27. EFFECTS OF THE ENVIRONMENT ON THE PROJECT

27.1 INTRODUCTION

This chapter assesses the potential for the environment to affect the Harper Creek Project (the Project), a proposed open pit copper mine located in south-central British Columbia (BC), approximately 150 kilometres (km) northeast by road from Kamloops. This chapter provides an assessment consistent with section 2(1) of the *Canadian Environmental Assessment Act* (CEAA; 1992) which describes environmental effects in subsection (c) as "any change to the project that may be caused by the environment".

In accordance with CEAA 1992a and the Project Application Information Requirements (AIR; BC EAO 2011) the following topics are considered in this assessment:

- climatic conditions, typically as a result of extreme weather events, including:
  - typical, wet and dry periods of precipitation;
  - extreme temperatures and freeze-thaw cycles;
- surface water flows;
- wildfires;
- geophysical events, including:
  - natural seismic events and associated effects such as liquefaction;
  - slope stability and mass wasting events; and
- climate change.

27.2 CLIMATE AND METEOROLOGY

27.2.1 Climate

Extreme weather events occur in many forms, including windstorms, thunderstorms, and heavy precipitation. Of the extreme weather events likely to occur in the future, this section focuses on heavy precipitation (also referred to as intense or extreme precipitation). Heavy precipitation occurs as a consequence of the variability in weather conditions. Weather refers to atmospheric conditions on time scales ranging from days to weeks, whereas climate refers to longer-term atmospheric conditions. Long-term climatic conditions are important to consider in the context of extreme weather events, since future variability is expected to change as a consequence of climate change.

This section provides a brief description of factors controlling weather and climate in the region, including drivers affecting large-scale natural climate variability. The concept of future climate variability and extremes is then presented. A discussion on heavy precipitation will explain trends and projections reported in the literature, as well as those obtained for the Project area. Possible effects from heavy precipitation on various mine infrastructure components will follow, along with mitigation measures.

27.2.1.1 Regional Climate

The climate of the North Thompson region is continental with strong seasonal variations. The chief characteristic is the long cold winter, liable to intense cold when continental polar air moves in from the north. Summers are short and generally cool. The topography of the region plays a large role in the region's climate and contributes to local variations in climate patterns. Climate elements such as temperature, precipitation, snow depth and wind show significant variations with elevation. The region is frequently influenced by moist air from the Pacific as well as drier continental air. Snow generally starts to accumulate in late October, peaking in April, and rapidly melting in late April.

The Project is located in the western foothills of the Columbia Mountains, approximately 150 km northeast of Kamloops, BC. The Project lies within the North Thompson River watershed, which is situated on the western extremities of the Columbia Mountains. The Project area is a transitional region between the interior plateau and the Rocky Mountain ranges. This area is characterized by continental air masses rising over the Columbia Mountains, resulting in increased orographic precipitation on the western (windward) slopes.

Complexities of topography and air movement create a high degree of spatial and temporal variability in precipitation. In general, precipitation increases with elevation due to the orographic effect resulting when Pacific air streams reach the western slopes of the Columbia Mountains. The elevation change forces moisture-laden air up the slopes. As the air rises and cools it is less capable of holding moisture and releases it as rain or snow. In the Project area air descends and warms, dispersing clouds and rain through evaporation. The Project region is therefore characterized by an elevation gradient, as well as an east-west precipitation gradient.

27.2.1.2 Local Climate

The elevation at the proposed Project Site is about 1,800 metres above sea level (masl). In December 2007, a meteorological station was installed by Dillon Consultants Ltd. (DCL) near the proposed open pit site. This station was established at an elevation of 1,680 masl and operated from December 2007 until April 2011 when it was phased out and replaced by a new meteorological station. In September 2011, a new meteorological station was installed by Knight Piésold Ltd. (KPL), hereafter referred to as the Harper Creek meteorological station. This new station was established at 1,837 masl. This location was chosen to be representative of Project Site weather conditions. Details of the meteorological station sensors and site layout are provided in the meteorological baseline report (ERM Rescan 2014).

In the following sections, local climate is summarized using data from four sources.

- **The on-site Harper Creek meteorological station**. These data provide site-specific information since 2007.
- **The computer program ClimateWNA**. ClimateWNA provides 30-year "climate normal" data for western North America on a 2.5 by 2.5 arcminute grid. ClimateWNA data are interpolated and adjusted for elevation effects based on gridded climatic datasets (from the Climate Research Unit and Global Historical Climatology Network; Wang et al. 2006; Wang et al. 2012).

- **Environment Canada regional rankings of air temperature and precipitation** (Environment Canada 2014). The Project area is within the South BC Mountains Climate Region. Air temperature and precipitation from 2011 and 2012 were ranked in relation to the long-term regional climatic record (1948 to 2013).
- **Climate data from regional meteorological stations**. These data are used here to assess air temperature and precipitation extremes from stations close to the Project area. Data from these stations are also summarized in the meteorology baseline report (ERM Rescan 2014).

27.2.1.3 Regional Climatic Patterns

The winter climate of the region is affected by the strength of the Aleutian Low, which is a low-pressure cell that forms in winter over the north Pacific Ocean and Aleutian Islands. The Aleutian Low migrates spatially along the coast of BC and Alaska and it advects warm, moisture-laden air into the jet stream. The strength of the Aleutian Low is directly linked to the phase and strength of the Pacific Decadal Oscillation (PDO).

The PDO is a measure of the difference in sea level pressure between the Aleutian Low and the Hawaiian High pressure cell (Mantua et al. 1997). The PDO is characterized by positive phases (1925 to 1946, 1977 to 2005) and negative phases (1947 to 1976, 2005 to present). The phase and strength of the PDO have been shown to influence changes in river flow, glacial mass balance, and salmon abundance throughout Oregon, BC, and Alaska (Dettinger et al. 1993; Mantua et al. 1997; Hodge et al. 1998; Bitz and Battisti 1999; Gedalof and Smith 2001; Neal, Walter, and Coffeen 2002).

The PDO was in a negative phase from approximately 1942 to 1977, and then transitioned to a positive phase from approximately 1977 to 2005, when it transitioned back to a negative phase and has remained in this phase until present. The specific phase of the PDO has been demonstrated to have a moderating effect on the strength and state of the El Niño Southern Oscillation (ENSO). In practice, during a positive phase of the PDO there is a greater propensity of El Niño events to occur. Conversely, during a negative phase of the PDO there is a greater propensity of La Niña events. This temporal clustering of El Niño (positive PDO phase; 1925 to 1946, 1977 to 2005) and La Niña (negative PDO phase; 1946 to 1976, 2005 to present) events has substantial effects on regional hydroclimatology.

The ENSO phenomenon is a measure of difference in sea surface temperatures (SSTs) between northern Australia and the coastal upwelling zone off western Ecuador. The significance of this phenomenon is that the SST anomalies generated by ENSO migrate from the equator up the west coast of North America and eventually pool off the coast of BC and Alaska. These SST anomalies are spatially expansive and, off the coast of northern BC, reside directly below the Aleutian Low. As such, warm (El Niño) phases of ENSO result in above-average SST off the north coast of BC, which then result in greater advection, and therefore more moisture-laden air masses rising into the Aleutian Low pressure cell and then into the jet stream to be transported inland.

The significance of the PDO and ENSO for the Project area is how each manifests in air temperature, precipitation, and streamflow. For example, since positive phases of the PDO tend to result in clustered El Niño events, it can be expected that the extreme events commensurate with El Niños will also be clustered during positive phases of the PDO. Similarly, since negative phases of the PDO tend to result in clustered La Niña events, it can then also be expected that extreme events commensurate with La Niñas will also be clustered during negative phases of the PDO. This was evidenced during the last positive phases of the PDO (1977 to 2005), and specifically in 1980s and 1990s when numerous clustered El Niño events were responsible for extreme precipitation events including both rainfall and snowfall. These events closed ski resorts, flooded out communities and highways, and shut down schools.

27.2.2 Air Temperature

Average annual air temperatures at the Harper Creek meteorological station between 2007 and 2011 ranged from a low of 0.7ºC (2008) to a high of 1.3ºC (2009). The coldest month was December 2008, when the mean minimum daily air temperature was -13.5ºC. The warmest month was July 2009, when the mean maximum daily air temperature was 14.1ºC (ERM Rescan 2014).

27.2.2.1 Typical Air Temperature

The Canadian "climate normals[1]" represent average climate variables (air temperature, precipitation, etc.) over a period of three decades for many cities across Canada. At the end of each decade the Canadian government updates the climate normals and provides online access for public use. ClimateWNA[2] is a web-interface software tool developed by the University of British Columbia to provide online mapping tools for climate data. ClimateWNA uses the climate normal datasets (1961 to 1990, 1971 to 2000, and 1981 to 2010) and provides spatially explicit interpolation for any point in BC.

Climate normal air temperature data extracted from ClimateWNA for the Project Site (51º30'N latitude, 119º48'W, 1,800 masl) suggest that mean annual air temperature in the Project area is 1.2ºC, based on the 1981 to 2010 dataset. The coldest mean minimum monthly air temperature was -12.2ºC (December), and the warmest mean maximum monthly air temperature was 18.7ºC (July). Average annual air temperature was lower for the 1961 to 1990 climate normal dataset at 0.7ºC.

