X		X
W23	Money Creek above Dollar Creek	163	X		
W31	Go Creek at Airstrip	4	X		
W40	Money Creek below Robert Campbell Highway	426	X		

Flow Frequency Analysis

Gartner Lee Ltd. (2004) conducted a flow frequency analysis, using data from the regional stations, to determine trends in expected monthly and annual flow by drainage area. The preliminary results of this analysis determined systematic variations by area in the regionally measured streamflows, with large drainages (>1000 km²) behaving differently statistically than small drainages. A corrective factor was applied to standardize the results from small and large drainages. The results, corrected so as to be applicable for small drainages were then applied to the drainage basins within the LSA

Gartner Lee Ltd. (2004) also analyzed mean annual flow frequency within the regional drainages. The results were used to develop ratios relating the expected flow in a dry or wet year to the expected flow in an average year. These ratios can be applied to predict wet and dry year flows for a range of return periods, as required for water management design purposes.

Peak Flow Analyses

Peak flows are flood events. Three methods were used to estimate peak flows for selected drainages within the LSA:

- flood frequency analysis using regional data (Gartner Lee Ltd. 2004)
- rational method, that is, flow modeling based on precipitation data (McCuen 1998)
- regional analysis using data from a similar hydrologic region, in this case the Rocky Mountains (Beckers, Alila and Mtiraoui 2002)

Each method has its drawbacks; however, by comparing the results of the three methods, trends can be determined. The rational method is often used for hydrologic engineering to estimate expected flow volumes. It has the advantage of being easy and effective to use, but it can be overly simplistic for modeling complex watersheds.

The region-wide analysis of drainages in the Rocky Mountains (Beckers, Alila and Mtiraoui 2002) included equations for estimating the 2-year and 100-year peak flows. The region of analysis did not include the Yukon; however, the Rocky Mountains are hydrologically similar to the Pelly Mountains in that they are both snowmelt-dominated, hence the analysis is considered applicable.

The 2-year and 100-year peak flows were determined for selected drainages using each of the three methods. In the case of the rational method, 2-year daily snowmelt (from Section 7.4.2.2) and 100-year daily rainfall totals (from Section 7.1: Climate) were used as the runoff inputs. The results of the three methods were then used to calibrate the frequency analysis of Gartner Lee Ltd. (2004) for floods of other specified return periods.

Low Flow Analyses

Gartner Lee Ltd. (2004) conducted a frequency analysis of low flows for specified return periods, using the regional data. This analysis was checked by modeling the low flows that would result from monthly precipitation in the average month (September or March) of the dry year with the same return period. For instance, the value Gartner Lee Ltd. (2004) determined for a 10-year low flow in Go Creek at Station W12 was compared to the predicted mean monthly runoff (the monthly precipitation minus the monthly evaporation) occurring in September of a 10-year dry year. There was good agreement between the values thus checked, indicating that the regional analysis may be accurate.

7.4.2.2 Results

Evaporation

Evaporation at the project site has been estimated in two ways:

- using mean temperature and latitude
- using regional evaporation data

Hamon (1961, 1963) derived two variations of an equation that estimates evaporation from the parameters of air temperature and length of day. Length of day is a function of day of the year and latitude. The project site is at latitude 61° 27’ N. Monthly evaporation totals were estimated from the Hamon equations using the mean monthly air temperature (Section 7.1: Climate) and mean monthly day length (defined as the length of day on the 15th day of each month). For example, the mean evaporation for June would be estimated using the mean monthly temperature for June and the length of day calculated for June 15th. The Hamon equations have been found to overestimate mean early summer evaporation, and underestimate mean late summer evaporation (Dudley, Hodgkins and Neilsen 2001); however, because of their simplicity, they provide the most reliable method of estimating evaporation when site specific data is unavailable. The numbers obtained from the Hamon equation were compared with the limited regional evaporation data for the Yukon. The data set used represents the mean of 19 years of observations taken at Carmacks over the period 1959-1992. Saruhashi (2001) considered the Carmacks data to be representative of the entire Yukon River basin and thus broadly representative of the Yukon as a whole. Carmacks is at approximately the same latitude as the project (61°50’ N), and at an elevation of 550 m. The mean monthly temperatures at Carmacks are higher than at the project site; therefore, evaporation rates at the project site should be lower than the values recorded at Carmacks. Accordingly the Carmacks values should be regarded as an upper bound on the estimates derived from the Hamon equations.

Figure 7.4-3 presents monthly and annual evaporation estimates from the two Hamon equations and from the Carmacks data.