Local and regional air temperature has historically been collected at several locations surrounding the Project area. These regional weather stations include Bridge Lake (69 km to the west), Buffalo Lake (91 km to the northwest), Criss Creek (83 km to the southwest), Darfield (35 km to the southwest), and Vavenby (10 km to the north-northeast). Table 27.2-1 provides a monthly summary of air temperature measured at these regional weather stations).

27.2.2.2 Extreme Air Temperature

Long-term data from nearby regional weather stations reveal a wide range between extreme warm and extreme cold air temperatures. Air temperatures as warm as 41.1ºC, and as cold as -46.1ºC, have been recorded near the Project area (Table 27.2-2). The potential for extremes in cold and warmth is characteristic of the continental climate of the Project area.

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[1] Figures derived from the observations of meteorological data calculated from the average over a 30-year period.
[2] Web-interface tool for mapping climate variables such as air temperature. Developed by the University of British Columbia: http://climatewna.com/

Table 27.2-1. Harper Creek and Regional Air Temperature Values (°C)

Month	Buffalo Lake Climate Normal (1981-2010) (1,003 masl)	Bridge Lake 2 Climate Normal (1981-2010) (1,155 masl)	Criss Creek Climate Normal (1981-2010) (1,122 masl)	Darfield Climate Normal (1981-2010) (412 masl)	Vavenby Climate Normal (1981-2010) (824 masl)
Jan	-7.8	-6.5	-7.5	-4.5	-5.2
Feb	-4.4	-4.3	-5.2	-1.8	-2.7
Mar	-0.8	-0.6	-1.4	3.5	2.7
Apr	4.3	3.7	3.7	8.4	8
May	8.6	8.3	7.7	12.9	12.3
Jun	12	11.8	11	16.5	15.7
Jul	14.4	14.3	13.8	19.1	18.2
Aug	13.8	14.1	13.2	18.4	17.6
Sep	9.8	9.7	9.4	13	12.1
Oct	3.6	3.8	3.4	6.4	5.7
Nov	-2.3	-2.8	-3	0.4	-0.2
Dec	-6.8	-7.2	-7.2	-4	-4.7
Average	3.7	3.7	3.2	7.4	6.6
Max	14.4	14.3	13.8	19.1	18.2
Min	-7.8	-7.2	-7.5	-4.5	-5.2

Table 27.2-2. Harper Creek and Regional Extreme Air Temperature Values (°C)

	Buffalo Lake (1969-2014) (1,003 masl)	Bridge Lake 2 (1980-2010) (1,155 masl)	Criss Creek (1988-2014) (1,122 masl)	Darfield (1956-2014) (412 masl)	Vavenby (1913-2014) (824 masl)
Extreme Maximum (°C)	33.5	33.5	33	38.5	41.1
Date	Jul 31, 2003	Jul 31, 2003	Jul 24, 1994	Jul 19. 1979	Jul 16, 1941
Extreme Minimum (°C)	-45	-43	-41	-41.1	-46.1
Date	Dec 29, 1990	Dec 29, 1990	Dec 20, 1994	Jan 29, 1969	Jan 25, 1950

Note: years represent full extent of data available from station.

Given the climatic setting of the Project area, effects on the Project might be expected from both extremely cold and extremely warm air temperatures. These extreme temperatures may affect workers, infrastructure, or machinery.

27.2.2.3 Freeze-Thaw Cycles

At high elevations in BC (over 1,000 masl), freeze-thaw is likely a concern in spring, summer, and fall; at lower elevations in BC (under 1,000 masl), it is more of a concern in the fall, winter, and spring. Freeze-thaw cycles are a causal factor of cracked pavement and road surfaces, and can cause damage to power and transmission lines.

Effects of Extreme Cold on the Project

- Extremely low air temperatures could adversely affect workers' health, causing frostbite and hypothermia. Workers can become distracted and prone to accidents under extreme low temperatures.
- Equipment and machinery is more likely to malfunction or become damaged during extreme low temperatures, increasing the potential for worker-related exposure and accidents. Extreme low temperatures may be accompanied by blowing snow, which could affect surface transport of materials and personnel, and could temporarily slow mine operations.
- Increased heating requirements on site would result from extreme low temperatures, increasing power demand.
- Extended cold spells could result in an extended winter and increased snow accumulation. As a result, access roads, haul roads, and diversion channels would require more frequent maintenance.
- Cold spells could cause later melting of the winter snowpack, delaying spring runoff.
- Construction of the tailings management facility (TMF) may be affected as "It may not be possible to place core zone material properly in temperatures below approximately -15°C, even with quality procedures in place." (pages 45 and 58 of 87; Knight Piésold Ltd. 2014)
- As the TMF is designed to a be zero discharge facility during Operations, extreme cold and freezing of the TMF should not have any effects on discharge.

Effects of Extreme Warmth on the Project

- Extremely high air temperatures may also adversely affect workers' health, potentially causing heat exhaustion, dehydration, and heat stroke. Workers can become distracted and more prone to accidents under extreme high temperatures.
- Equipment and machinery is more likely to malfunction during extreme high temperatures, increasing the risk of exposure and accidents.
- Increased air conditioning requirements on site would result from extreme high temperatures, increasing power demand.
- With sustained warm air temperatures, more precipitation would fall as rain than as snow, and earlier melting of the snowpack could cause increases in runoff during the late winter and early spring. Storms where precipitation falls as rain rather than snow could cause more rapid runoff, potentially increasing the erosive capabilities of flows. Costs of maintaining diversion channels and access roads could increase.
- Extremely high temperatures coinciding with dry periods could increase the likelihood of wildfires occurring in the area (discussed in Section 27.4).
- An extended heat wave would cause increased evapotranspiration within the TMF to increase, potentially exposing ML/ARD-generating material within the TMF to air.
- As the TMF is designed to a be zero discharge facility during Operations, extreme heat would not have any effects on discharge.

Effects of Freeze-Thaw Cycles on the Project

Given that air temperatures in winter can range above and below the freezing point, freeze-thaw cycles and frost heave in winter are likely. Frost heaving could affect transportation and utilities components of the Project; for example, frost heave may impact road surfaces and destabilize power transmission towers.

Mitigation Measures

Weather forecasts will be monitored, which will provide time to prepare for air temperature extremes. Health and safety policies will be implemented, and risk assessments will be undertaken before working in adverse weather conditions. Staff will be educated through formal training programs to ensure they understand the risks of working under extreme high or low temperatures, and to ensure they have good knowledge of the related procedures. Daily job safety analysis will be conducted. Personnel will be required to wear appropriate personal protective equipment, including cold weather gear, while working outside. Radio communication will be maintained with anyone working away from the Project Site.

Suitable equipment and design systems will be purchased and implemented for the Project to enable operation under both extreme high and low temperatures. Equipment will be maintained to ensure reliable operation. Potentially vulnerable infrastructure will be built to withstand freeze-thaw cycles, especially infrastructure related to transportation and utilities where layer works or foundations may be affected.

If extended cold temperatures affect TMF construction schedules, then construction may become focused on placing coarse rockfill in the embankment shell, with overburden material removal from the pit scheduled for the summer months so it can be utilized efficiently in embankment construction (Knight Piésold Ltd. 2014). The lag time for ML/ARD generation of PAG waste rock within the TMF is expected to be long enough that adaptive management measures such as increased water diversion or placement of a cover could be in place prior to ML/ARD generation.

The TMF will be designed, constructed, operated, closed and reclaimed according to the Canadian Dam Association's (CDA) Dam Safety Guidelines (Canadian Dam Association 2007 (Revised 2013)).

Air temperature-related risks to the Project and mitigation measures are presented in the Table 27.2-3.

27.2.2.4 Contingency Plans

Although the mitigation measures above will significantly reduce the risk of extreme air temperature on the Project, it is possible that such an event may occur over the life of the Project. In this case, HCMC has developed the Emergency Response Plan (Section 24.4) which will be followed if extreme air temperatures have an effect on the Project. Under this Plan, when extreme weather conditions such as cold or heat present health and safety concerns, the risk will be assessed and activities curtailed as appropriate. This Plan also outlines procedures, communications protocols, and responsible personnel in the case of an incident.

Table 27.2-3. Air Temperature-related Risks and Mitigation Measures

Category	Component	Project Effects	Mitigation Measures
Transportation	Rail line, road surface, ditches, culverts.	Blowing snow, frost heave.	Frequent snow clearing. Use of appropriate design standards to minimize frost heave.
	Buildings (maintenance, administration, warehouse), conveyor, stockpiles, contact water collection ditches, discharge pipeline, equipment and fuel storage facilities, explosive and storage facilities, non-contact water diversion ditch network, overburden and soil storage areas, sedimentation pond(s), sewage treatment and disposal facilities, washing plant, waste rock stockpile.	Effects to workers from cold: frostbite, hypothermia, distraction, accidents. Effects to infrastructure from cold: increased heating and power demands, freeze-thaw damage. Effects to workers from warmth: heat exhaustion, dehydration, heat stroke. Effects to infrastructure from warmth: increased air conditioning and power demands.	Staff will wear appropriate clothing, and be trained in risks and risk-mitigation relating to extreme temperatures. Suitable equipment will be used in mine infrastructure to withstand extremes of heat and cold.
Surface infrastructure	Electrical power line.	During extreme cold the conductors may ice up which could, in turn, result in an electrical failure during extreme temperatures.	Towers and conductor specifications should be appropriate for expected climate extremes. Additionally, routine inspections should be performed to monitor potentially problematic sections of the power line.
	TMF	Construction delays due to extended periods of extreme cold	Adaptive management of construction schedule to be less sensitive to extreme temperatures The TMF will be designed, constructed, operated, closed and reclaimed according to the Canadian Dam Association's (CDA) Dam Safety Guidelines (Canadian Dam Association 2007 (Revised 2013)).

27.2.3 Precipitation

The mean annual precipitation for the Project area between 2007 and 2011 was 420 millimetres (mm; ERM Rescan 2014). Due to gaps in the data record this average was the result of 350 mm in 2009, and 490 mm in 2010. It should also be noted that these values are thought to be under-estimated, as the DCL meteorological station was not equipped to measure snow depth. Snow depth is highly dependent on elevation; at the Harper Creek meteorological station (2011 to 2014), the highest average monthly snowpack was in December 2012 at 48.9 cm. In all years, snow cover was depleted by June (Rescan 2014). Within the Project area the wettest months are primarily in summer, when orographic rainfall events occur and secondarily in the autumn and early winter, as the Aleutian Low strengthens and delivers precipitation (rainfall and snowfall) inland (Table 27.2-4).

Table 27.2-4. Harper Creek and Regional Precipitation Values (mm)

Month	Buffalo Lake Climate Normal (1981-2010) (1,003 masl)	Bridge Lake 2 Climate Normal (1981-2010) (1,155 masl)	Criss Creek Climate Normal (1981-2011) (1,122 masl)	Darfield Climate Normal (1981-2010) (412 masl)	Vavenby Climate Normal (1981-2010) (824 masl)
Jan	45.3	43.3	30.6	45.6	40.6
Feb	21.9	24.6	19.2	25.3	23.2
Mar	23.7	29.6	26.5	22.5	21
Apr	27.5	34.4	29.8	23.8	23.2
May	49.7	56.3	48.4	39.3	35.7
Jun	73.4	79.6	65.1	50.6	50.3
Jul	61.2	67.9	48.5	45.1	42.6
Aug	48.7	52.3	40.9	41.2	40.0
Sep	36.5	49.1	35.2	35.3	35.8
Oct	42.8	41.6	32.5	34.8	38.5
Nov	49.4	49.8	35.8	43.2	36.6
Dec	48.6	53.2	37.7	48.3	41.7
Annual Total	**529**	**582**	**450**	**455**	**429**

27.2.3.1 Typical Precipitation

Precipitation data were monitored on site from 2007 to 2011 (DCL station) and from 2011 to present (Harper Creek meteorological station). Complete annual datasets have been collected on site since 2009.

Annual precipitation extracted from ClimateWNA for the 1981 to 2010 climate normal period predicts that 828 mm of precipitation is expected at the Project Site (1,800 masl). Annual precipitation for the 1961 to 1990 climate normal period was slightly lower at a mean of 791 mm. ClimateWNA predicts that between 51and 53% of the total annual precipitation falls as snow at the Project Site (depending on the climatic normal period used).

Typical intensity, duration, and frequency of precipitation events in the Project area are low, and will not have substantial effects on Project infrastructure in the short term. However, over long time periods, and in the absence of proper maintenance, the cumulative effects from "typical" precipitation events could cause erosion of roadways, sedimentation in drainage lines, and flooding of ditches and roadways. Access to and from the Project Site, and utility delivery, could be affected.

27.2.3.2 Extreme Precipitation

Many studies suggest, on a theoretical basis, that increases in mean global temperature should lead to increases in precipitation intensity (i.e., heavier or more extreme) over many portions of the globe (Cubash and Meehl 2001; Allen and Ingram 2002). A warmer atmosphere can hold more moisture, resulting in a more energetic system. This means that in regions where precipitation occurs, the potential would exist for more precipitation to fall during any given event. This process is summarized as the intensification of the global hydrologic cycle (Douville et al. 2002).

Concurrent with gradual global warming, the historical record reveals an increase in mean and heavy precipitation across many regions nationally and globally. For the period of 1910 to 2001 in BC, total annual precipitation increased by 7.2%. At the same time, heavy precipitation events increased by 16% (Groisman et al. 2005). Heavy precipitation was defined by the threshold depth of the top 5% of all observed events, or 26 mm. The increases in observed total and heavy precipitation were linked to precipitation changes simulated by Global Circulation Models (GCMs) for overlapping time periods. Given that GCMs incorporate the intensification of the hydrologic cycle, GCMs may be useful in predicting future changes in heavy precipitation for the Project area.

Heavy precipitation measured at regional meteorological stations can provide insight into the expected precipitation extremes. Nearby weather stations with records sufficiently long for 30-year climate normals are included in Tables 27.2-1 and 27.2-4. Extremes of air temperature and precipitation data are available for these sites (Environment Canada 2014) over a longer period of time than the climate normal data and are provided in Tables 27.2-2 and 27.2-5. Extremely high-magnitude rainfall and snowfall events, represented by the threshold depth of the top 5% of all observed events or 26 mm, as mentioned previously, do not occur frequently in this region, although moderate storms occur.

Table 27.2-5. Harper Creek and Regional Extreme Precipitation Values (mm)

	Buffalo Lake (1969-2014) (1,003 masl)	Bridge Lake 2 (1980-2010) (1,155 masl)	Criss Creek (1988-2014) (1,122 masl)	Darfield (1956-2014) (412 masl)	Vavenby (1913-2014) (824 masl)
Extreme Rainfall (mm)	58.6	40	42.8	53.3	39.6
Date	Jun 26, 1993	Jul 22, 2000	Jul 22, 2000	Aug 4, 1956	Aug 3, 1956
Extreme Snowfall (cm)	36.4	41	31.4	33	76.2
Date	Dec 19, 1989	Dec 19, 1989	Apr 22, 1992	Jan 7, 1982	Jan 21, 1935

<u>Effects of Heavy Precipitation on the Project (Flooding)</u>

High-magnitude rain and snow events are infrequent in the Project area. However, severe rainstorms in Project catchments could trigger flooding events, especially if they coincide with periods of peak snowmelt. Precipitation-related (flood) effects could include damage to buildings, site infrastructure, and the access roads, in addition to inundation of the open pit.

Buildings and Infrastructure

Increased precipitation in solid forms, such as sleet or hail, may damage building roofs. Similarly, warm temperature cycles in the winter can act to increase the density of snow, and therefore the force on roofs, anchoring cables, covered walkways, etc. Current construction design criteria for buildings are likely sufficient to withstand the expected increases in heavy precipitation.

Extreme heavy precipitation events also have the potential to cause overtopping of the TMF (the effects of which are discussed in Section 26.7.1), or in the worst-case scenario, catastrophic failure of the TMF embankment (the effects of which are discussed in Section 26.7.2).

Roads

Greater potential for large snowfall amounts during the winter could result in periods of high snow accumulation on roads. Heavy precipitation events could lead to road damage and/or erosion. Increased maintenance could be required to access various Project locations in winter and maintain road integrity. Current construction design criteria for roads are likely sufficient to withstand the expected increases in heavy precipitation.

Effects of Low Precipitation on the Project (Drought)

Effects of low precipitation are much more likely in the Project area as compared to heavy precipitation. Low precipitation generally manifests as low streamflow (Section 27.3). Prolonged periods of low precipitation could also increase the risk of wildfires (Section 27.4) and reduce available process water for mill operations. Each of these components is discussed in their relevant sections.

Mitigation Measures

Precipitation-related risks to the Project and subsequent mitigation measures are presented in Table 27.2-6 and discussed in detail in Section 27.3, Surface Water Flows. Mitigation measures for the effects of low precipitation, and therefore low streamflow, on the Project are also addressed in Section 27.3.

The TMF will be designed, constructed, operated, closed and reclaimed according to the Canadian Dam Association's (CDA) Dam Safety Guidelines (Canadian Dam Association 2007 (Revised 2013)). The TMF will also be designed to handle the inflow design flood (IDF) equal to the probable maximum flood (PMF) with at least 1 m of freeboard for wave run-up (Knight Piésold Ltd. 2014).

Buildings and Infrastructure

Roadways will be cleared during or after snow events. Roadways will be repaired and maintained as needed. Ditches and culverts will be cleared of debris and monitored. Snow should be shovelled off roofs after heavy snowfalls to prevent roof collapse from excessive loads. The plant site and other buildings will be constructed to withstand periods of heavy precipitation.