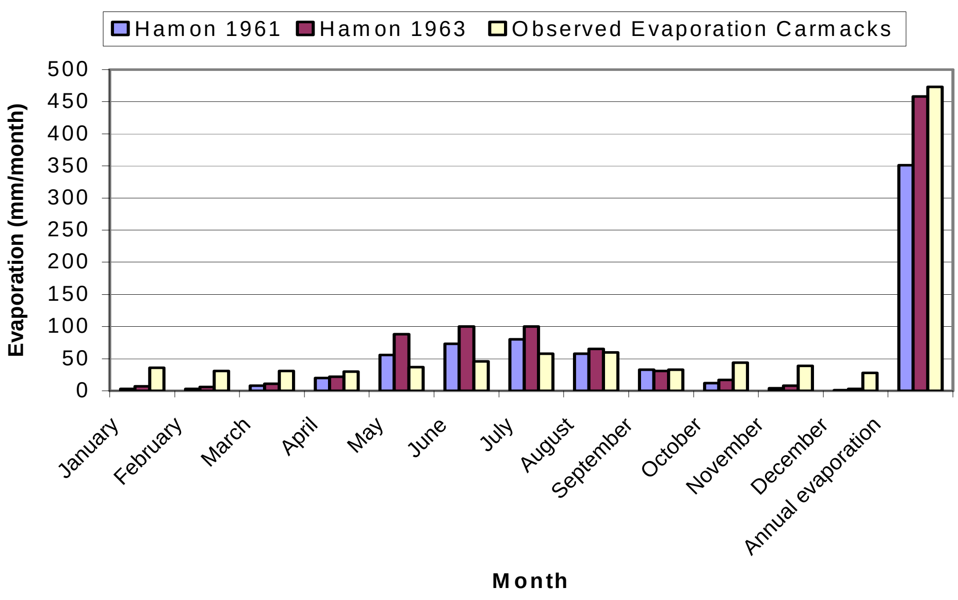

Figure 7.4-3 Monthly and Annual Evaporation Estimates

Snowmelt

Direct measurements of snowmelt have not been made at the project site. The regional climate stations Tuchitua and Watson Lake record daily depth of snow on the ground, in centimetres. It is possible to estimate snowmelt from changes in the depth of daily snow on the ground. However, these values are not directly equivalent because the snowpack consolidates as it ages, especially under warm conditions. Thus, it is difficult to determine if a change in snowpack depth represents melt, consolidation or a combination of both. A 10 cm reduction in snowpack might be the equivalent of 5-10 mm of snow water equivalent lost as melt, and a consolidation of the remaining snow. Or it could represent 20 mm of melt with little snowpack consolidation. Additionally, warm rain can result in the opposite process – the snowpack becomes rotten and hollow, fills with voids, and loses water equivalent without significantly reducing in depth.

The characterization of snowmelt is further complicated by the differences in elevation. The snowpack at Watson Lake and Tuchitua primarily melts in April and early May, the driest time of the year (Section 7.1: Climate); there are few instances of rain-on-snow, and little way to estimate the magnitude of such events as compared to snowmelt without rainfall. At the project site, the snowpack primarily melts in May with some melt in early June. Therefore, there is a greater overlap of rainy conditions with the period of snow cover, resulting in an increased frequency of rain-on-snow events at the project site.

With respect to estimating snowmelt, thirty years of snow-on-ground measurements at Watson Lake from the months of April and May were examined. Tuchitua has several periods where no data were recorded and is thus less suitable for this purpose. Peak annual daily change in snowpack over those 30 years ranged from 5 to 15 cm with the mean being 8.6 cm.

Regional analyses of runoff and streamflow already include both rainfall and snowmelt as runoff generating mechanisms. The only place where snowmelt must be explicitly compared to rainfall when evaluating runoff is when using the rational method, as was done in the peak flow analysis.

Stream Flows

Predicted Mean Monthly and Mean Annual Flows

Table 7.4-4 presents the results of the flow frequency analysis for selected monitoring stations within the LSA, based on the Gartner Lee Ltd. regional analysis (2004). The stations selected reflect a wide range of drainage areas. It should be noted that these results use drainage area as the only variable. Two drainages with exactly the same area would be predicted to discharge the same monthly and annual amounts. In practice, this is not the case. There is variability in discharges between watersheds of similar size resulting from factors, such as geology, aspect, and presence and volume of lakes, that are difficult to characterize in an analysis of this sort. This is discussed in more detail in the section on observed flows below.

Table 7.4-4 Expected[8] Mean Monthly and Annual Flows (m^3/s) for Selected Stations

	Drainage and Area							
Station	**W9**	**W31**	**W16**	**W12**	**W44**	**W14**	**W22**	**W21**
Month	Wolverine Creek at Little Wolverine Lake (3.3 km²)	Go Creek at Airstrip (4 km²)	Go Creek at Hawkowl Creek (10 km²)	Go Creek at Money Creek (36.5 km²)	Tailings Dam Catchment (0.01km²)	Money Cr. downstream of Go (238 km²)	Money Cr at highway (425 km²)	Nougha Creek at Highway (279 km²)
Jan	0.01	0.012	0.033	0.108	0	0.703	1.258	0.848
Feb	0.008	0.01	0.026	0.093	0	0.599	1.048	0.722
Mar	0.007	0.008	0.027	0.083	0	0.54	0.967	0.651
Apr	0.009	0.01	0.034	0.102	0.002	0.667	1.193	0.804
May	0.119	0.125	0.218	0.653	0.03	4.249	7.606	5.124
Jun	0.159	0.176	0.472	1.31	0.036	8.558	15.31	10.32
Jul	0.073	0.081	0.243	0.801	0.019	5.24	9.222	6.319
Aug	0.04	0.043	0.135	0.438	0.014	2.866	5.13	3.456
Sep	0.035	0.037	0.131	0.388	0.014	2.54	4.54	3.062
Oct	0.03	0.031	0.089	0.33	0.003	2.16	3.866	2.605
Nov	0.017	0.018	0.051	0.21	0	1.255	2.246	1.514
Dec	0.012	0.013	0.039	0.135	0	0.884	1.582	1.066
Year	0.035	0.0471	0.125	0.53	0.01	2.528	4.509	3.041