Table 27.2-6. Precipitation-related Risks and Mitigation Measures

Category	Component	Project Effects	Mitigation Measures
Transportation	Rail line, road surface, ditches, culverts	Infrastructure effects: erosion, sedimentation, flooding. Access effects: reduced access to Project Site and reduced productivity due to downed trees, snow drifts, damaged roads.	Snow clearing, roadway repair, ditch and culvert clearing.
	Buildings (maintenance, administration, warehouse), conveyor, storage area, stockpiles, contact water collection ditches, discharge pipeline, equipment and fuel storage facilities, explosive and storage facilities, non-contact water diversion ditch network, overburden and soil storage areas, sedimentation pond(s), sewage treatment and disposal facilities, washing plant, waste rock stockpile.	Flooding, erosion and sedimentation, snow loading. Leading to damage of infrastructure and reduced mine productivity	Flooding and drought-related mitigation measures are discussed in Section 27.3.
Surface infrastructure	Electrical power line	Erosion at footings, damage due to downed trees, leading to reduced mine productivity.	Periodic monitoring and repair as needed. Three principal transformers, to allow security of supply during maintenance or failure.
	TMF	Overtopping of TMF or catastrophic failure of TMF embankment	Design for IDF with at least 1 m of freeboard TMF will be designed to meet all current CDA *Dam Safety Guidelines* (Canadian Dam Association 2007 (Revised 2013))

27.2.3.3 Contingency Plans

Although the mitigation measures above will significantly reduce the risk of extreme precipitation on the Project, it is possible that such an event may occur over the life of the Project. In this case, HCMC has developed the Emergency Response Plan (Section 24.4) which will be followed if extreme air temperatures have an effect on the Project. Under this Plan, when extreme precipitation present health and safety concerns, the risk will be assessed and activities curtailed as appropriate. This Plan also outlines procedures, communications protocols, and responsible personnel in the case of an incident.

27.3 SURFACE WATER FLOWS

27.3.1 Typical Surface Water Flows

27.3.1.1 Local Hydrology

The 2011 to 2014 hydrometric program was initiated to collect and analyze baseline hydrologic data for specific streams within the Project area. The monitoring program began in 2011 with six hydrometric stations. In 2013, three new hydrometric stations were established. Installation and operation of the gauging stations were in accordance with the requirements of the *Manual of British Columbia Hydrometric Standards* (BC MOE 2009). Automated hydrometric stations recorded water levels every 15 minutes during open water periods to monitor surface water flows in order to characterize the hydrological variation in these waterbodies.

27.3.1.2 Regional Hydrology

Detailed results from the hydrometric program are provided in baseline studies and the *Harper Creek Surface Hydrology Baseline* report (Appendix 12-A). The regional hydrometric baseline program involved assessing a network of hydrometric stations in rivers/streams close to the Project area to provide estimated site-specific hydrologic data (Table 27.3-1). Baseline work also involved analyzing long-term datasets from these regional Water Survey of Canada (WSC) stations. This regional analysis allowed prediction of recurrence intervals for floods and low-flows within the Project area (Section 27.3.2).

The flow regime in the area is closely related to the seasonal distribution of precipitation and temperature. Rivers in this region are predominantly fed by spring and early summer snowmelt (freshet) and rainfall in the summer. High discharges occur from mid-April through July, with a low flow period during winter and early spring. Mean annual runoff is the amount of water running over the land surface during at any given time throughout the year (volume/watershed area) and is estimated to be 906 mm/year for the Project area, at an elevation of 1,800 masl (Table 27.3-2; KPL 2013).

The typical flow regime of Harper Creek (WSC station 08LB076) is quite different from the regime of the smaller higher-order tributary watersheds in the Project area. For example, an average peak runoff for Harper Creek (08LB076) is about 15 m^3/second, and occurs in July. Flow in Harper Creek typically continues throughout the winter (November through April), with an average baseflow of about 0.7 to 0.8 m^3/second (Appendix 12-A).

Table 27.3-1. Mean Monthly Discharge at Water Survey of Canada Stations in the Baseline Study Area

Name	ID	Drainage Area (km^2)	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean Annual Discharge (m^3/s)
Harper Creek near the Mouth	08LB076	1,66	m^3/s	0.8	0.7	0.9	3.2	13.1	14.8	6	2.1	1.7	1.9	1.6	0.9	4.0
			$L/s/km^2$	4.7	4.4	5.2	19.5	78.9	89.2	36.1	12.4	10.2	11.2	9.7	5.7	24.0
Barrière River below Sprague Creek	08LB069	624	m^3/s	2.5	2.3	2.9	10.5	38.1	42	16.2	5.5	4.2	4.6	4.8	3.1	11.4
			$L/s/km^2$	4.0	3.7	4.6	16.8	61.0	67.3	25.9	8.8	6.8	7.4	7.7	5.0	18.3
Barrière River at the Mouth	08LB020	1,140	m^3/s	3.6	3.5	4.5	15.5	48.4	50.4	19.7	6.9	5.3	5.6	6.2	4.2	14.5
			$L/s/km^2$	3.2	3.0	4.0	13.6	42.5	44.2	17.3	6.1	4.6	5.0	5.4	3.7	12.7
North Thompson River at Birch Island	08LB047	4,490	m^3/s	30.1	28.2	33.9	97.2	296.8	423.0	340.8	214.7	131.4	91.9	65.3	34.8	149.6
			$L/s/km^2$	6.7	6.3	7.5	21.6	66.1	94.2	75.9	47.8	29.3	20.5	14.5	7.7	33.3

Notes:
L = litre
s = second

Table 27.3-2. Monthly Runoff Values Estimated for the Harper Creek Project Area

Type	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean Monthly Unit Runoff	mm	5.4	4.4	4.6	38.9	214.3	427.7	120.5	24.1	15.6	26.8	15.6	8.0	906

Note: mean monthly runoff values are applicable for an elevation of 1,800 masl within the Project area.

Regional watersheds near Harper Creek can be two to three times larger than the Harper Creek watershed. The most notable difference in the hydrologic regime of these larger catchments is the increased fraction of total annual runoff in winter (Table 27.3-1). Regional streamflow indices for hydrometric stations throughout the Project area are provided below (Tables 27.3-1 and 27.3-3).

Table 27.3-3. Monthly Return Period Streamflow Relationships for the Project Area

Month	Return Period Ratio of Mean Monthly Discharge (m^3/s) within Project Area						
	Dry				Wet		
	20 Year	10 Year	5 Year	Mean	5 Year	10 Year	20 Year
Jan	0.56	0.60	0.66	1.00	1.22	1.54	1.93
Feb	0.57	0.61	0.67	1.00	1.21	1.52	1.88
Mar	0.57	0.61	0.67	1.00	1.22	1.55	1.95
Apr	0.39	0.50	0.64	1.00	1.33	1.56	1.76
May	0.62	0.70	0.81	1.00	1.19	1.30	1.38
Jun	0.50	0.58	0.69	1.00	1.28	1.49	1.69
Jul	0.37	0.42	0.51	1.00	1.32	1.85	2.54
Aug	0.36	0.42	0.51	1.00	1.32	1.78	2.35
Sep	0.33	0.42	0.55	1.00	1.37	1.73	2.11
Oct	0.37	0.44	0.55	1.00	1.34	1.74	2.18
Nov	0.35	0.44	0.57	1.00	1.36	1.70	2.03
Dec	0.54	0.60	0.69	1.00	1.26	1.50	1.73

27.3.2 Extreme Surface Water Flows

An understanding of flood potential is important to consider at the Project Site, as it could affect the design characteristics of infrastructure such as roads, ditches, dams, and dikes. Floods in southeastern BC are typically produced through two main mechanisms:

- rapid snowmelt during freshet conditions in spring and early summer; and
- rain falling on melting snow during freshet conditions in spring and early summer, or during early winters.

Based on analysis of the regional WSC stations, high-flow events are regularly generated by both mechanisms. Floods in the Project area can be caused by both mechanisms; however, because of the terrain, rapid snowmelt is the dominant mechanism for generating peak flow.

Return period estimates are generated to identify the expected frequency and magnitude of extreme (peak and low) flow events. For example, an event with a return period of 1:100 has a 1% chance (1/100) of occurring at any given time. Similarly, an event with a 1:5 return period has a 20% chance (1/5) of occurring at any given time. To complete the analysis, a long-term data record (i.e., over 10 years) is required; therefore, data from several regional WSC stations were used. For each return period, regression equations were developed relating peak or low flows with basin area. The equations were then applied to the Project watersheds, using the basin area to obtain return period estimates for peak and low flows (Table 27.3-4). Return periods for peak and low flows within the Project area are listed in Table 27.3-4. Return periods were calculated using data from long-term regional WSC stations. Notably, most of the stations incorporated in the regional analysis are rivers with large drainage areas (over 100 km^2). Extrapolation to smaller streams increases the uncertainty associated with the estimates; however, for the purposes of this assessment, these values are considered reasonable.

Table 27.3-4. Annual Peak and Low Flow Return Periods for Harper Creek at Water Survey of Canada Station 08LB076

Harper Creek (08LB076)	Drainage Area (km^2)	2 Year	5 Year	10 Year	20 Year	50 Year	100 Year	200 Year
7-Day Low Flow (m^3/s)	1,66	0.48	0.38	0.34	0.31	0.29	0.28	0.27
Peak Flow (m^3/s)	1,66	43	53	59	63	68	71	74

To minimize the potential effects from floods on the Project, most of the key Project components (e.g., diversions ditches and road stream crossings) have been designed to accommodate at least the 1-in-100-year flood event.