Predicted Monthly and Annual Flows for Wet and Dry Years

Gartner Lee Ltd. (2004) also analyzed mean annual flow frequency within the regional drainages. The results were used to develop ratios relating the expected flow in a dry or wet year to the expected flow in an average year. Table 7.4-5 gives the ratio of expected mean monthly and annual flows for return periods ranging from a 1-in-1000 year dry year to a 1-in-1000 year wet year as compared to the average year. For the purpose of illustration, estimated average annual flows in Go Creek at Money Creek (Station W12) are presented, based on this approach.

Table 7.4-5 Flow Frequency Ratios by Return Period

Return Period	Exceedance Probability	Ratio of Flow to Average Flow	Example – W12 Mean Annual Flow (m³/s)
1 in 1000 Year Dry	0.999	0.554	0.294
1 in 100 Year Dry	0.99	0.641	0.340
1 in 25 Year Dry	0.96	0.713	0.378
1 in 10 year Dry	0.9	0.779	0.413
Average Year	0.5	1.000	0.530
1 in 10 Year Wet	0.1	1.248	0.661
1 in 25 year Wet	0.04	1.364	0.723
1 in 100 Year Wet	0.01	1.524	0.808
1 in 1000 Year wet	0.001	1.773	0.940

[8] Gartner Lee Ltd. (2004)

A distinction should be made between mean annual flows for wet and dry years, derived from the frequency analysis, and the estimates of peak and low flows discussed below. The frequency analysis used in Table 7.4-5 relates to annual trends. There is no direct connection between the frequency of annual trends and the frequency of peak or low flow events. The mean annual discharge in the 200 year wet year is the average flow over that year, whereas the 200-year peak flow is the magnitude of the largest flood that will, on average, occur only once in 200 years. While statistically, it is more likely that the 200 year peak flow would occur during a wet year, there is no guarantee that it will.

Observed Flows

Table 7.4-6A and 7.4-6B present observed flows measured at hydrometric stations from 1996 through 2005 and along the access road route in 2005. These spot measurements are snapshots of flow taken at one point in time which can fall anywhere between the highest and lowest flow of the month. As described below, the trends observed through spot measurements can be used to calibrate results from the regional analysis.

Table 7.4-6A Flow Measurements at Local Hydrologic Stations, 1996 – 2005

Site	Station Name	Flow Measured 2005				Flow Measured 1996						Flow Measured 1997		
		May	July	Aug	Sept	March	May	Jun	July	Aug	Nov	May	July	Sept
W1	Nougha Creek below Wolverine Lake		2.622	2.143	1.937	0.56	5.16		1.76	1.25		5.124	2.079	
W8	Campbell Creek at mouth		0.101	.142E	0.134									
W9	Wolverine Creek at mouth		0.029	0.017	0.013	0.002	0.09		0.01	0.023	0.007			
W11	Money Creek above Go Creek		3.917	2.615	1.814	0.28			3.85	2.77		2.058	3.549	2.536
W12	Go Creek above Pup Creek		0.555	0.485	0.24									
W12A	Go Creek at Pup Creek (beaver dam)[9]		0.452	0.459		0.04	1.18	0.44	0.47	0.78		0.36	0.52	0.32
W13	Pup Creek above Go Creek				0.025				0.058	0.089		0.108	0.057	0.059
W14	Money Creek below Go and Pup		4.102	2.591	3.177									
W15	Hawkowl above Go	0.772	0.285	0.232	0.164									
W16	Go above Hawkowl	0.975	0.13	0.166	0.157				0.121			0.111	0.119	0.259
W18	Upper Go		0.078	0.176	0.044									
W19	Upper Hawkowl below beaver ponds		0.205	0.093	0.133				0.047	0.047		0.024	0.074	0.039
W21	Nougha Creek above highway	4.78E	3.018	3.423	3.156									
W22	Money Creek above highway		6.427	6.373	5.622	1.6			4.106	7.6		4.91	7.58	
W23	Money Creek above Dollar Creek		3.26	3.104	2.175									
W31	Go Creek above airstrip		0.031	0.061	0.023									
W40	Money Creek below highway		9.175	5.343	5.215									

[9] Station W12 was located at the current Site 12A until 2004 when a beaver dam constructed at the site made it unusable. The site was relocated upstream approximately 150 m to a usable reach. The beaver dam broke sometime in June 2005. The W12 staff gauge remains at Station W12A.
Additional flow measurements were made at Station W12A in 2001. These are as follows: June 6: 2.63 m^3/s; June 14, 0.809 m^3/s; July 13, 0.309 m^3/s; August 4, 0.289 m^3/s.