In addition to the event return period presented for the Project area, climate change should be considered while assessing flood risk. Projections show an increase in median precipitation in the future, with the possibility of shorter return periods for heavy precipitation events. These issues are discussed in Section 27.6.

<u>Effects of Extreme High Streamflow on the Project</u>

Floods can damage river crossing structures, including bridges and culverts. Floods can cause erosion and deposition of sediment, negatively affecting water quality. Floods can cause rapid channel avulsion, and could cause damage to any infrastructure in the new channel. They can also trigger mass wasting, when stream beds undercut steep banks.

Diversion Ditches

Non-contact water diversion ditches are intended to manage the volume of water collected within the Project Site. The ditches have been designed to accommodate a 1-in-100-year flood event. Should design flows be exceeded, the ditches will overflow, causing excess water to flow through the Project Site. Such an occurrence would be relatively short lived and, with on-site management, would be of minor consequence for Project infrastructure.

Project Site Roads and Access Corridor

Floods occurring along the Project Site and access roads could result in road closures caused by excess water on the road surface, erosion of the road surface, damage to stream crossings, or debris blocking the roads. Under the most extreme flood events there is the potential for drainage structure washouts (bridges, culverts, and cross-drains).

For floods in excess of the design criteria, it is likely that road closures would be put in effect as there is potential for crossings to partially obstruct flows, resulting in elevated upstream water levels (backwatering) and overtopping onto the road surface. Road closures under these conditions would be temporary and the road would re-open once water levels recede and structural checks of the crossings have been made.

Extreme surface water flows could cause inundation in the TMF, potentially causing an overtopping of the TMF event (the effects of which are discussed in Section 26.7.1), or in the worst-case scenario, catastrophic failure of the TMF embankment TMF (the effects of which are discussed in Section 26.7.2).

Mitigation Measures

Project infrastructure will be designed to withstand flood events. Specific mitigation measures for extreme high streamflow are presented in Table 27.3-5 and, specifically, flooding will be mitigated by:

- monitoring weather forecasts to anticipate and prepare for large rainfall events;
- slowing or stopping work if rainfall runoff is anticipated to cause unsafe working conditions;
- placing Project-related infrastructure above flood high-water marks wherever possible; and
- appropriately reinforcing stream channels at road crossings to minimize sediment movement.

Diversion Ditches

The diversion ditches have been designed to accommodate a 1-in-100-year flood event. A regular inspection and maintenance program will be established to ensure that the ditches are free of obstructions and able to convey design flows efficiently. This will be especially important during early spring before freshet conditions, in early fall ahead of potential fall rain storms, and following any major flood event.

Project Site Roads and Access Corridor

Stream crossings on site roads will be designed to pass the 1-in-100-year instantaneous peak flow. Appropriately sized riprap will be placed at the inlet and outlet of bridges and culverts to protect structures from erosion. A regular inspection and maintenance program will be established to ensure that stream crossings are free of obstructions and able to convey design flows. This will be especially important during early spring before freshet conditions, in early fall ahead of potential fall rain storms, and following any major flood events.

The TMF will be designed, constructed, operated, closed and reclaimed according to the CDA *Dam Safety Guidelines* (Canadian Dam Association 2007 (Revised 2013)). The TMF will also be designed to handle the IDF equal to the PMF with at least 1 m of freeboard for wave run-up (Knight Piésold Ltd. 2014).

Effects of Extreme Low Streamflow on the Project

Low flows are an important consideration for the Project because they could affect aquatic communities. While the annual low flow will occur during winter months, flow volumes during the summer season (June to September) are also important as they can strongly influence species presence. Low flows are characterized using different indices, with the most common measure being the seven-day low flow over a given time period (Table 27.3-4).

Table 27.3-5. Streamflow-related Risks and Mitigation Measures

Category	Component	Project Effects	Mitigation Measures
Transportation	Rail line, road surface, ditches, culverts.	Floods: erosion and sedimentation at ditches, culverts, and road surface. Negative effect on water quality if sediment concentrations increase. Delay of materials and personnel if access to Project Site is limited. Droughts: negative effect on water quality through decreased dilution.	Floods: Constructing infrastructure to withstand extreme flood events; monitoring weather forecasts to anticipate and prepare for large rainfall events; slowing or stopping work if rainfall runoff is anticipated to cause unsafe working conditions; placing Project-related infrastructure above 100 year flood level. Drought: maintain separation between contact and non-contact water; hold back as much discharge as possible for potential recirculation to processing needs.
Surface infrastructure	Buildings (maintenance, administration, warehouse), conveyor, storage area, stockpiles, contact water collection ditches, discharge pipeline, equipment and fuel storage facilities, explosive and storage facilities, non-contact water diversion ditch network, overburden and soil storage areas, sedimentation pond(s), sewage treatment and disposal facilities, washing plant, waste rock stockpile.	Floods: erosion and sedimentation at ditches, culverts, and road surface. Negative effect on water quality if sediment concentrations increase. Delay of materials and personnel if access to Project Site is limited. Drought: reduction in water quality in receiving environment. Reduction in water available for use in process, resulting in slowed production.	Floods: Development of appropriate water balance model, water management plan, and environmental management plans. Drought: Maintaining water quality by limiting sediment erosion, and reducing inputs of contaminated material.
	Electrical power line.	Floods: erosion or sedimentation where power lines are near streams or areas prone to flooding. Drought: n/a	Floods: Constructing infrastructure to withstand extreme flood events. Drought: n/a
	TMF	Overtopping of TMF or catastrophic failure of TMF embankment	Design for IDF with at least 1 m of freeboard TMF will be designed to meet all current CDA *Dam Safety Guidelines* (Canadian Dam Association 2007 (Revised 2013))

As the annual low flows occur in the winter months, it was further necessary to calculate flows for each month during dry years (Table 27.3-3; Appendix 12-A).

A drought could reduce water available for diluting flows, resulting in a water quality decline in the receiving environment. Biota dependant on water quality could therefore also be affected. Maintenance of water quality during low flows is particularly important at the discharge location.

An extreme low streamflow event may cause a decrease of surface water within the TMF, potentially exposing ML/ARD-generating material within the TMF to air. As the TMF is designed to be a zero discharge facility during Operations, extreme low flows would not have any effects on discharge.

Mitigation Measures

Project infrastructure will be designed to accommodate drought events. Specific mitigation measures for extreme low streamflow are presented in Table 27.3-5 and, specifically, mitigation measures relating to reducing drought-induced water quality declines include:

- separating hazardous waste from non-hazardous waste to maintain water quality and transporting it off site for disposal;
- constructing storage areas to minimize spills of fuel and other hazardous materials;
- diverting non-contact water around Project Site infrastructure;
- constructing drainage ditches to collect Project area contact water;
- developing a water management plan that accounts for low-runoff years; and
- developing and implementing an environmental management plan for waste that describes waste sources, waste types, and waste streams (recycling, re-use, off-site disposal).

The lag time for ML/ARD generation of PAG WR within the TMF is expected to be long enough that mitigation measures such as increased water diversion or placement of a cover could be in place prior to ML/ARD generation.

27.3.2.1 Contingency Plans

Although the mitigation measures above will significantly reduce the risk of extreme surface water flows on the Project, it is possible that such an event may occur over the life of the Project. In this case, HCMC has developed the Emergency Response Plan (Section 24.4) which will be followed if extreme surface water flows have an effect on the Project. Under this Plan, when extreme surface water flows present health and safety concerns, the risk will be assessed and activities curtailed as appropriate. This Plan also outlines procedures, communications protocols, and responsible personnel in the case of an incident.

27.4 WILDFIRES

27.4.1 Effects on the Project

Wildfires are common landscape disturbances throughout forested and grassland ecosystems in BC. On average, 1,900 wildfires occur in BC every year; approximately 39% are caused by human activity and 61% by lightning ignition (BC MFLNRO 2012). The probability of wildfire occurrence is dependent on fire behaviour, ignition potential, and suppression capability.

Fires are one of the most significant natural disturbances in BC, and the characterization of fire history aids in predicting fire frequency and severity. Natural disturbance frequencies and types have been identified for ecosystems across BC, and five classes have been created and assigned to Biogeoclimatic Ecosystem Classification (BEC) zones (Table 27.4-1). These Natural Disturbance Types (NDTs) summarize the dominant disturbances for each BEC zone and provide an indication of the disturbance type, extent, and frequency (BC MOF 1995).