Table 7.4-6B Spot Measurements of Streamflow (m^3/s) Along Access Road Route, 2005

Site	Station Name	Flow Measured 2005	
		August	September
W51	Small unnamed tributary of Light Creek	0.0078	
W51A	Light Creek above Robert Campbell Highway	0.34	
W61	Bunker Creek in upper canyon	0.29	
W62	Unnamed creek 200m upstream of Bunker Creek	0.073	
W69	Headwaters of Chip Creek	0.017	
W71	Pitch Creek upstream of Light Creek		0.014
W72	Light Creek upstream of Pitch Creek		0.17
W73	Bunker Creek 2km downstream of W61		0.57
W74	Chip Creek tributary below waterfall		0.002E[10]

A large enough database of observed flows, when associated with staff gauge measurements or automated stage recording, can be used to construct a stage-discharge curve, which allows determination of flows based on recorded water levels. Unfortunately, due to a lack of sufficient measurements of peak flows during spring freshet, it is not yet possible to construct representative stage-discharge curves for any of the stations within the LSA. As hydrologic monitoring continues during the pre-production phase of the project, it will be possible to develop reliable stage-discharge curves. At that point staff gauge readings will allow a determination of discharge at selected stations.

To date, spot flow measurements have yielded some interesting data. For instance, flows in Go Creek at W31 (Upper Go Creek) decrease significantly at W18 (500 m downstream). This indicates that water is flowing from the surface to the subsurface along the intervening channel reaches. Local topography and surficial geology indicates that W31 is located in an area with shallow soils over bedrock, while W18 is located on a broad fan above the airstrip, with relatively deep surficial materials. This can explain the decreasing surface flow – the depth to the water table increases downstream as the surficial materials thicken, and water flows from surface to subsurface as a result.

Similarly, the flows measured in Money Creek at W22 (above the Robert Campbell Highway crossing), are consistently higher than flows at W40 (100 m downstream, below the Robert Campbell Highway crossing). Again, W22 is located near the mouth of a bedrock-controlled canyon, while W40 is located on the broad fan of Money Creek where it flows into Frances Lake, so water may be flowing into or out of the fan as it flows downstream.

A discrepancy between Money Creek flows measured at W11 (above Go Creek), and W14 (below Go Creek), is harder to explain. Repeat measurements at the same site in close time sequence indicate that the measurement error is insufficient to explain the observed discrepancy. The flow at W14 is not equal to the sum of flows measured at Stations W11, W12 (Go Creek above Pup Creek) and W13 (Pup Creek above Go Creek),

[10] This creek was dry at the planned road crossing site. 100 m upstream of the crossing, some water was flowing. Water quality samples were taken from the upstream location. The volume of flowing water was too low to use the current meter to measure flow; flow was estimated from the time it took to fill a 1L bottle.

as would be expected. In one case flows at W14 are actually lower than at W11. It is likely that there is also water transfer between the surface and subsurface flows in this area but more measurements will be required to verify this.

The spot flow measurements do highlight some differences between the predicted flows (Table 7.4-4) and observed flows. These discrepancies are to be expected because the flood frequency analysis used considers watershed size as its only variable. It is unlikely that two watersheds of the same size will actually experience annual or monthly flow volumes of exactly the same magnitude. One important variance between predicted and observed flows is noted in Wolverine Creek, at Station W9. Spot flows observed at Station W9 have consistently been lower than predicted mean monthly flows. If some of the observed flows were higher than predicted mean monthly flow and others were lower, a statistical discrepancy would not exist. However, that all flows measured have been consistently lower than predicted indicates that the actual monthly and annual flow in Wolverine Creek is probably less than the values predicted in Table 7.4-4.

Peak Flows

Table 7.4-7 compares the estimated 2-year and 100-year peak flows in the selected watersheds, based on the three methods of analyses. Table 7.4-8 gives the estimated peak flows for selected return periods in selected drainages. In Table 7.4-8, peak flows for the 2-year and 100-year events were based on weighted averages using the three estimates from Table 7.4.7; the values for the remaining return periods were then interpolated according to the Gartner Lee Ltd. (2004) frequency analysis. Scale makes a difference with respect to estimating peak flows. Thunderstorms deposit very high precipitation in a small area. As the size of the watershed increases, the relative contribution of the storm to flows in the watershed decreases. In very small watersheds, rainfall is probably responsible for the majority of observed peak flows. In the largest watersheds, rainfall events typically will not produce peak flows of the same magnitude as flows from basin-wide snowmelt. The rational method probably gives the best estimate of peak flows in the smallest watersheds (less than 10 km^2) while the regional methods probably more closely approximate the peak flows to be expected in the largest watersheds.

Table 7.4-7 Comparison of 2-Year and 100-Year Floods (m^3/s) Estimated by Various Methods

Station Number	Location	2-Year Peak Flow Estimated by Rational Method[11]	2-Year Peak Flow Estimated by Regional Analysis[12]	2-Year Peak Flow Estimated by Flow Frequency Analysis[13]		100-Year Peak Flow Estimated by Rational Method	100-Year Peak Flow Estimated by Regional Analysis	100-Year Peak Flow Estimated by Flow Frequency Analysis
W31	Go Creek at Airstrip	0.53	0.60	0.44		1.22	1.41	0.976
W16	Go Creek at Hawkowl	1.32	1.51	1.03		3.04	3.43	2.23
W12	Go Creek at Money Creek	4.81	5.54	3.55		11.1	12.07	7.34
W14	Money Creek below Go Creek	29.18	33.27	20.84		67.1	60.13	41.16
W22	Money Creek at RC Highway	48.05	54.78	35.99		111	96.97	48.52
W9	Wolverine Creek at Little Wolverine Lk.	0.43	0.49	0.366		0.99	1.17	0.805
W8	Campbell Creek at Lake	0.95	1.08	0.769		2.19	2.5	1.65

[11] McCuen (1998)
[12] Beckers, Alila and Mtiraoui (2002)
[13] Gartner Lee Ltd (2004)

Table 7.4-8 Estimated Peak Flows for Selected Return Periods by Drainage (m^3/s)

Station	Station Number	Drainage Area (km^2)	2-year[14]	10-year	50-year	100-year[15]	200-year	1000-year
Go Creek at Airstrip	W31	4	0.523	0.884	1.13	1.202	1.28	1.422
Go Creek at Hawkowl	W16	10	1.286	2.16	2.67	2.9	3.06	3.45
Go Creek at Money Creek	W12	36.5	4.63	7.78	9.64	10.16	10.92	12.13
Money Creek below Go Creek	W14	238	27.76	43.3	52.7	56.13	58.85	65.51
Money Creek at RC Highway	W22	425	46.27	68.3	80	85.33	88.83	98.09
Wolverine Creek at Little Wolverine Lk.	W9	3.3	0.429	0.737	0.926	0.988	1.046	1.17
Campbell Creek at Lake	W8	7.2	0.933	1.58	2.01	2.113	2.277	2.54

The presence of Wolverine Lake in the Nougha Creek drainage acts as a reservoir that buffers the response of Nougha Creek to flood events. Therefore, it is likely that the actual peak flows in Nougha Creek (Stations W1 and W21) would be significantly lower than the values estimated through the rational equation or through regional analysis.

Low Flows

Table 7.4-9 presents expected values for summer and winter low flows of different return periods at selected hydrologic stations. In the case of small drainages, such as Wolverine Creek at Station W9, some predicted winter flows are very low. For instance, the normal year winter flow for Wolverine Creek is predicted to be 0.007 m^3/s, which is approximately 25 m^3/h. The 10-year and 25-year winter low flows are significantly lower - 6 m^3/h and 4 m^3/h respectively. It is quite probable that during the winter, Wolverine Creek freezes solid at times and the net flow is actually zero.

7.4.3 Effects Assessment Methodology

Project and cumulative effects on hydrology are characterized in accordance with the EA Report Guidelines using effects attributes defined in Table 7.4-10.

[14] Weighted average from Table 7.4-7 2-year flows
[15] Weighted average from Table 7.4-7 100-year flows

Table 7.4-9 Seasonal Low Flows For Various Return Periods by Drainage

Station	Station Number	Drainage Area	Normal Year Summer	Normal Year Winter	10-year Dry Summer	10-year Dry Winter	25-year Dry Summer	25-year Dry Winter
Go Creek at Airstrip	W31	4	0.038	0.008	0.0145	0.0017	0.011	0.0013
Go Creek at Hawkowl	W16	10	0.096	0.026	0.039	0.0057	0.029	0.0043
Go Creek at Money Creek	W12	36.5	0.356	0.083	0.158	0.025	0.12	0.019
Money Creek below Go Creek	W14	238	2.16	0.54	1.20	0.201	0.97	0.162
Money Creek at RC Highway	W22	425	3.86	0.97	2.25	0.384	1.84	0.313
Wolverine Creek at Little Wolverine Lk.	W9	3.3	0.031	0.007	0.012	0.0017	0.0083	0.0012
Campbell Creek at Lake	W8	7.2	0.068	0.019	0.027	0.004	0.020	0.003

Notes: 1. Summer low flow is in late September or early October, just before freezeup.
2. Winter low flow is immediately before breakup – late March or early April.

Determination of Effects Significance

The significance of residual project and cumulative effects will be determined based on the defined effects attributes, as follows:

An effect will be considered significant if it is:

- an adverse effect of high likelihood, moderate magnitude and that is far future in duration or irreversible
- an adverse effect of high likelihood, and high magnitude, unless it is local in geographic extent and short to long term in duration
- an adverse effect of high likelihood, and high magnitude, that is local in geographic extent and far future in duration or irreversible

Otherwise, effects will be rated as not significant.

7.4.4 Project Effects

There are several ways in which the project can potentially affect surface water hydrology throughout the life of the project:

- ***Water use for domestic and industrial purposes*** – There will be no direct extraction of water from surface water bodies for project use during the operations phase. Potable water will be supplied from deep aquifer wells. The majority of water for ore processing will come from mine dewatering and reclaim water from the tailings facility. Small amounts of fresh make-up water will be supplied by a deep well (Section 2.9: Site Water Management). Water supplied from deep aquifers for the project will not result in significant drawdown or dewatering of shallow groundwater (Section 7.6: Groundwater) and thus will not significantly affect surface water hydrology.