Table 27.4-1. Natural Disturbance Types in the Local Study Area and Fire Return Intervals

Natural Disturbance Type	BEC Unit	Stand Replacement Disturbance Cycle	Area in LSA (ha)	Description
NDT 1	ESSFwc2, ESSFwcw, ICHwk1	250- 350 years	5,323.9	Ecosystems with rare stand initiating events. Disturbances such as windthrow, fire, and landslides occur, but are generally small and irregularly shaped.
NDT 2	None Present	200 years	0	Ecosystems with infrequent stand initiating events. Wildfires are often of moderate size (20 - 1,000 ha) with unburned areas due to terrain, soil moisture, or fire behaviour.
NDT 3	ICHdw3, ICHmw3	150 years	3,541.0	Ecosystems with frequent stands initiating events. Fire is the dominant disturbance and the largest fires in the province occur in this NDT (often > 100,000 ha)
NDT 4	IDFmw2	4 - 50 years	2,098.2	Ecosystems with frequent stand maintaining events. Low intensity fires occur frequently and limit encroachment of woody trees and shrubs and fire-resistant species are common. Stand initiating events occur in the IDF but are not common or large. Stands tend to be uneven aged.
NDT 5	ESSFwcp	-	58.3	Alpine tundra and subalpine parkland – rare low-intensity fires.

In the Project area, there are seven BEC zones assigned to NDTs: the Thompson Moist Warm Douglas-fir variant (IDFmw2); the Thompson Dry Warm Interior Cedar – Hemlock variant (ICHdw3); the Thompson Moist Warm Interior Cedar – Hemlock variant (ICHmw3); the Wells Gray Wet Cool Interior Cedar – Hemlock Variant (ICHwk1); the Northern Monashee Wet Cold Engelmann Spruce – Subalpine Fir variant (ESSFwc2); the Wet Cold Engelmann Spruce – Subalpine Fir Woodland subzone (ESSFwcw); and the Wet Cold Engelmann Spruce – Subalpine Fir Parkland Subzone (ESSFwcp).

Project infrastructure is located primarily in the ESSF in NDT 1. Full stand replacing fires are those that burn the entire forest to the ground and these are rare in the NDT 1 (every 250 to 350 years). While this indicates a reduced risk of wildfire due to the long fire return interval, changing climate, the effects of forest health pathogens, and increasing fuel loading and human-caused ignitions elevate the risk posed to Project infrastructure in comparison with historical fire regimes. The majority of the study area is found in NDT 3 and NDT 4, although only relatively minor amounts of infrastructure are associated with these areas (i.e., the road and power line). However, given the frequency of fire in these NDT types, significant disturbance to operations and possible closure of evacuation routes from the mine, due for instance to bridges becoming unserviceable, could result from a fire occurring on the lower valley slopes.

Forest health is also a consideration when addressing fire hazard. Extensive mortality associated with *Dryocoetes confusus* (western balsam bark beetle) has occurred in the local study area (LSA). While other forest health agents are also present, western balsam bark beetle is the most prevalent agent. Tree mortality caused by the beetle can result in increased ignition potential and fire behaviour due to cured standing and downed fuels. Fire behaviour is highest during the red-attack phase (1 to 4 years) and decreases in grey-attack phases as fine fuels (less than 7.5 cm in diameter) decrease over time (2 to 10 years). [3] As the standing grey-attack trees fall, they contribute to surface fuels. These surface fuels, in combination with tree regeneration during this stage, can result in an increase in expected fire behaviour during this stage (approximately 10 to 30 years). As these fuels decay, fire behaviour decreases. Adjacent to valued infrastructure components, fuel mitigation measures in beetle-attacked stands are important to consider to reduce the likelihood of fire-related losses or impacts.

To provide a more locally specific assessment of fire history, the use of fire ignition records is pertinent. The BC Government Wildfire Management Branch maintains a spatial database of fires back to 1950 (BC WMB 2014). The database indicates fire location, date, and cause (human or lightning), and is useful in determining wildfire probability for an area. In the 150,010 hectare (ha) regional study area (RSA), 50% of the fires were human caused; the remainder were started by lightning (43%) or have unknown causes (7%; Table 27.4-2). Since 1951, there have been 1,029 fires recorded in the RSA.

In the LSA, which is 11,084 ha in size, human and lightning ignitions are responsible for 52 and 41% of fires, respectively, and 7% had unknown causes. There have been 105 fires recorded in the LSA since 1951. Ignition potential is considerable in the region and supports the characterization of the high fire probability in the Project area.

Fire weather for the Clearwater area is described in the *District of Clearwater Community Wildfire Protection Plan* (Andrew 2011) and summarized below. Fire Danger class rating is a key fire weather parameter from the Canadian Wildfire Danger Rating System. It is a measure of the ease of ignition of a fire and the difficulty associated with suppression effort (Table 27.4-3). In the Clearwater and Vavenby area, fire weather data from the Clearwater HUB weather station show that in July there are on average seven days in High Fire Danger class and six days of Extreme Fire Danger class. In August, seven days are high and eight are in the extreme class. The fire weather data provide a clear indication that the weather conditions can support high to extreme fire behaviour in suitable fuel types.

[3] Red- and grey-attack phases are indications of the percentage of tree volume killed by beetles.

Table 27.4-2. Fire Occurrences for Each Decade by Cause in the Local Study Area and Regional Study Area

Decade	Number of Fires by Cause in the LSA				Number of Fires by Cause in the RSA			
	Lightning	Human	Unknown	Grand Total	Lightning	Human	Unknown	Grand Total
1950	1	4		5	25	28		53
1960	6	5		11	74	55		129
1970	8	27		35	84	146		230
1980	8	10		18	82	80		162
1990	13	5		18	107	41		148
2000	6	4	7	17	61	149	59	269
2010	1			1	12	11	15	38
Grand Total	**43**	**55**	**7**	**105**	**445**	**510**	**74**	**1,029**

Table 27.4-3. Fire Danger Classes and Descriptions

Fire Danger Class	Description
Class 1 – Low	Fires are likely to be self-extinguishing and new ignitions are unlikely.
Class 2 – Moderate	Fires are creeping or gentle and are easily contained by ground crews.
Class 3 – High	Fires exhibit moderate to vigorous surface fire and intermittent crown fire. Heavy equipment and air support is often required to control these fires.
Class 4 – Very High	Fires are high intensity with partial to full tree crown engagement. Air attack with retardant is required to attack the fire's head.
Class 5 – Extreme	Fires are fast spreading, have high fire intensity, and are difficult to control. Only the flanks of the fire can be controlled by suppression efforts.

Linear infrastructure, such as the power line to the Project Site, is vulnerable to damage by wildfire. The power line also has the potential to act as an ignition source in the event of a flash-over from a tree strike or growth of vegetation into the clearance zones around energized conductors or other components. A vegetation maintenance and hazard tree removal program are key to reducing power line-caused fires.

A single access road is envisaged to the Project Site. In the event of a wildfire, egress using the road may become vulnerable and wildfire evacuation planning that considers other existing Forest Service Roads is critical to ensuring mine personnel safety.

Human safety is one of the key focuses in developing mitigation measures for effects that the environment may have on the Project. Reducing the probability of fire spreading to or from Project infrastructure, ensuring suppression training and equipment is adequate, and developing wildfire relevant evacuation planning are all important measures to consider in reducing risk to workers.

Adequate setbacks from coniferous fuels should be maintained to help reduce the probability of fire spreading to or from Project infrastructure. Conducting a Fire Hazard assessment after construction is recommended. Potential costs due to shutdowns or losses to infrastructure related to wildfire can be mitigated through fire risk reduction measures, which are detailed below.

A wildfire could also have secondary effects related to the loss of surface vegetation cover in the local catchment area. Increased amounts of runoff with elevated levels of total suspended solids would report to the diversion channels, requiring increased maintenance. Additionally, slope stability may be compromised by vegetation loss.

General mitigation measures, operating procedures, training and educational considerations are provided below. The *District of Clearwater Community Wildfire Protection Plan* provides additional information regarding wildfire risk mitigation and planning (Andrew 2011). Consultation with the District of Clearwater in regards to wildfire planning is recommended.

27.4.2 Mitigation Measures

To reduce the chance of infrastructure loss and/or damage due to wildfires, the following mitigation measures will be implemented:

- contacting the District of Clearwater to identify opportunities for collaboration and coordination regarding wildfire;
- conducting FireSmart Canada Industry Partner assessments to reduce fire risk (https://www.firesmartcanada.ca/become-firesmart/industry-partners/);
- incorporating vegetation management and building design where possible;
- creating zones of 30 m around all structures where vegetation is maintained in a low hazard state;
- implementing a hazard tree inspection program for the power line to ensure the right-of-way is maintained in a condition that reduces the risk of tree failure;
- training for designated permanent employees (e.g., Provincial S100 Basic Fire Suppression and Safety training) and ensuring sufficient trained personnel are on site during the fire season to action a fire;
- ensuring employees have access to appropriate personal protective gear to action a wildfire;
- developing an evacuation plan in case of wildfire, in particular consider loss of the egress route along the access road;
- identifying safe zones for workers at the Project Site in the event that evacuation is not possible;
- erecting fire danger signs in visible locations that are updated throughout the fire season to ensure personnel are aware of current fire hazard conditions;
- ensuring water sources have adequate volumes to action fires and that pumps or other water delivery systems can provide sufficient pressure for the effective use of hoses, sprinklers, and other fire suppression tools;
- locating water pumps and fire-fighting equipment strategically around the Project to help contain/extinguish any fire;

- equipping a vehicle with firefighting tools (shovels, pulaskis, and axes), water, and portable pumps to supply initial attack to accessible fires;
- using mining equipment such as dozers in the case of a fire to remove vegetation around the infrastructure, thus removing fuel for the fire;
- providing backup generators for use in the event of power line loss. The generators will have enough power capacity to operate essential equipment (e.g., ventilation, fire suppression);
- properly storing flammable materials, banning heat and flame in these areas, and providing proper signage;
- training personnel in fire response and containment, including:
  - use of fire extinguishers for small fires in buildings; and
  - raising an alarm and seeking assistance;
- monitoring British Columbia Ministry of Forests, Lands and Natural Resource Operations fire alerts; and
- complying with all relevant legislation in the BC *Wildfire Act* (2004).