Table 7.4-10 Effect Attributes for Surface Water Hydrology

Attribute	Definition
Direction	
Positive	Condition of VECC is improving
Adverse	Condition of VECC is worsening or is not acceptable
Neutral	Condition of VECC is not changing in comparison to baseline conditions and trends
Magnitude	
Low	Effect occurs that might or might not be detectable, but is within the range of natural variability and does not compromise ecological, economic or social/cultural values
Moderate	Clearly an effect but unlikely to pose a serious risk to the VECC or represent a management challenge from an ecological, economic or social/cultural standpoint
High	Effect is likely to pose a serious risk to the VECC and represents a management challenge from an ecological, economic or social/cultural standpoint
Geographic Extent	
Site-specific	Effect on VECC confined to a single small area within the Local Study Area (LSA)
Local	Effect on VECC within Local Study Area (LSA)
Regional	Effect on VECC extends into the Regional Study Area (RSA)
Duration[16]	
Short term	Effect on VECC is limited to the <1 year
Medium term	Effect on VECC occurs between 1 and 4 years
Long term	Effect on VECC lasts longer than 4 years but does not extend more than 10 years after decommissioning and final reclamation
Far future[17]	Effect on VECC extends >10 years after decommissioning and abandonment
Frequency (Short Term duration effects that occur more than once)	
Low	Effect on VECC occurs infrequently (< 1day per month)
Moderate	Effect on VECC occurs periodically (seasonal or several days per month)
High	Effect on VECC occurs frequently throughout the year (weekly)
Reversibility	
Reversible	Effect on VECC will cease to exist during or after the project is complete
Irreversible	Effect on VECC will persist during and/or after the project is complete
Likelihood of Occurrence	
Unknown	Effect on VECC is not well understood and based on potential risk to the VECC, effects will be monitored and adaptive management measures taken, as appropriate
High	Effect on VECC is well understood and there is a high likelihood of effect on the VECC as predicted

- ***Project site and access road clearing and soil compaction*** – Removal of vegetation and site development causes reduced transpiration, increased soil moisture and decreased infiltration leading to increased site runoff. The potential effect of increased runoff on stream flows will be minimal as the disturbed area is very small in comparison to the total drainage areas and site water management will further minimize potential of effects (see below).
- ***Project site water management*** – Clean water diversions around facility sites, site drainage collection ditches and settling ponds will minimize potential effects of

[16] Reclamation goals are to approximate original (pre-mine) climate and hydrology within the range of natural variability or to approximate regional climate if post-operational regional climate differs from pre-operational regional climate.
[17] Effects to some VECCs may be permanent (See reversibility).

ground surface disturbance on runoff and streamflows in the project area (Section 2.8 Tailings Disposal; Section 2.9: Site Water Management).

- ***Access road development*** – Road ditches intercept shallow subsurface flow and bring it to the surface. Road surfaces become compacted and relatively impermeable, reducing infiltration of precipitation. Road ditches and drainage structures form preferred pathways for drainage, hastening runoff. The density of roads that will be built is low (less than 1 km of road length per square kilometre of drainage area) which indicates that the overall contribution of the road drainage network to watershed runoff will not be significant (BC Ministry of Forests 1999). Increased runoff from road development is not expected to affect peak flows in local streams. Road drainage structures and stream crossings will be appropriately sized for passing design flows (Section 2.11: Transportation) and will be capable of passing bedload sediment of the size range normally transported by the streams.
- ***Snow plowing*** – Piling up of snow, compaction by vehicle travel, and introduction of sediment, particularly dust, to the snowpack in the vicinity of the project site and access road, will result in both more rapid snowmelt (in the case of dirty snow) and slower snowmelt (in the case of compacted or piled snow). Localized changes in the snowpack melt rate resulting from more rapid melting, and slower melting, will be small and should cancel each other out. No measurable effects on peak flows during spring freshet are expected.
- ***Mine dewatering affecting flows in Wolverine and Go Creeks*** – Underground mine development will intercept groundwater flows, primarily in the Wolverine Creek basin. The mine water will be treated in the water treatment plant and either recycled to the process plant or discharged to Go Creek. At full development this could potentially result in measurable flow reductions in Wolverine Creek and increased flows in Go Creek.

Based on the small project footprint in the affected drainage basins and site water management to minimize effects of increased runoff, no measurable effects on surface water hydrology are expected from surface disturbances. The main issue with respect to project effects on hydrology is groundwater interception due to underground mine dewatering and diversion to Go Creek. This effect would occur primarily during operations, decommissioning and initial years of closure, when the ground water table will re-establish in the mine area. Effects and mitigation are described in detail below.

Wolverine Creek

The effect of mine dewatering on groundwater contributions to stream flow will be greatest in Wolverine Creek. Reductions in low flows are expected to be proportional to the ratio of area dewatered to total watershed area. The Wolverine Creek drainage area is 3.3 km^2 at W9 near Little Wolverine Lake. The area affected by dewatering is between 1.4 and 1.65 km^2 in Wolverine Creek watershed (Figure 7.4-4). Therefore, low flows in Wolverine Creek could be expected to decrease by 40-50% while the mine is in operation (Table 7.4-11). Mean summer flows and peak flows will not be significantly affected by the reduction in baseflow, as these flows are primarily derived from snowmelt and rainfall runoff, rather than from baseflow.