27.4.2.1 Contingency Plans

Although the mitigation measures above will significantly reduce the risk of wildfires on the Project, it is possible that such an event may occur over the life of the Project. In this case, HCMC has developed the Emergency Response Plan (Section 24.4) which will be followed if wildfires could potentially have an effect on the Project. This Plan also outlines procedures, communications protocols, and responsible personnel in the case of an incident. The Sediment and Erosion Control Plan (Section 24.11) and Vegetation Management Plan (Section 24.17) outline measures that would minimize the effects of a wildfire on the Project, as well as treatment measures to restore and wildfire-generated areas of erosion.

27.5 GEOPHYSICAL EFFECTS

27.5.1 Baseline Summary/Existing Conditions

This section discusses effects and mitigation measures relating to geophysical activity. No effects are expected from avalanches, and minimal effects are expected from rapid mass movements.

27.5.2 Landslide Geohazards

Evidence of mass movement and soil erosion has been noted in the Project area, mostly slow mass movements and gullying. Slow mass movement typically refers to slope movement that occurs at a very slow rate and usually travels a short distance; conversely, rapid mass movement refers to a rapid, gravity-induced down slope movement by sliding, falling, rolling, or flowing of either bedrock or surficial material. The Project area is characterized by unconsolidated surficial materials overlying bedrock with occasional bedrock outcrops. There are kame terraces and fluvial deposits closer to the North Thompson River. Geohazard mapping for the Project area was completed in 2014 (Polar 2014).

The potential for landslides to affect the Project area was assessed based on terrain stability maps prepared for the area following procedures outlined in the British Columbia Ministry of Environment guideline *Terrain Stability Mapping in British Columbia* (1996) and on information collected from available records.

Terrain stability maps were based on terrain classification and slope gradient information prepared by Polar and presented in the terrain mapping geohazards report. The terrain stability maps provide a relative assessment of stability but provide no indication of the expected frequency, magnitude, or consequence of failure.

27.5.2.1 Effects on the Project

Effects of Liquefaction on the Project

Liquefaction is defined as the transformation of granular material from a solid state into a liquid state as a consequence of increased soil saturation. Liquefaction is the primary cause of landslides and other ground failures associated with earthquakes. Earthquakes catalyze liquefaction by shaking the ground and altering the pore water pressure of the surficial material. The risk of liquefaction is greatest in steep terrain with unconsolidated substrate and saturated soils.

Effects of Channel Debris Flows on the Project

Some steep-sided creek channels show evidence of local gully erosion which could lead to rapid mass movement on the mid to lower slope positions. Creek bank instability and potential channel debris flows along the sections of creeks within the LSA could affect the planning of road crossing locations and the design of bridges or culverts.

Effects of Rockfalls on the Project

Rockfalls occur as a result of mechanical action on unstable (or occasionally stable) rock. In the Project area, rockfalls would likely be the result of seismic activity, freeze-thaw activity, or unsecure overhead hazards.

Seismic activity could result in the release of small or large sections of rock. Freeze-thaw is a mechanical trigger for rock with existing cracks and fissures. When water or snow is introduced into cracks and fissures of rocks (cliffs and outcrops primarily), and is then exposed to free-thaw cycles, the contraction and expansion of solid state water acts to progressively ratchet the rocks loose. This process could be relatively fast or occur over a long period of time, dependent on the specific circumstances.

27.5.2.2 Mitigation Measures

Liquefaction*:* Identify areas with high potential for liquefaction. Prevent construction of buildings in those areas. Use engineered piles for footings if required.

Channel Debris Flows*:* An assessment of creek bank stability and debris flow potential should be made at road crossings for bridge and culvert design. Such an assessment would allow for appropriate mitigation measures to be developed.

Rockfalls*:* The most effective way to mitigate risks to the Project from rockfalls is to locate Project Site buildings, infrastructure, machinery, and work zones away from overhead hazards.

27.5.2.3 *Contingency Plans*

Although the mitigation measures above will significantly reduce the risk of landslide geohazards on the Project, it is possible that such an event may occur over the life of the Project. In this case, HCMC has developed the Emergency Response Plan (Section 24.4) which will be followed if landslide geohazards could potentially have an effect on the Project. This Plan also outlines procedures, communications protocols, and responsible personnel in the case of an incident. The Sediment and Erosion Control Plan (Section 24.11) outlines measures that would minimize the effects of a landslide on the Project, as well as treatment measures to restore any affected areas.

27.5.3 Seismic Activity

The Pacific Coast is the most earthquake-prone region of Canada due to the presence of offshore active faults, particularly dominated by the northwestward motion of the Pacific Plate relative to the North American Plate. However, the Project is distant from these faults (more than 300 km) and earthquake frequency and size decrease moving inland from the coast. As a result, seismic activity is relatively low in the Project region.

A probabilistic seismicity assessment for the Project was carried out by Knight Piésold in 2012, as a required informant into the design parameters for the tailings management facility (TMF) and other Project geotechnical structures (Appendix 5-F, Seismicity Assessment). The findings indicated that shallow crustal earthquakes in the southeastern region of BC would be the predominant seismic hazard for the Project. Return periods of 5,000 and 10,000 years for earthquakes of 7.0 and 7.3 magnitude respectively were selected as conservative design parameters (KPL 2012).

Peak Ground Acceleration (PGA) is a measure of how vigorously the earth shakes, and is measured in units of acceleration due to gravity (g). PGA was calculated for the Project area for six return periods (Table 27.5-1). The range of results indicates that the Project area could experience PGA associated with earthquakes which range between 0.04 g (1:100 year event) and 0.26 g (1:10,000 year event; Table 27.5-1). Events of these magnitudes in turn could be expected to result in “very light” (1:100 year event) to “moderate” (1:10,000 year event) structural damage (USGS 2014).

Table 27.5-1. Exceedance Probability, Risk, and Peak Ground Acceleration for Seismic Events at Harper Creek

Event	PGA[2] (g)	Probability for Any Single Year[2] (%)	Probabilities for Project Phases[1] (%)		
			Operations (Year 1 to Year 23)	Operations and Closure (Year 24 to Year 28)	Closure, and Post-Closure (Year 29 to Year 85)
1 in 100 year	0.04	21	21	25	57
1 in 500 year	0.08	4	4	6	16
1 in 1,000 year	0.11	2	2	3	8
1 in 2,500 year	0.16	1	1	1	3
1 in 5,000 year	0.19	0.5	.5	.6	2
1 in 10,000 year	0.26	0.2	.2	.3	.8

[1] *The probabilities of events occurring in Project phases are calculated using the hydrology frequency analysis formula: Probability (risk) = $1 - (1 - P)^n$ where P is the probability for an event in any single year, and n is the Project phase length.*
[2] *Data derived from Seismicity Assessment produced by Knight Piésold for the Harper Creek Project (2012).*

27.5.3.1 Effects on the Project

The above analysis points towards the Project being at low risk of a damaging seismic event. For example, for the entire period there is a 8% chance of a 1 in 1,000 year event occurring, with a PGA of 0.11, which would cause "light" structural damage at the surface (USGS 2014). However, where infrastructure is not built on firm ground, or where unconsolidated material is deposited on slopes, damage to infrastructure and risk to workers could be greater.

27.5.3.2 Mitigation and Contingency Measures

A mine rescue emergency response plan will be developed. The plan will ensure that there are always trained first response personnel on site whenever there are workers active in the Project Site. The number and type of first responders depends on the number of active workers. There will also be on-site personnel trained in first aid, firefighting, and hazardous material handling and clean up. Appropriate emergency equipment will be maintained and made available on site.

Site infrastructure will be located in areas that avoid or minimize exposure to weak, unconsolidated soils or soils that are assessed to be potentially liquefiable, where practical. Where infrastructure is to be built on weak, compressible, or potentially liquefiable soils, deep foundation support or foundation treatment (soil replacement, preloading, dynamic compaction, vibro-compaction, vibro-replacement, or deep soil mixing) will be incorporated into the design. All structures will be thoroughly assessed for stability and integrity after seismic events.

27.6 CLIMATE CHANGE

27.6.1 Climate Change Projections for the Project Area

Global climate is unequivocally 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 direction and amount of change in precipitation is lower than that of air temperature (AMS 2012). Uncertainty increases when considering local effects, and the effects of climate change on the biophysical environment, such as vegetation, glaciers, streamflow, and wildfires.

As noted in Section 27.2.1.3, several cyclical climatic patterns influence the climate of the Project area, including the PDO and ENSO. The effects of global warming on these patterns are poorly understood. However, in a review of GCMs results from the IPCC AR4 (2007) report, it was found that the negative phase of the PDO will increase in frequency, especially after 2050. Overall, the climate of the Project area is expected to warm and experience more precipitation in the future. However, if the PDO were to increasingly experience a negative phase, then these effects would be dampened, but not reversed. As global sea-surface temperatures continue to warm, the ENSO is expected to experience an "El Niño-like" mean state change, but no change in amplitude (Lapp et al. 2012).

Extreme weather in the Project weather area is correlated with both the PDO and ENSO, including each phase. For example, during a negative phase of the PDO (2005 to present) there is a greater propensity for La Niña events, and during La Niña events the interior of BC tends to experience colder winters and drier summers. Conversely, during a positive phase of the PDO (1977 to 2005) there is a greater propensity for El Niño events, and during El Niño events the interior of BC tends to experience warmer winters, and record high snowpack, increased rainfall, and extensive flooding. Given this understanding of local weather conditions, climate change in the Project area will likely continue to result in extreme weather from both the PDO and ENSO cycles. According to climate change projections, both the frequency and magnitude of these events are likely to increase.

27.6.2 Project-related Adaptation and Mitigation Measures

Climate change impacts are unique in that they cannot be predicted by extrapolating from historical measurements and return periods (BCWWA 2012). Climate change impacts are also unique due to the sustained nature of change, and an increase in the frequency and magnitude of extreme events.

By analyzing extreme return period events for temperature, precipitation, and streamflow, climate change impacts are implicitly considered in the Project's engineering design. As noted above, most extreme weather in BC is the result of ENSO conditions. Thus, by considering extreme events through the 50-, 100-, and 200-year return periods, the direct impacts of ENSO phases on possible extremes in air temperature, precipitation, and streamflow are accounted for within the scope of the assessment. For example, climate change projections are currently suggesting an annual increase in precipitation of 6% by 2050. Whereas when considering extreme streamflow return periods, the 7-day 200-year low flow event is 50% below baseline and the 200-year peak flow event is 90% above baseline. This demonstrates that by examining extreme events, the analysis is inherently including the projected effects of climate change.

Components of the environment and Project affected by climate change are listed below. Each component is discussed and categorized in terms of the severity of its anticipated impacts. Categories are **negligible, low, moderate,** and **high**. Each are defined relative to the likelihood of change in interaction, risk of effects to Project, and consequent effects to the environment, human health, and safety.

27.6.2.1 Air Temperature

Project components will be designed to withstand a wide range of air temperatures, including the temperature ranges for extreme events (Table 27.6-1). Increasing the number of freeze-free days would be beneficial to the Project in some respects, such as reducing heating costs, and reducing exposure of personnel to extreme cold. Climate change is predicted to induce milder winters in this region, which would likely produce more freeze-thaw cycles. If improperly designed, this increase would accelerate roadway and railway deterioration, and increase maintenance costs. More frequent freeze-thaw cycling also has the potential to compromise the strength of other site infrastructure, including power lines and building foundations. As such, roadways and transportation corridors have **moderate** sensitivities and all other Project components have **negligible** to **low** sensitivities to increased or decreased air temperature due to climate change (Table 27.6-1).

Table 27.6-1. Potential Project Component Sensitivities Arising from Climate Change

		Air Temperature			Precipitation		Streamflow			
Category	Component	Increase from Mean Climate Normal	Freeze-Thaw Cycles	Extreme Heat	Increase from Mean Climate Normal	Extreme Rain and Snow	Flooding	Drought	Increased Wind Velocity	Increased Wildfires
Transportation	Rail line, road surface, ditches, culverts	Low	Moderate	Low	Moderate	High	High	Low	Low	High
Surface infrastructure	Buildings (maintenance, administration, warehouse), conveyor, storage area, stockpiles, contact water collection ditches, discharge pipeline, equipment and fuel storage facilities, explosive and storage facilities, non-contact water diversion ditch network, overburden and soil storage areas, sedimentation pond(s), sewage treatment and disposal facilities, washing plant, waste rock stockpile	Low	Moderate	Low	Low	Moderate	High	Low	Low	High
Utilities	Electrical power line	Low	Moderate	Low	Low	Moderate	High	Low	Low	High

27.6.2.2 Precipitation

Project components will be either designed to handle snow, or have management plans in place for handling snow and rain. It is possible that extreme snowfall events will increase in frequency and magnitude. Engineering systems in place could handle increases in snowfall from current climate projections, as climate projections are approximately proportional to the 2 to 10-year return period event and Project components are often designed to withstand the 100-year or 200-year events. Increases in the frequency and magnitude of extreme snow and rain may occasionally limit travel on access roads. All other Project components are ranked as having **negligible** to **low** sensitivities to increased precipitation due to climate change (Table 27.6-1).

27.6.2.3 Streamflow

As precipitation extremes unfold, the Project will likely experience long return period (Q50-Q200) streamflows for both dry and wet conditions. Given the relationship between the PDO and ENSO it is probable that the Project will experience both extreme low flows (PDO negative, La Niña) as well as extreme high flows (PDO positive, El Niño). Water management systems within the Project area have been designed to withstand floods with long return periods (50-, 100-, and 200-year). Access and site roads will have the most exposure and will likely require increased maintenance during high streamflow years (and thus high precipitation). The road systems are ranked as **moderate** in terms of climate sensitivity for the Project, due to increased streamflow. All other Project components are ranked as having **negligible** to **low** sensitivities to increased or decreased streamflow due to climate change (Table 27.6-1).

27.6.2.4 Wind

Project components will be designed to handle extreme winds. The anticipated effects of climate change with respect to wind will likely be secondary effects. For example, wind is a primary component of evaporation, as wind increases so too does evaporation. Thus, the likely effects of climate change on the Project will be increased evaporation of water in the TMF. A possible implication of this would be less water available for processing. In low water years this may present a constraint if the Project is highly reliant upon tailings water for processing. However, the Project components as a whole are believed to have **low** sensitivities to increased or decreased wind velocities due to climate change (Table 27.6-1).

27.6.2.5 Wildfire

As wildfire extremes as a consequence of climate change emerge over time, the Project area may experience increased fire behaviour. Given the relationship between the PDO and ENSO it is probable that fire occurrences will increase during the current (negative) phase of the PDO, which have resulted in frequent La Niña events between 2005 and 2014. In the southeast region of the province, the coupling of negative PDO phases with La Niña events has been demonstrated to significantly increase both fire weather as well as wildfire occurrences (Daniels 2002). As such, all Project components have **high** sensitivities to increased wildfire due to climate change (Table 27.6-1).

27.6.3 Climate Change Regulatory Context and Adaptation

27.6.3.1 Regulatory Context of Climate Change

The BC government is currently drafting policy regarding climate change adaptation and how to mainstream adaptation considerations into other regulatory and guidance documents (BC MOE 2010). As yet, there is no specific legislation applicable to adapting Project components to climate change risk. Infrastructure design for water structures in BC is currently regulated for a wide variety of meteorological risk factors (i.e., temperature extremes, storms, and floods), but these provisions are based on analyses of past climate and so do not currently explicitly address climate change projections that may differ from past ranges (APEGBC 2012).

With regards to the effect of the environment on the Project in relation to climate change, the Federal-Provincial-Territorial Committee on Climate Change and Environmental Assessment recommends that:

> *Potential risks to the project, providing they do not affect the public, public resources, the environment, other businesses or individuals, may be borne by the project proponent and are not generally a concern for jurisdictions* (CEA Agency 2003).

It is believed that climate change in the Project area will not increase risks to the public, public resources, the environment, other businesses, or individuals. However, this chapter has discussed the likely effects of climate change on the Project and the related mitigation measures in a manner that should allow for informed decision-making.

27.6.3.2 Climate Change Adaptation and Contingency Planning

Climate change adaptation is the "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC 2007). It is distinct from climate change mitigation, which is the reduction in the magnitude and rate of climate change itself (West Coast Environmental Law 2012). Planning for adaptation is difficult, given unknowns in the timing and magnitude of climate change, and the environmental effects of this change.

Planning and decision making will take climate change into account wherever possible. This includes obtaining relevant climate information, assessing likely effects, considering infrastructure vulnerability, and adopting a cooperative approach with governments, stakeholders, and Aboriginal groups. Recommendations and position statements from relevant scientific literature, institutions (e.g., AMS 2012; IPCC 2013), and professional associations will be followed wherever applicable or possible (e.g., APEGBC 2010, 2012; BCWWA, 2013a, 2013b).

To respond to the known uncertainties surrounding climate change impacts, an adaptive management approach (to climate change) will be taken. Adaptive management involves using learning to continuously improve policies and practices. Adaptive management is useful because it allows for flexible responses to early signals of change when timing and magnitude are not known. Adaptive management has six components: assess the problem, design a solution, implement the solution, monitor the results, evaluation, and adjustment (BC MOFR 2013; CEA Agency 2013). Employing adaptive management to the likely effects of climate change may iteratively bridge the gap between GCM projections and the actual climate impacts experienced in the Project area, thereby allowing the Project to adapt to such effects by formulating appropriate mitigation to the extent possible.

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