Figure 7.4-4 Area of Groundwater Drawdown and Dewatering with Respect to Go Creek and Wolverine Creek Drainages (Vol. 2)

Table 7.4-11 Effects of Groundwater Drawdown and Treated Water Discharge on Low Flows (m³/s) – Wolverine and Go Creeks

Station	Station Number	Drainage Area	Normal Year		10-year Dry		25-year Dry	
			Summer	Winter	Summer	Winter	Summer	Winter
Go Creek at Hawkowl - baseline conditions (from Table 7.4-9)	W16	10	0.096	0.026	0.039	0.0057	0.029	0.0043
Go Creek at Hawkowl – with drawdown			0.091	0.025	0.037	0.0054	0.028	0.0041
Go Creek above Money Creek baseline (from Table 7.4-9)	W12	36.5	0.356	0.083	0.158	0.025	0.120	0.019
Go Creek at Money Creek – with drawdown and summer discharge of treated water[18]			0.361	0.082	0.166	0.025	0.128	0.019
Go creek at Money Creek – with drawdown and no summer discharge of treated water[19]			0.351	0.082	0.156	0.025	0.118	0.019
Wolverine Creek at Little Wolverine Lk.- baseline conditions (from Table 7.4-9)	W9	3.3	0.031	0.007	0.0117	0.0017	0.008	0.0012
Wolverine Creek at Little Wolverine Lake – with drawdown			0.015	0.003	0.006	0.0009	0.004	0.0006

As was noted in Section 7.4.2.2, under current conditions, Wolverine Creek may freeze solid at times during the winter and have a net discharge of zero. The predicted reduction in low flow from mine dewatering increases the probability that the creek will freeze solid during the winter. If the creek does freeze, it will remain frozen for a longer duration as well. Effectively, similar to baseline conditions, there may be no flowing water in Wolverine Creek for much of the winter while mine dewatering exists.

Following closure of the mine, the restoration of groundwater will proceed in two phases, as described in Section 7.6. The refilling of the mine itself will take approximately two and a half to three years, and the restoration of the water table above the mine will take approximately thirteen more years. During the first period, the reduced low flows described above will continue to occur. During the second thirteen-year period, low flows will gradually increase as the water table above the mine re-establishes itself. By the time the groundwater table above the mine is fully restored, approximately sixteen years after closure, low flows in Wolverine Creek will have returned to their original levels.

[18] Summer discharge of treated water will vary between 0 and 35.8 m³/hr. Numbers used here assume maximum discharge (35.8 m³/hr, equivalent to 0.01 m³/s).
[19] This row represents the conditions when discharge is not occurring.

Dewatering will have minimal effects on summer mean flows, and on peak flows, as these flows are primarily composed of runoff from snowmelt and precipitation rather than groundwater. Reduction in low flows in Wolverine Creek during operations and closure will not reduce the water level in Little Wolverine Lake. The main concern regarding reduced low flows in Wolverine Creek are on productive instream habitat for benthic communities and fish. Flow monitoring in Wolverine Creek will continue during operations to observe the effects of mine dewatering and assess the related effects on fish habitat in the lower reaches (Section 7.8: Fish Resources).

Requirements and mitigation options will be refined based on follow-up studies (Section 7.4.7).

Go Creek

Groundwater contributions to surface flows in upper Go Creek may also be affected by mine dewatering. The area of the Go Creek drainage basin above Hawkowl Creek (at Station W16) is 10 km^2. The area of the Go Creek drainage potentially affected by dewatering is approximately 0.5 km^2. The relative effect on Go Creek from mine dewatering will be minimal– approximately a 5% reduction in low flows.

Mine water will be diverted for use as ore processing water and ultimately discharged to Go Creek via the water treatment plant (Section 2.9: Site Water Management) The maximum volume of water to be discharged has been calculated at 35.8 m^3/hour (Section 2.6: Ore Processing). This is equivalent to 0.01 m^3/s. This discharge will only occur during the summer months, approximately May to October, if the treated water is not recycled to the process plant. The net effects of mine dewatering and treatment plant discharges on Go Creek low flows are summarized in Table 7.4-11. As the volume of treated water is minimal compared to the amount of precipitation and runoff, the discharge of treated water will not significantly affect peak flows or mean monthly flows.

During the commissioning of the tailings facility, water will be diverted from Go Creek near Station W31. The volume of water to be diverted is 203 m^3/hour, equivalent to 0.056 m^3/s. This will reduce monthly flows in Go Creek during the period of diversion. Water will be diverted during May, June and part of July when the mean monthly flow in Go Creek near Station W31 is greater than 350 m^3/hour. The amount of water to be diverted will not reduce downstream flows in Go Creek (Stations W16 and W12) below normal summer low flow levels.

Residual Project Effects

Predicted residual effects of mine dewatering on low flow conditions in Wolverine Creek are a concern in as much as they could affect aquatic habitat in a short reach above Little Wolverine Lake. Effects will be reversible after closure when the groundwater table in the mine area is restored. Accordingly residual effects of mine dewatering on Wolverine Creek are adverse, of moderate magnitude, site specific, long term and reversible. There is a high likelihood of effects as predicted. Based on criteria in Section 7.4.3, residual project effects on Wolverine Creek hydrology are considered not significant.

Predicted residual effects of mine dewatering and treatment plant discharges on flows in Go Creek are positive or neutral, moderate, local, long term and reversible. The likelihood of effects as predicted is high. Because the predicted effects are not a concern with respect to hydrologic conditions or aquatic habitat, no mitigation measures are required. Based on criteria in Section 7.4.3, residual project effects on Go Creek hydrology are considered not significant.

7.4.5 Cumulative Effects

The residual project effects identified in Section 7.4.4 are site-specific to local in geographic extent. No additional projects are currently planned within the area which would overlap with predicted project effects. Therefore, there will be no significant adverse cumulative or residual cumulative effects in the project area. The likelihood of occurrence of effects as predicted is high.

7.4.6 Mitigation Measures

Mitigation measures pertaining to project effects on surface water hydrology are summarized in Table 7.4-12.

Table 7.4-12 Mitigation Measures for Effects on Surface Water Hydrology

Potential Project Effect	Mitigation Measures
Effects of clearing and construction on runoff and streamflows	• Site water management plan (Section 2.9: Site Water Management) • Erosion and sediment control plan (Section 9: Environmental Management Plan)
Effects of stream crossings on stream flows	• Design flow specifications to allow unobstructed passage of flows and bedload (Section 2.11: Transportation) • Erosion and sediment control plan (Section 9: Environmental Management Plan)
Reduced low flows in Wolverine Creek due to mine dewatering.	• None planned

7.4.7 Monitoring and Follow-up

Follow-up Studies

Existing water gauging sites established for the project will continue to be used during project construction, operations and decommissioning phases. Additionally, automated monitoring equipment will be reinstalled at Site W9 to better quantify flows in Wolverine Creek. A new monitoring station will be installed 50 m downstream of the confluence of Go and Hawkowl Creeks in order to create a control point upstream of the proposed treated water discharge point. Data collected will be used to improve and refine stage-discharge curves and estimated peak and low flow magnitudes for specified return periods. Improved values will lead to more accurate understanding of project hydrology and the range of natural variability. Due to fisheries concerns with altered flows, streamflow in Wolverine will be monitored on an ongoing basis in conjunction with observations of effects on fish habitat to define minimum instream flow requirements for fish habitat. As the underground mine is developed, flows will continue to be monitored in Go and Wolverine Creeks to verify the accuracy of the predicted effects of dewatering on low flows.

Monitoring Programs

Selected manual and automated monitoring sites will continue to be used for monitoring surface water flow, in conjunction with planned monitoring for fisheries and water quality (Table 7.4-13).

Table 7.4-13 Monitoring and Follow-up Programs for Hydrology

Potential Project Effect	Program Objectives	General Methods	Reporting	Implementation
Follow-Up and Monitoring Programs				
Site water management	• Develop stage discharge curves and refine peak and low flow projections for water management purposes	• Ongoing operation of recording staff gauges at Stations W8, W12, W15 and W21 • Continued monthly manual monitoring, May-September • Continued automated monitoring at Stations W12, W21, and W22 plus reinstallation of automated monitoring station at W9 • Install new manual monitoring station 50m downstream of confluence of Go and Hawkowl Creeks	• Internal	Proponent
Reduced low flows in Wolverine Creek from mine dewatering	• Define minimum instream flow requirements for aquatic habitat • Maintain identified minimum flows by monitoring effects and implementing mitigation measures as required	• Reinstallation of automated monitoring equipment at Station W9 plus monthly manual monitoring May-September • Develop stage/discharge relationship to assess effects on wetted stream habitat	• Internal for adaptive management purposes • YTG as required • DFO as required	Proponent
Monitoring Programs				
Project effects on flows in Wolverine and Go Creeks	• Monitor flows to check effects predictions and support interpretation of water quality monitoring results	• Ongoing operation of recording staff gauges at Stations W12 and W15 • Monthly summer manual monitoring at Stations W8, W9, W18, W31, W15, W16 and W12 plus at new station located 50m downstream of Go-Hawkowl confluence • Manual discharge measurements in conjunction with water quality sampling (Section 7.5: Surface Water and Sediment Quality)	• YTG as required • DFO as required for compliance with MMER	Proponent

7.4.8 Summary of Effects

Table 7.4-14 provides a tabular summary of the project effects on surface water hydrology.

Table 7.4-14 Summary of Effects on Surface Water Hydrology

Potential Effect	Level of Effect[1]						Effect Rating[2]	
	Direc-tion	Magni-tude	Extent	Duration/ Frequency	Reversi-bility	Like-lihood	Project Effect	Cumulative Effect
Construction, Operations and Decommissioning								
Reduced low flows in Wolverine Creek due to mine dewatering	Adverse	Moderate	Site specific	Long term	Reversible	High	Not significant	Not significant
Increased low flows in Go Creek due to treatment plant discharge	Positive	Moderate	Local	Long term	Reversible	High	Not significant	Not significant
Closure								
Reduced low flows in Wolverine Creek and Go Creek due to mine dewatering	Adverse	Moderate	Site specific	Long term	Reversible	High	Not significant	Not significant

Notes:
1 Based on criteria in Table 7-4-10
2 Based on criteria in Section 7.4.3